

Experimental Investigation of a Side-Emitting Optical Fibre Mop Fan for Air Cleaning

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ABSTRACT: The photocatalyst mop fan system comprises a flexible fiber mop, which is mounted on a shaft within a centrifugal fan casing, and is rotated by a direct drive, high efficiency motor. The system performs self-cleaning when circulating indoor air throughout the building space, thus reducing need of outdoor fresh air and energy for heating/cooling the air. The fibre mop fan is constructed of many flexible fibres, each coated with the photocatalyst, titanium dioxide (TiO_2). In operation, the air being moved by the mop fan will pass over the large surface area of the flexible fibres. The UV lamps are used to facilitate photocatalytic oxidation. The internal surface of the fan casing is coated with a highly reflective material, to spread the light evenly over the mop, and finished with a layer of TiO_2 to achieve self cleaning. Following the design, construction and testing of a photocatalytic polymer mop fan prototype, a photocatalytic side-emitting optical fiber mop fan prototype was designed, constructed and tested. The performance was compared with the polymer fiber mop fan. It was found the system has better efficiency than the polymer fiber mop fan due to more reasonable UV lamp arrangement and evenly UV-light transmittance. It was also found the final room pollutant concentration depends on the pollutant generating rate by using the photocatalyst mop fan air cleaning system. The system is more compact than the polymer fiber mop fan.

Keywords: Optical fiber mop fan; Reaction; Photocatalyst; Pollutant concentration; Air cleaning

1. INTRODUCTION

Environmental remediation using photocatalysts has been the most intriguing issue in many countries for the past decade [1]. As traditional air purifiers use filters to remove particulate matters or use sorption materials (e.g., granular activated carbon)

to adsorb gases or odors, these techniques only transfer the contaminants to another phase rather than eliminating them, and additional disposal or handling steps are subsequently required. As an alternative remediation technology, the use of heterogeneous photocatalytic oxidation (PCO) offers a number of advantages over conventional technologies [2]. Attractive

advantages with photocatalysis for air treatment and purification are ambient temperature and pressure operation, use of molecular oxygen as the oxidant, and final oxidation products that are usually innocuous (CO_2 and H_2O for the oxidation of small hydrocarbons) [3]. It has been shown that PCO operating at ambient conditions can be employed to destroy a wide variety of organic compounds which are representative of common indoor air contaminants [4].

The photocatalytic reactors include honeycomb monolith reactors, fluidized-bed reactors, annular reactors, Pyrex glass tube reactor, etc [2] [5-7]. All the above reactors are static equipment and can not move air; therefore, these systems need the separate equipment, such as air blowers, to introduce the air into the reactors. The photocatalytic mop fan introduced in this paper can act as an air impellor as well as a filter for removal of particulate pollutants. The photocatalytic mop fan system is therefore compact and robust, and requires little or no maintenance. The system has low energy consumption, as, unlike conventional air cleaning devices, there is negligible pressure drop incurred in its operation.

The major part of the photocatalytic mop fan system is a flexible fiber mop, such as the polymer fiber mop. As an alternative arrangement, using side-emitting fiber optics as the flexible fibers of the mop has several advantages, i.e., the UV-lamp can be positioned at the centre of the mop, so the light is carried along the length of the fibers and spreads more evenly over the mop, and the system is more compact and efficient.

2. DESCRIPTION OF THE SIDE-EMITTING OPTICAL FIBRE MOP FAN

In order to describe the side-emitting optical fiber mop fan, a polymer fiber mop fan, which has been investigated previously

by authors, is shown in Fig. 1 for the purpose of comparison. As shown in Fig.1, the system comprises a polymer fiber mop, which is mounted on a shaft within a centrifugal fan casing, and is rotated by a direct drive, high efficiency motor. The flexible fiber mop, similar in appearance to a chimney sweep brush, is constructed of 240 bunches of flexible polymer fibers, each fiber is coated with the photocatalyst, titanium diode (TiO_2) by dip coated method. In operation, the air being moved by the mop fan passes over the large surface area of the flexible fibers. Eight small UV lamps with the wave length of near 300-370nm are installed within the fan casing (around the fan casing, see Fig.1) to facilitate photocatalytic oxidation. The power of each bulb is 4 watt. The titanium diode coated on the fibers, activated by the UV radiation, chemically oxidize volatile organic pollutants, thus converting them primarily to carbon diode and water. The internal surface of the fan casing is covered with aluminum foil sheet, a highly UV reflective material, to spread the light evenly over the mop, and finished with a layer of TiO_2 to achieve self cleaning. As an alternative arrangement, the side-emitting optical fiber mop fan was constructed which has the same scale as the previous polymer fiber mop fan (the same diameter, same thickness, the same number of fiber bunches and the same length of the fiber, using the same sizes of hub and fan casing). The side-emitting optical fiber mop fan uses side-emitting fiber optics as the flexible fibers of the mop, in this case, the UV lamp is positioned in the hollow hub and fixed on the fan casing, the system is shown in Fig.2 and Fig.3. The optical fiber mop is also constructed of 240 bunches of side-emitting optical-fibers, the end of each bundle is mounted on the hub of the mop fan and has a diameter of $\Phi 3\text{mm}$, each fiber has the length of 10cm and coated with the photocatalyst, titanium dioxide (TiO_2) by dip coated method. The mop fan has the airflow rate of $0.019\text{m}^3/\text{s}$, $0.027\text{m}^3/\text{s}$,

0.033m³/s and 0.040m³/s at the fan speed 120 rpm, 180 rpm, 240 rpm and 300 rpm respectively. The UV lamp has a wave length of near 300-370nm and the power of lamp is 25 watt. To transmit more light to the fiber surface, the space between the fiber bundles are utilized---there are 240 small holes on the hub surface, the small holes are distributed on the interval space of the fiber bundles (see Fig.2); each hole has a diameter of $\Phi 3\text{mm}$. The UV light can go through both the side-emitting optical fibers and the small holes and dissipate on the optical fiber surface; the UV light therefore illuminates the fiber surface. The titanium dioxide coated on the fibers, activated by the UV radiation, chemically oxidize volatile organic pollutants, thus converting them primarily to carbon dioxide and water. The internal surface of the fan casing is covered with the aluminum foil sheet, a highly UV reflective material, to reflect and spread the light evenly over the mop, and finished with a layer of TiO₂ to achieve self cleaning; the mop fan is located in a big wood box (1.2mx1.2mx1.2m).

Side-emitting optical fiber Side emitting optical fiber distributes the light from the illuminator along the entire length of the fiber and is usually used in fiber optic lighting system in any commercial, industrial or residential lighting application. In a side-emitting fiber, light refracts out of the fiber by way of deliberate imperfections at the boundary of the core and cladding.

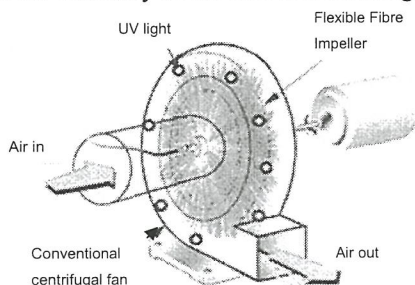


Figure 1. Photocatalytic Mop Fan

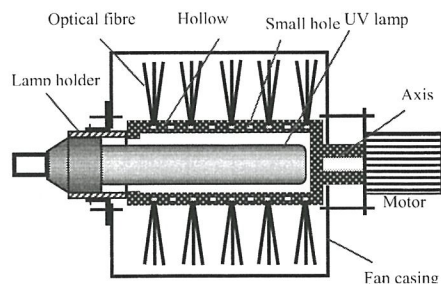


Figure 2. The structure of the Optical Fibre Mop Fan

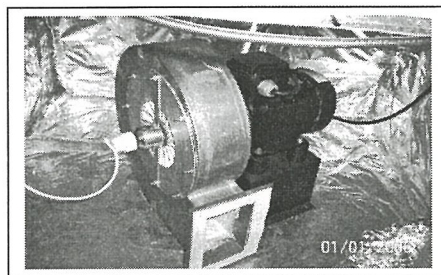


Figure 3. Photos of the Optical fibre Mop Fan System

3. RESULTS AND DISCUSSES

3.1 Test Method and Analysis

To monitor the reaction process when the side-emitting optical mop fan is operating, the concentrations of the pollutant, carbon dioxide as well as the temperature and relative humidity inside the box were monitored during the test. The methanol was used as a pollutant for the experimental investigation.

A typical test with the fan speed of 120rpm and initial pollutant concentration of 762mg/m³ is shown in Fig.4 and Fig.5. Fig.4 shows the decay of pollutant with a corresponding rise in carbon dioxide and water vapor. Increase in carbon dioxide and water vapor clearly indicates photocatalytic oxidation as being responsible for the decay of methanol, as the two final products of oxidative process are carbon dioxide and water. Fig.5 shows the air state change inside the box, the temperature rose from

19.5°C to 36.2°C in the first 250 minutes due to the rotation of mop fan motor and then kept constant because the thermal balance was achieved while the amount of the heat transfer from the box to the ambient was equal to the heat production by the motor rotation. The relative humidity decreased in the first 250 minutes due to the temperature inside the box increased although the oxidative process produced water vapor and after 250 minutes it rose slightly due to the produced water vapor and the temperature inside the box became constant.

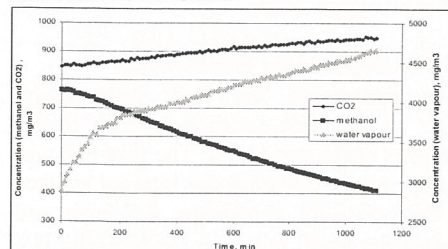


Figure 4. Variation of the concentration of methanol, CO₂ and water vapour with time

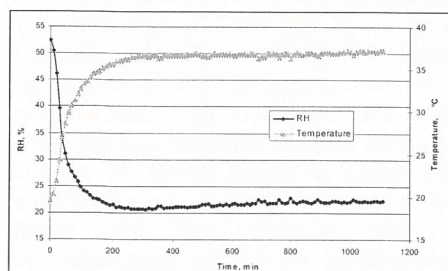


Figure 5. Variation of the relative humidity and temperature with time

3.2 Comparison of the Test Results of the Polymer Fibre Mop Fan and the Optical Fibre Mop Fan

Tests were carried out to compare the performance of the polymer fibre mop fan (shown in Fig.1) and the side-emitting optical fibre mop fan. The results are shown in Fig.6 and Fig.7.

Fig. 6 shows a comparison of the reaction process of the two types of mop fans working at the same conditions (UV

light power around 25W and fan rotation speed of 120rpm, no pollutant source inside the box). It is shown that it took 160 minutes for the optical mop fan to reduce the pollutant concentrations from 656mg/m³ to 593mg/m³ and it took 220 minutes for the polymer fibre mop fan to do so.

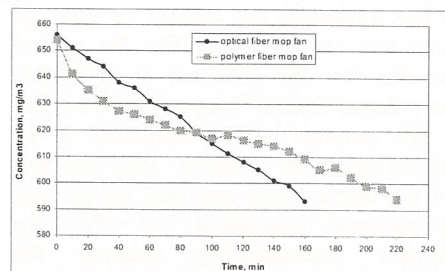


Figure 6. Comparison of the reaction rate of two mop fan at the fan speed of 120rpm

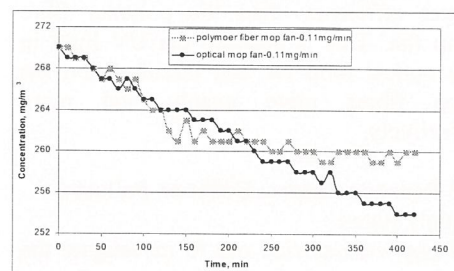


Figure 7. Comparison of the reaction rate of two mop fan at the pollutant supply rate of 0.11mg/min

Fig.7 shows another comparison of the reaction process of the two types of mop fans working at the same condition (UV light power around 25W and fan rotation speed of 180rpm, there is a pollutant source inside the box). The two tests were carried out on the condition of the same pollutant generation rate, 0.11mg/min. The two tests were carried out for a period of 420 minutes. It is shown that for the polymer fibre mop fan the pollutant concentration was reduced from 270mg/m³ to 260mg/m³ in the first 250 minutes and the concentration kept nearly constant after 250 minutes while the balance had been

achieved. The balance was achieved due to the reaction rate decreased with the decrease of the pollutant concentration and finally equalled to the pollutant generation rate. For the photocatalytic oxidation, the reaction rate decreases with the decrease of the pollutant concentration in a certain range because the lower the concentration, the less molecules can contact the mop fan fibres and are adsorbed. For the optical mop fan test the pollutant concentration was reduced from 270mg/m^3 to 254mg/m^3 in 420 minutes and it continued to be reduced after 420 minutes. This indicates that the reaction rate was still higher than the pollutant generating rate when the pollutant concentration reached the 254mg/m^3 .

The above comparison of the test results shows that the optical fibre mop fan has better efficiency than the polymer fibre mop fan. This is because the UV light in the optical mop fan can distribute on the mop fibres more evenly and more effectively.

3.3 Reaction Rates at Different Pollutant Supply Rates

Tests were carried out to investigate the performance of the optical mop fan at various pollutant generating rates. The reaction processes at pollutant generating rates of 0.15mg/min , 0.18mg/min and 0.22mg/min are shown in Fig.8. It is shown that for the test of pollutant generating rate of 0.22mg/min the balance was achieved at the pollutant concentration of 302mg/m^3 and for the test of pollutant generating rate of 0.18mg/min the balance was achieved at the pollutant concentration of 245mg/min . For the test of pollutant generating rate of 0.15mg/min the pollutant concentration was reduced from 175mg/m^3 to 104mg/m^3 in 1400 minutes and it continued to be reduced due to the balance had not been achieved after 1400 minutes.

The testing results show that the final room pollutant concentration depends on the pollutant generating rate. The higher the

pollutant generating rate, the higher the final pollutant concentration.

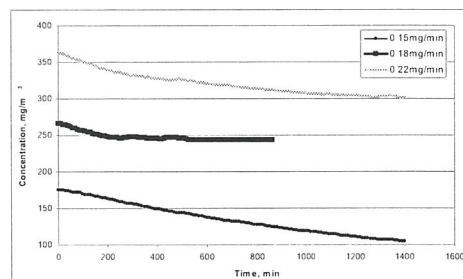


Figure 8. Reaction processes at various pollutant supply rates

3.4 Test of the Light Transmitting

To investigate the light transmitting effect of the side-emitting optical fibres, two tests were carried out. The first test was carried out by covering the internal surface of the hub with aluminium foil tape and opened the small holes on the hub, the UV light can only transmit through the small holes. The second test was carried out by covering the end of the optical fibre with the black ink and the UV light can only transmit through the small holes. The test results were compared with the test of the optical fibre mop fan on its normal working state (with both the fibre end and the small holes open), as shown in Fig. 9. All the three tests shown in Fig.9 were carried out for 240 minutes and the initial concentrations for all the three tests are 1040mg/m^3 . It is shown that when the end of the optical fibre was covered, the reaction rate got lower than the normal working state of the mop fan, this is because on this condition the optical fibre acts as a normal glass fibre and doesn't transmit the light, the UV light can only transmit through the small holes. The light intensity on the fibre surface is lower. This result indicates that the side-emitting optical fibres of the mop fan can transmit the UV light effectively.

The Fig.9 also shows that when the ends of the optical fibres were covered with

black ink the reaction rate got much lower than the test covered with aluminium foil tape. This is because the aluminium foil is a highly UV reflective material, which can resist the UV light being absorbed by the plastic hub. This result also indicates that the mop fan can be improved by coating the internal surface of the hub with UV reflective material.

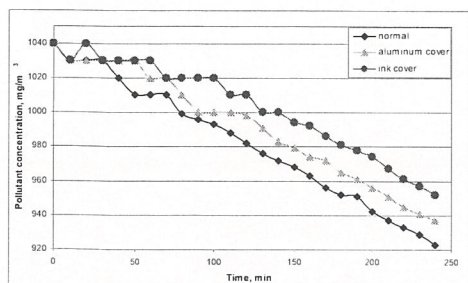


Figure 9. Comparison of the tests with the optical fibre end opened and covered

4. CONCLUSIONS

A photocatalytic side-emitting optical fiber mop fan prototype was designed, constructed and tested. The results have been compared with the previously tested polymer fiber mop fan. It was found the optical fiber mop fan has better efficiency than the polymer fiber mop fan due to the UV light in the optical mop fan can distribute on the mop fibers more evenly and more effectively.

Tests were carried out to investigate the performance of the optical mop fan at various pollutant generating rates. The testing results show that the final room pollutant concentration depends on the pollutant generating rate. The higher the pollutant generating rate, the higher the final pollutant concentration.

Tests were also carried out to investigate the light transmitting effect of the side-emitting optical fibres on the photocatalytic oxidation. It was found the side-emitting optical fibres of the mop fan can transmit the light to the fibre surface effectively.

The tests also indicate that the mop fan can be improved by coating the internal surface of the hub with UV reflective material.

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