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# UV-A photocatalytic treatment of high flow rate air contaminated with *Legionella pneumophila*

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**Abstract**

A new photoreactor geometry has been designed to treat high flow rate air contaminated with airborne *Legionella pneumophila* bacteria by exclusive UV-A photocatalysis. A specific tangential reactor geometry with periodical illumination allowed high efficiencies for strongly contaminated air streams to be obtained, whereas its self-driven property strongly decreased the charge loss phenomena, crucial for targeting high flow rate air treatment applications. This type of photoreactor has been used as the basis for designing and commercializing photocatalytic decontamination devices for applications in the field of air treatment technology.


*Keywords:* UV-A photocatalysis; *Legionella pneumophila* bacteria; Decontamination; Air treatment; Tangential reactor; Technology transfer

## 1. Introduction

Since the first report of microbiological effects of $TiO_2$ by Matsunaga et al. [1], the application of photocatalysis to the life science area and the resulting crossing-over between both photocatalysis and microbiology research topics have been receiving increasing interest. However, whereas heterogeneous photocatalysis has attracted great attention as alternative method for both liquid- and gas-phase applications since decades [2–5], the active investigation field of photocatalysis applied to the removal of target microorganisms has remained very scarce outside liquid-phase applications, with water decontamination and potabilization. The public concern over human health and water potability has created a strong incentive and driving research in this area, together with a growing interest in the development of new UV-A and solar light processes for water disinfection. Many fundamental and applied studies have described the photocatalytic behavior of $TiO_2$ suspensions for *Escherichia coli* bacteria and virus inactivation [6–9]. An extended well-documented review by Blake et al. details the applications of the photocatalytic chemistry of $TiO_2$ to disinfection and the killing of cancer cells, and summarizes mechanisms reported for explaining the bactericidal effect of $TiO_2$ in photocatalysis [10].

Up to now, the most used processes for disinfecting fluids are chlorination, ozonation and germicidal UV-C lamps (low pressure Hg vapor lamps emitting at 254 nm) for water treatment [11–13] while size exclusion filters, germicidal lamps, thermal treatments or disinfection using chemical agents are used for air decontamination [14,15]. Filtration usually implies high costs, due to the micrometric size of the biological species. This recuperative process requires a post-degradation treatment to kill bacteria. Moreover, the short lifespan of filtration systems is restrictive and thermal/chemical treatments require compulsory isolation of the contaminated zone during disinfection treatments.

Works on the photocatalytic decontamination of bacteria-polluted air remain however scarce, despite a great interest for public health reasons and a large spectrum of applications. In previous works, the UV-A photocatalytic decontamination of

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*E.coli*-containing air was done on a commercial $TiO_2$ powder coat in the 1–6 L/min range in a Vigreux-like Pyrex tubular reactor with internal spikes [16,17].

The goal to meet industrial requirements needs obviously to treat larger air volumes. A step toward the high flow rate treatment was overcome with the increase in the bacteria-contaminated flow from few L/min up to several $m^3$/h by playing on the photoreactor design. This article reports on the use of the UV-A photocatalysis for the efficient one pass on-stream treatment of airborne *Legionella pneumophila* bacteria in semi-real working conditions, around 5 $m^3$/h of flowing air. *L. pneumophila* remains a problematic micro-organism since it is responsible for the legionnaire's disease (a kind of pneumonia) and the Pontiac fever. The American Center for Disease Control and Prevention claims that up to 10,000 and 18,000 people contract such a disease each year within Europe and the U.S.A., respectively, deadly for 5–30% of the cases. The French "Institut National de Veille Sanitaire" has reported that 610 people contracted the legionnaire's disease in 2003 in France with a mortality ratio of 15%, while the number of fatal cases increased twofold in 2004. The main contamination sources are aero-refrigerated towers, warming water, air-recirculation and -conditioning systems. The produced aerosols could be found as far as 12 km from the source location [18].

Within a common photocatalytic device, for both biological agent inactivation and gaseous molecule degradation, polluted air is usually sucked-in or blown by a fan and transferred through the photocatalytic reactor in order to be treated or purified. The efficiency of photocatalytic reactors mainly depends on the irradiance value and its distribution on the $TiO_2$-coated support [19], and also on the contact between the air pollutants and the photocatalyst. The optimal light power use corresponds to the range for which the reaction rate is proportional to the radiant flux, i.e. for measured irradiances generally lower than 25 mW $cm^{-2}$ according to Herrmann [20], what is generally the case for compact photocatalytic reactors using low-pressure Hg vapor lamps. Therefore, research in the reactor engineering area is often focused on reactors exhibiting a high-coating surface per unit volume photocatalytic support (e.g. honeycomb materials), which led usually to high-photocatalytic efficiencies for air treatment since the contact probability between organic pollutants and $TiO_2$ is high, providing that irradiance remains relatively homogeneous in each honeycomb material cell [21]. Within this trend, the major drawback of most reactor geometries is an inefficient light use [22], i.e. a low photoefficiency [23].

Emphasis is mainly put on a new photoreactor geometry, designed to get high efficiencies for strongly contaminated air streams at high flow rates. This photoreactor design has been used as the basis for designing and commercializing photocatalytic decontamination devices for applications in the field of air treatment technology.

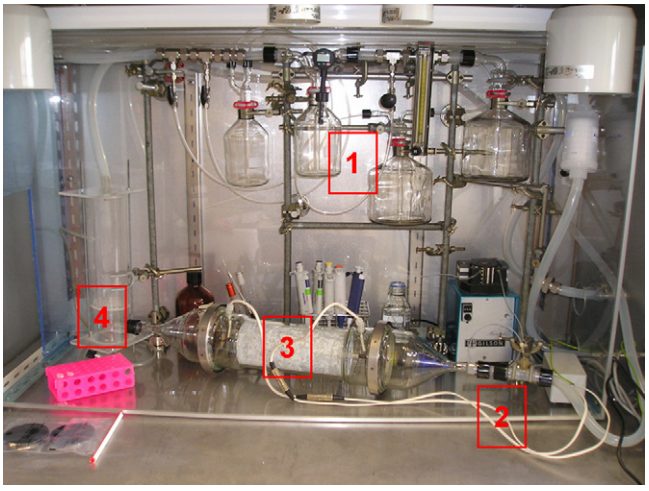


Fig. 1. Decontamination micropilot for contaminated-air photocatalytic treatment. (1) Pure air inlet line consisting of Pyrex glass vessels and filters for purifying the external air from oil residue, particles, water and external microorganism contamination, tuning the relative humidity and controlling the temperature of the clean air. (2) *Legionella pneumophila* bacteria injection system, based on the *Venturi effect*. (3) Photoreactor in which the bacteria-contaminated flowing air is passing through. (4) *On-line* bacteria collecting column allowing the sampling in the total flow rate, downstream of the photoreactor.

## 2. Experimental

### 2.1. Photocatalytic micropilot for contaminated-air treatment

Fig. 1 shows the micropilot decontamination unit built for UV-A photocatalytic treatment of contaminated-air. The unit is located inside a safety glove box (Jacomex, France) adapted for airborne pathogenic bacteria manipulations. It consists in an air inlet line composed of different Pyrex glass vessels and filters for purifying the introduced air from a compressor, from oil residue, dust particles gaseous pollutants and contamination by external microorganisms (sterilization was performed using a Kleenpak. Capsule with an Emflon® PFR Membrane, Pall, U.S.A.). This inlet line allowed the clean air temperature to be measured, and its relative humidity (RH) to be tuned, by bubbling the flowing air through water or using a drying agent (Silica gel Rubin, Fluka). The inlet air flow was regulated by an electronic mass flowmeter (Brooks 5853), before a bacteria aqueous suspension of *L. pneumophila* was aerosolized in the flowing air. The injection rate was controlled by a peristaltic pump (Minipuls II, Gilson). The contaminated air subsequently passed through the photocatalytic reactor. Bacteria in the effluent stream were collected on-line in a glass bubble column containing distilled and sterilized water.

To prevent any release of bacteria out of the glove box, a second 0.003 μm cut-off diameter Kleenpak. filter (Pall, U.S.A.) was placed downstream of the column and the outlet air was finally evacuated through the laboratory ventilation system.

### 2.2. Decontamination photoreactor design

A new UV-A-exclusive photocatalytic reactor geometry was elaborated and designed to get high efficiencies for strongly contaminated air streams at high flow rates. The tangential

denomination of this photocatalytic reactor resulted from the use of a tangential fan simultaneously as photocatalytic coating support and as air drive system. Both aluminium blades and internal surface of the duct housing acted as $TiO_2$ supports. An external U-shape UV-A lamp ($\lambda$ = 365 nm) was placed at the fan air inlet as described in Fig. 2, at a 30 mm distance between the lamp and fan axes, so that the photocatalytic coating on the blades of the fan remained, thus periodically irradiated during a regular drive of the fan blades. Tables 1 and 2 report the technical data of the UV-A lamp and of the fan used in the photocatalytic reactor.

The blade rotation speed was around 3800 rpm for a supply voltage of 12 V, with a round being completed in 15.8 ms. As the propeller diameter was 30 mm, the rotation rate of a blade was ranging from 4.0 to 6.0 m $s^{-1}$ and the air speed at the surface of a blade was ranging from 2.7 to 4.1 m $s^{-1}$. The fan air flow can be controlled by varying the supply voltage within the 4.5–12 V range.

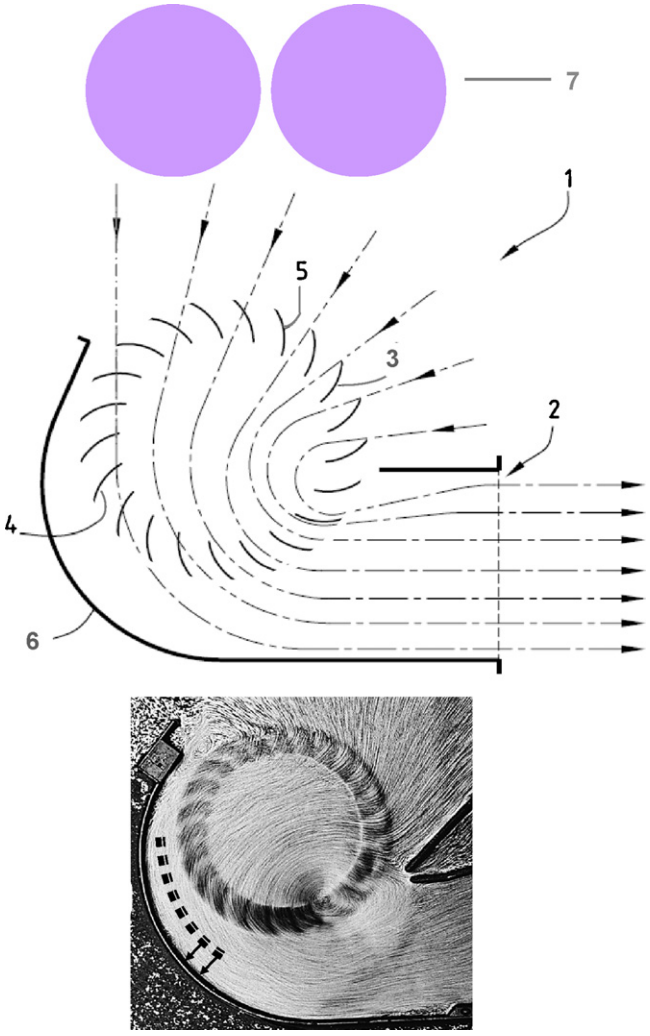


Fig. 2. (Top) Side-view scheme of the self-driven tangential decontamination photoreactor: (1) contaminated air inlet, (2) purified and decontaminated air outlet, (3)–(5) fan blades, (6) air duct housing and (7) U-shape 24W UV-A lamp. (Bottom) Side view scheme of the Vortex stream through the tangential photoreactor, with the possible sticking of bacteria onto the duct housing through the centrifugal force.

Table 1
UV-A lamp characteristics

| | |
|---|---|
| Type | TC-L |
| $\lambda$ (nm) | 350–400 |
| Ratio UV-B/UV-A | <0.1 (%) |
| Electric power (W) | 24 |
| UV-A power (W) | 7.2 |
| Cap-base | 2G11 |
| Quartz length (mm) | 290 |
| Total length (mm) | 320 |
| Useful life (h) | 5000 |
| Ballast type | Electronic |

The coating surfaces on the 22 blades of the fan and the internal surface of the duct housing were around 0.080 and 0.024 $m^2$, respectively. The deposition procedure for immobilizing $TiO_2$ consisted first in the cleaning of the blades and the duct housing with ethanol, before their rinsing with distilled water. $TiO_2$ was subsequently dip-coated using a 10 wt.% aqueous suspension of $TiO_2$ P25 from Degussa AG and the impregnation surfaces were further dried at ambient temperature under compressed air at an output pressure of six bars in order to obtain adherent $TiO_2$ layers after each coat. With this deposition method, the coat withstood pressurized air jet and direct air flow up to 1000 $m^3$ $h^{-1}$; the amount of $TiO_2$ that took down the support after many experiments remains usually around 1 wt.% [21]. In addition, strong and very restrictive mechanical stress tests resulted in $TiO_2$ weight losses at a maximum of 6 wt.%.

### 2.3. Microbiology procedure and bacteria numeration

*L. pneumophila* (strain GS3.11) was grown within 48 h at 37 °C on agar plates (Medium BCYE Biomérieux), from −80 °C stored strain sample. About 20 glass beads and 1 mL of a glycerol/water (20/80) mixture were added to each plate under sterile conditions before vigorous shacking in order to recover the beads with bacteria. Numerated aliquots were further sampled from each plate, by recovering two glass beads after shacking, and immersing them in 100 μL of the former glycerol/water solution inside a cryotube. The different aliquots were finally stored at −80 °C, the surrounding glycerol/aqueous media allowing the bacteria to withstand such a low-temperature storage.

This method allowed performing the experiments using genetically similar microorganisms as target biological agent with a 2-day procedure: after defrosting of an aliquot, the glass

Table 2
Tangential fan characteristics (values given for a supply voltage of 12 V)

| | |
|---|---|
| Fan type | Tangential |
| Electrical power (W) | 8.7 |
| Noise level (dB) | 51 |
| Rated voltage (V) | 12 |
| Propeller length (mm) | 303 |
| Total length (mm) | 363 |
| Air flow ($m^3$ $h^{-1}$) | 140 |
| Speed (rpm) | 3800 |
| Useful life (h) | 30,000 |

beads were shacked onto an agar plate (Medium BCYE Biomérieux). After 48 h growth at 37 °C on the agar plate, the colonies were suspended in 2 mL distilled water using glass beads. This starting suspension was then diluted to get the adequate bacteria concentration necessary for performing the experiments.

The quantification of the living bacteria was achieved by fluorescence microscopy using the "LIVE/DEAD BacLight Bacterial Viability kit ®" from Invitrogen® following manufacturer's instructions. According to Invitrogen®, this staining method has been positively tested on *L. pneumophila* and has proved to be less sensitive to bacteria stress than the numeration by plate counting [24]. Moreover, it provides more reliable results [25] within 30 min than plate counts which need for *L. pneumophila* to wait 48 h. Another positive consequence of this technique is the very low influence of possible external contamination than by using the plate growth method, since the staining takes place immediately after the experiment (other bacteria have no time to multiply).

This efficient numeration procedure is based on the fact that the SYTO 9™ stain is not selective towards the integrity of the cell membranes, and thus penetrates the cell membrane whatever its integrity (integrate as well as damaged membranes), whereas propidium iodide (PI) only enters the damaged cells. In the case of integrate membranes, the SYTO 9™ – DNA complex let the living cells fluoresce green (excitation/emission maxima: 480/500 nm), while the higher affinity of PI to DNA removes the SYTO 9™ – DNA complex and reacts with the DNA, what let dead cells emit red light (excitation/emission maxima: 530/620 nm). Details can be found in [26].

Fig. 3 shows two optical views (1000×) of a sample filtered on a Ø25 mm 0.22 μm black Isopore Filter Membrane™ (Millipore) and observed on a f luorescence microscope (Leica) with two optical sets. The first optical set "I3" (Leica) allows to see both live and dead cells because of the large excitation band of the IP – DNA complex which includes that of the SYTO 9™ – DNA complex. As a matter of fact, some bacteria emit orange light (actually the mix of green and red wavelengths) traducing a more limited permeability of those membranes to IP due to a less damaged membrane. The second optical filter "N2.1" (Leica) lets only the IP – DNA fluoresce at its maximal emission wavelength.

The live bacteria ratio was then defined as the ratio of the number of live bacteria to the total number of bacteria (live and dead). Viability numeration was considered to be reliable after counting more than 1000 bacteria for one sample.

## 3. Results and discussion

### 3.1. UV-A versus UV-C for treating contaminated air

The use of germicidal UV-C light for air decontamination is a well-known method since decades and has been studied over many kinds of airborne microorganisms, such as bacteria, viruses [27], bacterial spores and mycobacteria [28]. A quantitative method for determining the lethal effect of UV-C on bacteria suspended in the air was already reported by

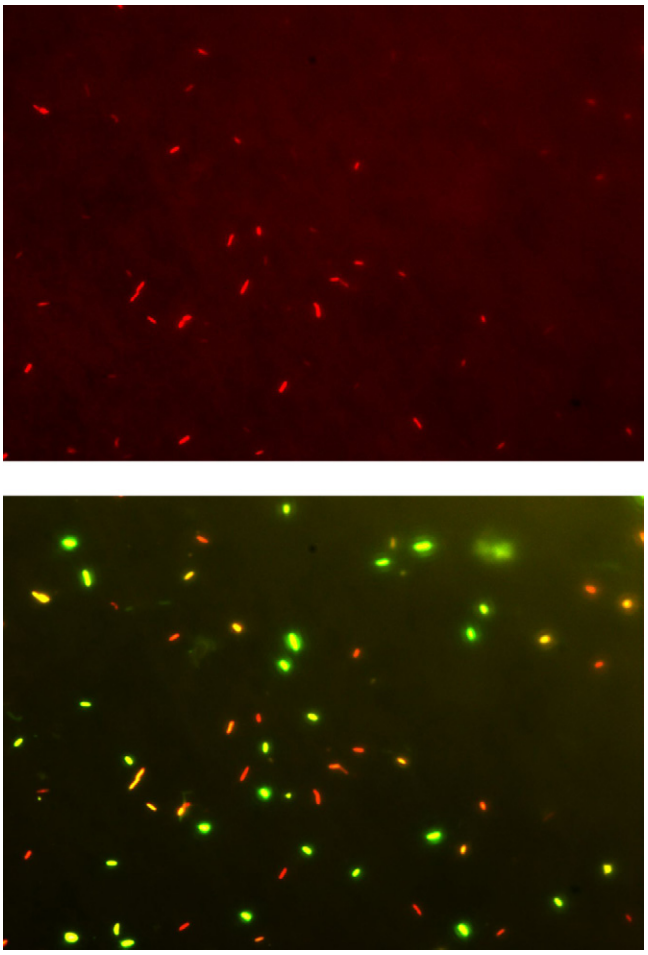

Fig. 3. Fluorescence microscopy images (1000×) of the same sample after filtration, observed with the two different optical filters after staining. (Top) Optical set I3 allowing visualization of both dead and live cells and (Bottom) Optical set N2.1 allowing only dead cells to be evidenced.

Sharp before World War I [29]. In addition to that, the suitability of the UV-C irradiation for activating photocatalysts as a high-energy light radiation logically results in the combination of both effects and allows UV-C photoreactors to achieve higher decontamination performances than pure UV-A photocatalysis. However, UV-C light suffers from occupational medicine risks even after short irradiation times [30]. They should be as far as possible avoided for domestic applications since the hazard of UV-C for customers remains much greater than the benefits of its use, especially when applied in sub-lethal doses. Actually, damages due to low UV-C doses, i.e. sub-lethal doses, such as dimerization of pyrimidines (usually thymines) in the DNA, can be restored by the deoxyribodipyrimidine photolyase enzyme [31,32], but only with a low fidelity. This low fidelity led to microorganism mutations, as explained by Livneh et al. when studying the replication of damaged DNA and the molecular mechanism of ultraviolet light mutagenesis [33], what is far away from an "eco-process" or "environmentally friendly process" concept.

In particular, *Legionella* spp. are UV-C-sensitive organisms, however with an efficient repair system, detailed in studies on the photoreactivation of UV-irradiated *L. pneumophila* and

other *Legionella* species [34,35] which renders the use of UV-C for such kinds of bacteria not worthy, under sub-lethal doses especially. Moreover, *Legionella* spp. are used to grow whether with other pathogenic bacteria in biofilms – which sometimes dislodge and aerosolize – [36] or inside other microorganisms like protozoans [37]. Within such strong protections, UV-C is clearly inefficient for damaging *Legionella* spp. [38]

As a result, UV-A photocatalysis should be preferred to UV-C activation, especially for domestic applications.

### 3.2. General considerations on the tangential self-driven photocatalytic reactor

Sczechowski et al. claimed that photoefficiency could be increased by irradiating the photocatalyst of a controlled and periodic optimal manner for degrading organics in aqueous solution, with a ratio between light and dark recovery times of 1:10 or 1:20 [39–41]. Some non-exclusive explanations have been put forward to explain this phenomenon, reported for liquid-phase applications. Hoffmann proposed that it would allow the relative rate of electron and electron-hole recombination process to be delayed [42] whereas Ohko assigned the photoefficiency enhancement by controlling the periodic illumination to the lowering of light intensity, since the light intensity could be defined as the average time between photon impacts [43]. It could be noted that Ollis experimentally proved that a dark recovery time allowed more time for the adsorption of $O_2$ on the catalyst surface and/or for transferring photoelectrons to adsorbed $O_2$ [44].

Beside liquid-phase reactions, this ‘‘tangential’’ photocatalytic reactor for air treatment applications belongs to this photoreactor scope, its specific design resulting in the periodic irradiation of the $TiO_2$ coating on the blades. The ratio between light and dark recovery times for a $TiO_2$ particle could be estimated around 1:3 when the $TiO_2$ particle was coated on the outer surface of blades, whereas the ratio increased to around 1:2 when the $TiO_2$ particle was coated on the lower surface of blades.

Modelling irradiance on blades surface is very difficult since it depends on a lot of various parameters (wavelength and reflexion of light, distance between UV lamp and fan, propeller diameter, blade angle and length,. . .). Fig. 4 shows at a t instant and for a given configuration, a schematized example of the light distribution on blades without considering the effect of wavelength and reflexion of light on the photocatalytic support. Distinction has to be made between four different kinds of irradiated $TiO_2$ surfaces, upper and lower parts of the photoreactor being also distinguished. The main fraction of the UV light from the U-shape lamp irradiates blades of the upper part of the propeller. The light irradiates the outer surface (Fig. 4A) and lower surface of blades (Fig. 4B). UV light that goes through the upper part of the propeller can reach the lower blades in the lower part of the propeller (Fig. 4C). Finally, a very small fraction of the irradiation can reach the $TiO_2$-coated air duct housing directly or through the propeller (Fig. 4D).

The following advantages of the photocatalytic ‘‘tangential’’ reactor could be put forward:

- The geometry of the tangential reactor seems to positively affect the contact between the target microorganisms and the photocatalytic coat, especially that located on the outer surface of blades. Indeed, in the case of a tangential fan after a long-term period of drive without dust filters, we could observe that dust was mainly coated on the outer surface of blades, which probably composes the main active surface, due notably to a short distance to the UV-A lamps and to a direct illumination. This location of dust could be considered as a possible visualization of the contact and impact between the photocatalytic coating and objects with non-negligible mass, such as living microorganisms.
- The self-driven nature of this photoreactor geometry is of high interest relative to the pressure drop problematic. Pressure drops in such a photocatalytic device are only caused by contingent dust filters avoiding the clogging of the coat, and not by the photocatalytic reactor as it is the case for most of photoreactors. For industrial applications of this ‘‘tangential’’ photoreactor, no additional inlet or outlet fans for driving the polluted air should be incorporated into the commercial device, due to its self-driven nature. This allowed the design of a compact unit for treating air contaminated with bacteria, the DPA® unit reported in Section 3.4, and resulting in a technology transfer outside the laboratory.
- As a consequence, the noise level of the system remained very low, being only caused by the fan motor and not by the air flow circulation. The insertion of the self-driven photocatalytic reactor inside the DPA® unit decreased the noise level below the 51 dB level of the fan motor.

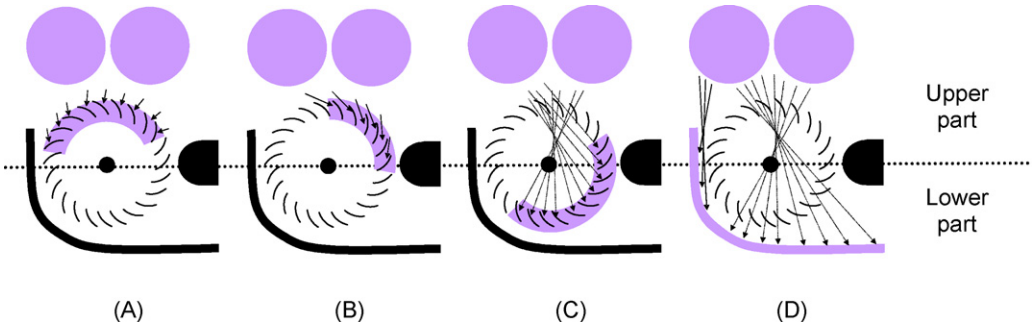


Fig. 4. Schematized distribution of irradiance at a *t* instant: (A) on the outer and (B) on the lower surfaces of blades. A part of the irradiation that went through upper blades (close to the lamp) could reach lower blades (close to the air outlet) (C) and a very small fraction could reach duct housing (D).

Table 3
Decontamination results

| Run | Photoreactor | Coating | UV-A | Live bacteria ratio in the inlet stream (%) | Live bacteria ratio in the outlet stream (%) | Decontamination efficiency (%) |
|---|---|---|---|---|---|---|
| 1 | Yes | No | No | 47 | 31 | 34 |
| 2 | Yes | No | Yes | 60 | 35 | 42 |
| 3 | Yes | Yes | No | 50 | 31 | 38 |
| 4 | Yes | Yes | Yes | 61 | 4 | 93 |

Operating conditions: air flow rate: 5 $m^3$/h; single pass mode; temperature in the 26.1–30.8 °C range; flow rate contamination at $6 \times 10^9$ bact./h ($1.2 \times 10^6$ bact./L); bacteria suspension in the aqueous media at $10^9$ bact./mL; live bacteria ratio before aerosolization at 46–60%

### 3.3. Decontamination efficiency

Table 3 reports the decontamination results obtained in a single pass mode for an air flow rate of 5$m^3$/h using the self-driven tangential photocatalytic reactor. The concentration of the bacteria containing aqueous solution used for creating the contaminated air flow was set at $10^9$ bact./mL, with a live bacteria ratio before aerosolization in the 46–60% range. The flow rate of contamination was set at $6 \times 10^9$ bact./h, corresponding to a bacteria concentration in flowing air of $1.2 \times 10^6$ bact./L. It should be noted that tests performed without reactor have shown that aerosolization and recuperation in the bubble liquid phase column have no significant effect on the bacteria viability.

Blank experiments led to inactivation ratios between 34 and 42%. This was probably induced by the drastic experimental conditions towards this sensitive stain of bacteria. Effectively, the first blank test (Run 1, Table 3) showed that the tangential reactor without $TiO_2$ coating and without UV-A irradiation seems to induce a stress on the bacteria contained in air stream (ratio between the number of living bacteria in the inlet stream and that in the outlet stream, of about 34%), that could be caused inter alia by the rotating effect of the blades. Runs 2 and 3 evidenced that "UV-A light without $TiO_2$ coating" and "TiO2 coating without UV-A light" have no effect on the bacteria viability. By contrast, the decontamination efficiency obtained with the tangential self-driven photocatalytic reactor reached around 93% in a single pass mode when $TiO_2$-coated blades and $TiO_2$-coated duct housing are irradiated by the UV-A lamp (Run 4).

The damage of the bacteria cell membrane in contact with $TiO_2$ particles resulting from the photocatalysis action in the gas phase probably occurred according to the mechanism reported by Maness et al. for the bacteria killing in liquid phase [45]. In this mechanism, the destruction of the cell membrane is initially caused by peroxidation of the polyunsaturated phospholipid component of the lipid membrane which would induce major disorder in the bacteria cell impairing respiratory activity and other essential functions and finally cell death. Eventually dead bacteria leave the photocatalytic surface. In the gas phase, as a consequence from the aerosol generation, it could be proposed that the bacteria-containing droplets initially impact and spread onto the photocatalytic surface due to the photoinduced superhydrophilicity effect of the $TiO_2$ [46]. This could strongly improve the contact between the microorganisms and the photocatalytic coating.

Fig. 2 shows a side-view scheme of the Vortex stream through the tangential photoreactor. It is proposed that bacteria driven by the air stream flowing parallely to the duct housing, could take advantage of the centrifugal force exhibited by the fan, due to their non-negligible weight compared to gaseous molecules. This could improve the sticking of the microorganisms on the duct housing, and thus enhance the contact between the bacteria and the photocatalytic coat.

The photocatalytic results obtained using this specific photoreactor geometry for the oxidative degradation of volatile organics and the inactivation of other airborne biological agents together with the influence of test conditions on the decontamination efficiency will be reported in a future article.

### 3.4. Technology transfer and commercial photocatalytic devices

An improved modified geometry of the self-driven tangential photocatalytic reactor has been inserted inside a DPA® (Désinfection Permanente de l'Air) air purifier and commercialized by the BIOWIND company for disinfecting and purifying air. Characteristics such as the blade angle, their numbers and width, the UV-A lamp—blade distance and the UV lamp power, have been specifically tuned for increasing the air flow treatment capacity of the DPA®, compared to the

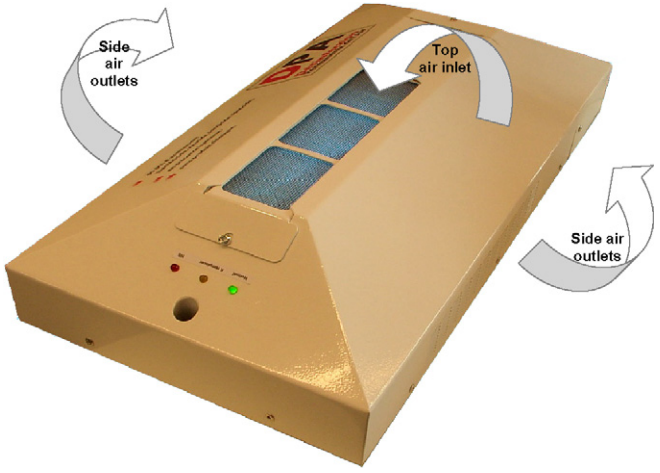


Fig. 5. First generation DPA® air purifier commercialized by the BIOWIND company, with a top-air inlet and side-air outlets. Based on an improved modified version of the self-driven tangential photocatalytic reactor, it resulted from the technology transfer to a private company, with the strong partnership of the Region Alsace (France).

precursor laboratory-scaled photoreactor. Depending on the targeted air volume, adequate size and specific standards are available, allowing the treatment of up to several hundreds of $m^3/h$ to be performed. Throughout the first elaboration and conception of a prototype, this DPA® air purifier resulted directly from the technology transfer of academic results to a private French company, with the strong partnership of the Region Alsace (France). Fig. 5 shows a top-view of the DPA® air purifier with one top air inlet and side air outlets for rejecting treated air. The self-driven nature of the device led to very low-charge losses, not induced by the photocatalytic reactor it-self, but only resulting from the inlet and outlet protective filters, required by the Particulate Matter Legislation and for safety considerations. The characteristics of the self-driven tangential photoreactor geometry allowed the DPA® unit to exhibit advantages such as its compactness, reduced noise level and pressure drop, beside a high single-pass efficiency. This led to a decrease in the overall manufacturing costs. The photocatalytic results and performances exhibited by this air purifier device for other airborne biological agents such as viruses and spores will be reported elsewhere in a future article.

## 4. Conclusion

This article reports on the design concepts and use of a photocatalytic reactor for treating high flowing rate *L. pneumophila* bacteria contaminated air by UV-A photocatalysis. The specific procedure for adequate and easy bacteria numeration has been pointed out.

The geometry of a tangential self-driven UV-A photocatalytic reactor with periodic irradiation of $TiO_2$ coating surfaces is reported. Decontamination efficiency of 93% was obtained in a single-pass mode at 5 $m^3/h$ air a flow rate with a 1.2 $10^6$ bact./L of air contamination.

Works are ongoing to evaluate the efficiency of this photoreactor design for the UV-A photocatalytic inactivation of other airborne microorganisms, including P. fluorescens bacteria, the B. subtilis spores, the C. albicans fungi and viruses, testing being carried out in our laboratory or in biohazard laboratories. Further efforts will be devoted to the optimization of the UV-A responsive photocatalyst and to the improvement of the photoreactor geometry design, in order to increase the process efficiency in a single pass mode and to perform higher flow rate experiments for industrial applications.

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