Study of a new photocatalytic air cleaner applied to the management of the microbiological indoor air quality

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ABSTRACT

The objective of this research consists of studying the effectiveness of devices used in the microbiological purification of the air. This specifically involves the inactivation of biological aerosols in an air handling unit. The study of a first device working on the principle of photocatalysis has been carried out. This system, called NEO developed by the CIAT Company (patent WO 2004/081458), involves the combination of filtration on an adsorbent and heterogeneous photocatalysis.
The air cleaning device in question is installed in a test box located in a wind tunnel called "ONE-PASS". This test facility is composed of an intake air fan and an exhaust air fan, in order to regulate the test box to maintain a slightly negative pressure, which prevents any exterior leakage. A HEPA filtration unit is installed upstream to remove any particles from the supplied air and another HEPA filtration unit is present downstream to avoid any pollution in the exhaust air.
The "ONE-PASS" is characterized in terms of the homogeneity of velocity profiles and particulate profiles. The aerosolisation of the bacteria Staphylococcus Epidermidis used for the tests is controlled. The flow of bacteria is stable and its concentration is known. Three main criteria of the purification rate are studied to determine the level of effectiveness: concentrations of total flora, cultivable bacteria and particle count. A purification rate superior to 98 % was found for the NEO system in the "ONE-PASS" platform for the cultivable bacteria.

1. INTRODUCTION

An influenza pandemic, Legionnaires' disease, intoxications by mold and mildew, nosocomial infections, and bio-terrorism are topics that have largely contributed to an increase in public awareness regarding airborne microbiological risks.
Omnipresent in our varied environments, biological pollutants, inhaled or ingested, can have a considerably negative consequence on our health. Enclosed spaces sometimes constitute "ecological niches" which facilitate the reproduction of biocontaminants and further increase the exposure of the occupants to them.
The microbiological composition of the air is complex. We can observe "live" microorganisms (molds, bacteria, and viruses), antigenic or toxic microbial fragments, as well as volatile organic substances of microbiological origin (COVm). This pollution, depending of the level of exposure and the sensitivity of the occupants, can be the origin of diverse pathologies.
In this context and in complementing the main prophylactic measures implemented to limit the propagation of such biological entities, the control of the microbiological indoor air quality in buildings through the use of adapted systems for air cleaning seems to be important. This paper describes a method to test air cleaners and the results obtained for a particular technology.

2. MATERIALS AND METHODS

2.1 Test Platform

A test platform named "ONE-PASS" has been developed by CIAT and located at CSTB, which is the French Scientific and Technical Building Center. This platform is specifically designed to determine the efficiency of new technologies used in air cleaners for a one pass through. It is composed of two fan handling units at the end of each side of a long stainless steel 304L duct with a diameter of 200 mm (Figure 1). These units are composed of two filtration stages, one F9 (EN 779) and the other HEPA (H14 according to EN 1822) and an incorporated fan. One of these units is used to supply the air and the other to extract the air.

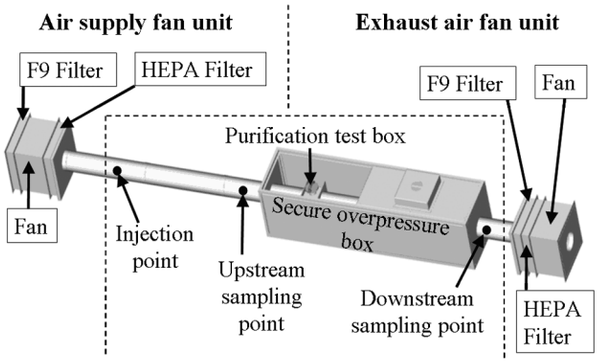

Figure 1 : Platform test schema

A small purification box, which is located in the stainless steel duct, permits the testing of a variety of techniques used in air cleaning.
There is an injection point at the beginning of the duct which introduces aerobiocontamination into the platform and two sampling points on each side (upstream and downstream) of the purification box to evaluate its efficiency. Injected microbiological aerosol introduced into this platform was predetermined by CSTB research standards.

2.2 Measurement materials and methods
2.2.1 Flow and physic measurements
The profile of air velocity in the platform test is measured by a hot-wire anemometer (KIMO VT 100) according to the standard NFX 10-112.
The pressure upstream of the purification test box and the pressure drop of the tested air cleaner is measured by a manometer (KIMO MP 100).
The relative humidity and the temperature in the platform test is checked during all the tests with a thermo-hygrometer.

2.2.2 Particle sampling and measurements
An optical particle counter (Grimm Technology 1.108) is used to verify the particulate density and to measure particulate efficiency of the air cleaner test. To sample airborne particles with the optical counter, we use an isokinetic probe, which reduces any loss during the sampling. The data acquisition is made every 6 seconds on 16 granulometric channels from 0.3 to 20 µm with an air flow of 1.2 $L.min^{-1}$. The analysis of the optical counter data transferred reveals the concentration and size distribution of the aerosol.

2.2.3 Bacteria sampling and measurements
The difficulty in the microbiological sample consists of the fact that there is a notion of viability. As a consequence, we must not destroy the bacteria, for example, before their analysis. To reduce this obstacle, the sampling probes have been tested and some liquid impingers (SKC) have been used. The culture on dishes is conducted on a liquid section of the sampling, and the filtration and analysis by microscopy on a other section. Sampling flow of the impinger is 12.5 $L.min^{-1}$.
The culture of bacteria is done on Petri dishes and is analysed by Unit Forming Colonia (UFC) counting, according to the standard EN 13098.
The technique of analysis in microscopy was fluorescence coloration and UFC counting, giving total flora data.

2.3 Patented NEO technology by CIAT
The NEO concept is based on the combination of filtration on an adsorbent material such as activated carbon and heterogeneous photocatalysis. In addition to the advantages of these two technologies, the combination of them creates a synergy. In the case of activated carbon, contaminants are mainly adsorbed on its specific surface area. The major drawback of this type of filter is activated carbon saturation. Its usage limit is known as the breakthrough point and is very difficult to anticipate in the case of variations of concentration and flow rates. Once this point has been reached, the device no longer provides the desired output concentration. Photocatalysis using titanium dioxide (TiO2) consists of heterogeneous catalysis in which the solid catalyst is only active under ultraviolet range irradiation. Under certain conditions, the heterogeneous photocatalytic process is capable of mineralising the pollutants completely. It is broken down into five phases. First is the transfer of reagents to the photocatalytic surface, the second is the adsorption of reagents on the photocatalytic surface, the third one is the photochemical reaction between the reagents adsorbed on the photocatalytic surface; mineralisation of organic compounds, the fourth is the desorption of photocatalytic reaction products and the last is the diffusion of products from the photocatalytic surface. The major drawback of photocatalysis used on its own is the low adsorption capacity of the catalyst (titanium dioxide) which does not enable it to handle pollution peaks. In this case, in the event of high concentrations and/or increase in passage rate, pollutant mineralisation will not be complete. Combining an activated carbon filter with a photocatalysis system makes it possible to eliminate the respective major drawbacks of both processes when used independently and substantially reduces maintenance operations.

3. PLATFORM TEST QUALIFICATION

3.1 Air and particle tightness
The air tightness of "One-pass" has been tested according to the standard NF EN 1886. The results of this test confirm the good tightness of the platform.
The particle tightness was checked using a particulate

counter upstream and downstream of the small box tested. To preserve the tightness, when we test a technology in a air cleaner with a high pressure drop, we have enclosed the small box within an over pressurised box. The measurements of particle levels reveal that there were no particles of 0.3 to 20 µm in the platform. So we obtain a perfect clean slate as result of the tests.

3.2 Velocity profiles

The velocity profiles were determined for the upstream and downstream sampling points, for three different air flows and for three pressure drops in the air cleaner unit (minimal, medium and maximal) according to the standard NFX 10-112. The different measurement points of air velocity are shown in the Figure 2.

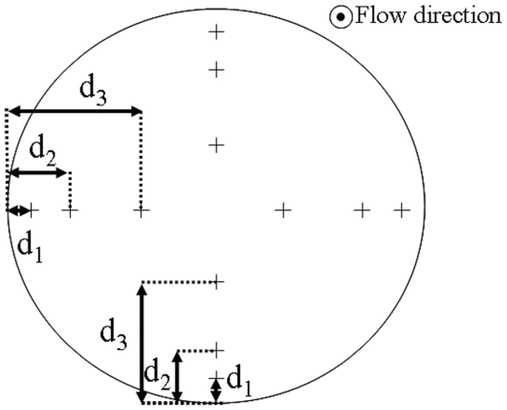

Figure 2 : Points position

The duct diameter is 200 mm so the different distances are d1 = 6.4 mm, d2 = 27.5 mm and d3 = 62.5 mm.

The results demonstrate that the homogeneity of the profiles is maintained in every case. For example, for an air flow velocity regulated at 0.66 m.s-1 ± 0.05 m.s-1, two velocity profiles are presented in Figure 3 and Figure 4. We see that the two profiles are homogeneous, whereas one is the upstream profile and the other the downstream one.

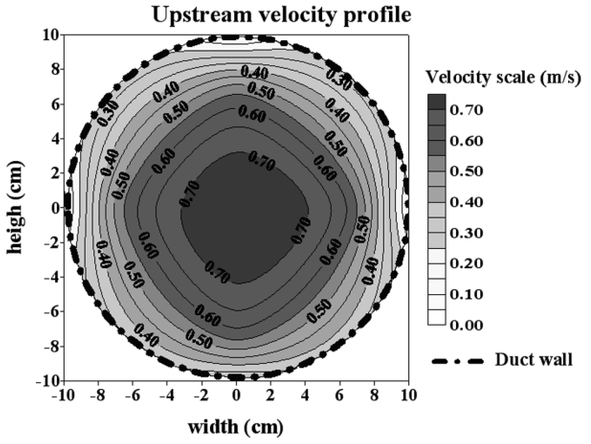

Figure 3 : Upstream velocity profile

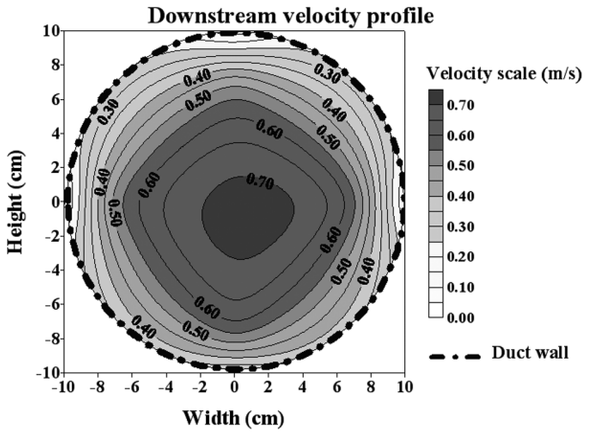

Figure 4 : Downstream velocity profile

For all the tests realised on the profiles the homogeneity is conserved.

The regulation point of the velocity was also defined by these profiles after more than six tests. The velocity measurement at this point represents the medium velocity in the duct. For the subsequent testing the velocity of air flow will be set at this point.

3.3 Particulate profiles

The homogeneity of particulate profiles was verified by injection of a calibrated aerosol of Staphylococcus Epidermidis. After obtaining non homogenised profiles with the injection probe oriented in the direction of the airflow, we took the measurements with the injection probe oriented in the opposite direction. By changing the probe orientation, we were able to obtain a homogenisation of the particulate profiles for all granulometric ranges, with negligible sedimentation of particles superior to 1 µm. To see if this effect could impact the results, we determined the losses of aerosol without the air cleaner system installed in the duct.

3.4 Particulate and microbiological loss

Three kinds of measurements have been conducted to quantify all particulate loss. For every tests, an aerosol of Staphylococcus Epidermidis was used in the injection. The use of this microbiological aerosol makes it possible to evaluate the impact of the loss of particulate, total flora and cultivable microorganisms concentrations determinations. The first measurements concerned particlate loss. A comparison between upstream and downstream sampling points has been performed. To prevent the differential which can exist between two optical counters, only one is used. Therefore measurements were taken in cycles of sampling. The cycles were defined after several tests of defining stabilisation time. The measurement cycle is described in Figure 5.

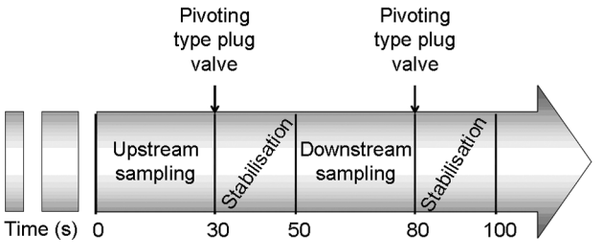

Figure 5 : Particulate measurement cycle

Some measurements have also been taken after an injection of saline solution to cover all the entire granulometric range. The second and third measurements targeted microbiological losses. The sampling was conducted by liquid impingers at the same time for upstream and downstream points every 15 minutes. The analysis of particles, cultivability and total flora loss had revealed that the loss is negligible because there magnitude is in the measuring error range, which is ± 10%.

4. RESULTS

4.1 Test conditions

The tests on NEO technology were conducted on a reduced scale prototype. It consists of two flat square filters with a flow area of 100 mm by 100 mm aside and a UV lamp positioned between the two filters (Figure 6).

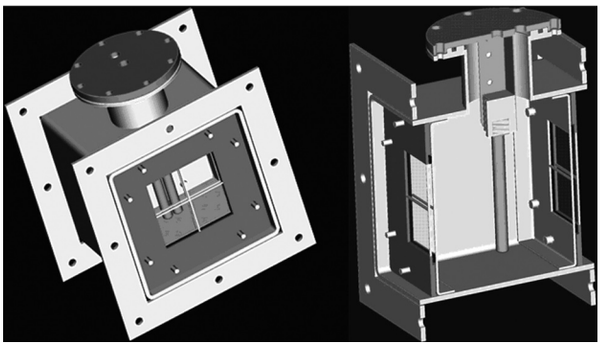

Figure 6 : Schemas of NEO prototype

The measurements, whose results will be presented later in this article, were taken with a frontal air velocity of 0.7 $m.s^{-1}$ and the UV lamp switched on. The air velocity flow had been chosen in order to replicate the velocity of air recommended for ventilation systems. During tests on the NEO system, physical parameters have been checked. Table 1 gives the average values and the standard deviations (SD) for the relative humidity (RH) and the temperature obtained for the five tests (n=5).

Table 1 : Physical parameters conditions

TESTS	Conditions	Medium (n=5)	SD
PARTICULATE	**RH** (in %)	41,3	4,3
	T (in °C)	23,1	4,1
MICROBIOLOGICAL	**RH** (in %)	49,5	10,7
	T (in °C)	23,6	3,5

4.2 Particulate effectiveness

According to CSTB, the Staphylococcus Epidermidis has a size included in the range of 0.5 to 1.5 µm. So the granulometric channel, whose size is from 0.3 to 0.4 µm presumably coming from particulate debris, likewise the channel superior to 2 µm, are not integrated in the calculation of the efficiency rate, because this size does not correspond to the size range of the bacteria and therefore its counting is not significant. The particulate removal efficiency rate on the Staphylococcus Epidermidis of the NEO system in one pass is 56% with a standard deviation equal to 4%.

4.3 Microbiological effectiveness

The counting of bacteria after a culture is only valid if the number of UFC ranges from 30 to 300 according to the standard EN 13098. According to the annexe D of this standard, the concentration of UFC obtained in an impinger is calculated using the following equation (1).

$$C = \frac{\sum C \times V_0}{V_1 \times (n_1 + 0.1 \times n_2) \times d \times V_a} \quad (1)$$

C: Concentration in $UFC.m^{-3}$

d: Dilution factor from which the first countable dilution was obtained

n_1: Number of identical Petri dishes in the first countable dilution in UFC

n_2: Number of identical Petri dishes in the second countable dilution in UFC

V_0: Total volume of suspension liquid in mL

V_1: Inoculum volume applied on each gelose in mL

Va: Total volume of sampling air in m^3

with $Va = Q \times t$ (2)

Q: sampling flow

t: sampling time

The cultivability efficiency rate on the Staphylococcus Epidermidis of the NEO system in one pass is 98.8% with a standard deviation equal to 0.9 %. This result is illustrated on the Figure 7.

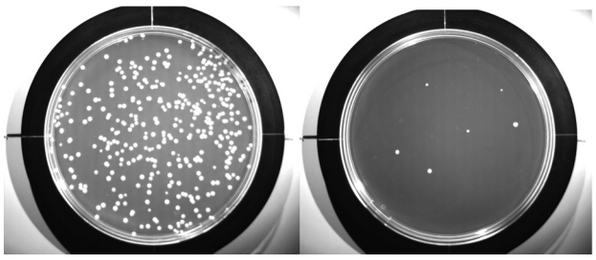

Figure 7 : Photography of upstream (the left one) and downstream (the right one) culture boxes

The total flora efficiency rate on the Staphylococcus Epidermidis of the NEO system in one pass is 62% with a standard deviation equal to 14 %.

5. DISCUSSION

The normally tests conducted on efficiency rates of air cleaners on microbiological contaminants had been done in real life conditions, so the parameters of the tests are not under control. This configuration does not permit the determination of the true purification efficiency of air cleaner given that some of the contaminants are lost (remain on the sidewalls of the duct, walls and ceiling in the case of measurements taken in a room),…In our configuration of the "ONE-PASS", all the risks of losses are eliminated by all the controls which have been performed during the qualification phase. This advantage allows us to say that the efficiency rate calculated is the real efficiency of the air cleaner tested.

Beyond the primary results obtained with the reduced scale prototype of NEO, these tests show the inherent difficulties with the qualification of systems intended for the destruction of micro-organisms in the form of aerosols, especially due to the absence of a normative environment. The qualification of the test facility requires a multitude of tests in order to guarantee the reliability of the results, and especially their reproducibility. The results obtained on this first prototype of the air cleaner are encouraging even if certain mechanisms occurring in the reactions remain to be specified.

The next stage is the introduction of an optimized purifier in a real scale in a test facility reproducing as accurately as possible the indoor environment. The above described experiment could be transferred to the "ASTERIA" plateform which could allow for an even more realistic experiment. This platform of tests was conceived and built within the framework of the public-private partnership between the CSTB and CIAT. It is composed of a reproduction of two office rooms, which are ventilated by a HVAC system. This reproduction is enclosed in an overpressure box. The test platform named "ASTERIA" would make actually the subject of qualification tests identical to those which were realized on the platform test that we have just described.

The first results of the works completed within the framework of the thesis of M. Stephane DELABY, were already the subject of a publication presented at the 22nd French Congress on the Aerosols in Paris in November 2006. In parallel to the performance testing of purification systems, the analysis of the risks posed on human health by the by-products (nanometric particles, COV, toxin...), resulting from the destruction of microorganisms, continues.

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