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Effectiveness of UV Radiation for Reducing *Aspergillus Niger* and *Actynomices* Contamination in Air-conditioning Systems.

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ABSTRACT

The effectiveness of UV radiation lamps in order to reduce fungal contamination of HEPA filters, to extend filter efficacy and to reduce maintenance costs, is experimentally studied by means of a dedicated air conditioning unit. An experimental HVAC system, with HEPA filters and UV-C lamps (λ=254 nm), was built. Two experiments were performed. After disinfection and control of airtightness, the internal surface of the HVAC system was contaminated (1) with *A. niger* spores and (2) with *Actynomices*. Temperature level was 300 K and Relative Humidity (RH) ranged from 30-90%. The results show that the addition of UV-C lamps to HVAC system reduces *A. niger* and *Actynomices* air concentrations; the effectiveness increases with the decrease of RH level in the HVAC system.

INTRODUCTION

The need of reducing the particulate contamination in hospital wards, especially the one biologically active, is of paramount interest for the health of both patients and hospital personnel, in the light of the recent UNI-EN 14644 ([1], [2], [3]) regulations on clean rooms and the associate controlled spaces, and also of regulations UNI EN 14698 [4] and [5] for the control of biocontamination. For the latter purpose several researchers have considered the possibility to adopt UV-C rays (wavelength λ=100÷280 nm) with the germicide lamps located inside the air ducts of the conditioning systems or directly on the roofs, with the purpose to inactivate the microorganisms present in the air flow ([6], [7], [8], [9], [10]).

The germicide capacity of UV-C rays is well known, and is explained by the absorption of such rays into the nucleic acids structure, especially for those with λ=254 nm. Many researchers have studied in detail their mode of action, and the susceptibility of several microorganisms to UV-C ([11], [12] ,[13], [14]).

During the disinfection procedures generally four types of survival curves have been observed for the microorganisms, described by linear-logarithmic graphs, having the log of the surviving microorganisms number plotted as a function of the employed treatment parameter (time of exposure or the doses of UV-C rays).

Such types of graphs are represented through linear curves A, curves with one shoulder B, curves with a tail (two stage survival curves C) or sigmoid curves D ([15], [16], [17], [18], [19]), such as qualitatively reported in Figure 1.

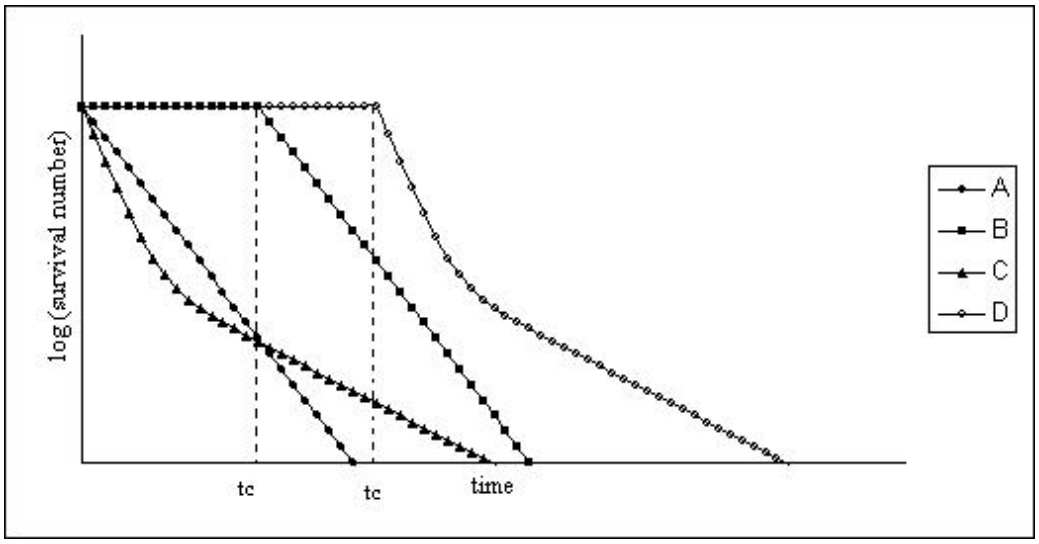


Figure 1- Survival curves (generic for bacteria or fungi):
linear (A), shoulder curve (B), two stage curve (C), sigmoid (D)

The mathematical models which represent such curves A, B, C, D can be expressed respectively as

$$N = N_0 e^{-\alpha t} \quad (1)$$

$$N = N_0 e^{-\alpha (t - t_c)} \quad \text{for } t \geq t_c \quad (2)$$

$$N = N_0 \left[(1 - F_0) e^{-\alpha_1 t} + F_0 e^{-\alpha_2 t} \right] \quad (3)$$

$$N = N_0 \left[(1 - F_0) e^{-\alpha_1 (t - t_c)} + F_0 e^{-\alpha_2 (t - t_c)} \right] \quad \text{for } t \geq t_c \quad (4)$$

where

- N and N_0 represent the microorganisms surviving at time t and those initially present at time t=0 respectively;
- α is a parameter proportional to the applied UV-C intensity and depends on the sensitivity of the microorganism to the UV-C rays exposure;
- F_0 represents the most resistant fraction, characterized by a lower sensitivity to the UV-C rays exposure, in a population of microorganisms, compared to the fraction (1 - F_0) less resistant to such exposure;
- t_c is the time during which microorganisms are substantially not inactivated

Among the different factors influencing the phenomenon of UV-C disinfection there are the air temperature and the air relative humidity ([20], [21], [22]).

The paper showes the results of an investigation on microorganisms *Aspergillus niger* and *Actinomices spp* exposed to UV-C both in the air stream and on the surface of HEPA filter. Inactivation curves at different values of relative humidity (RH) for the air (30%, 60% and 90%) are presented.

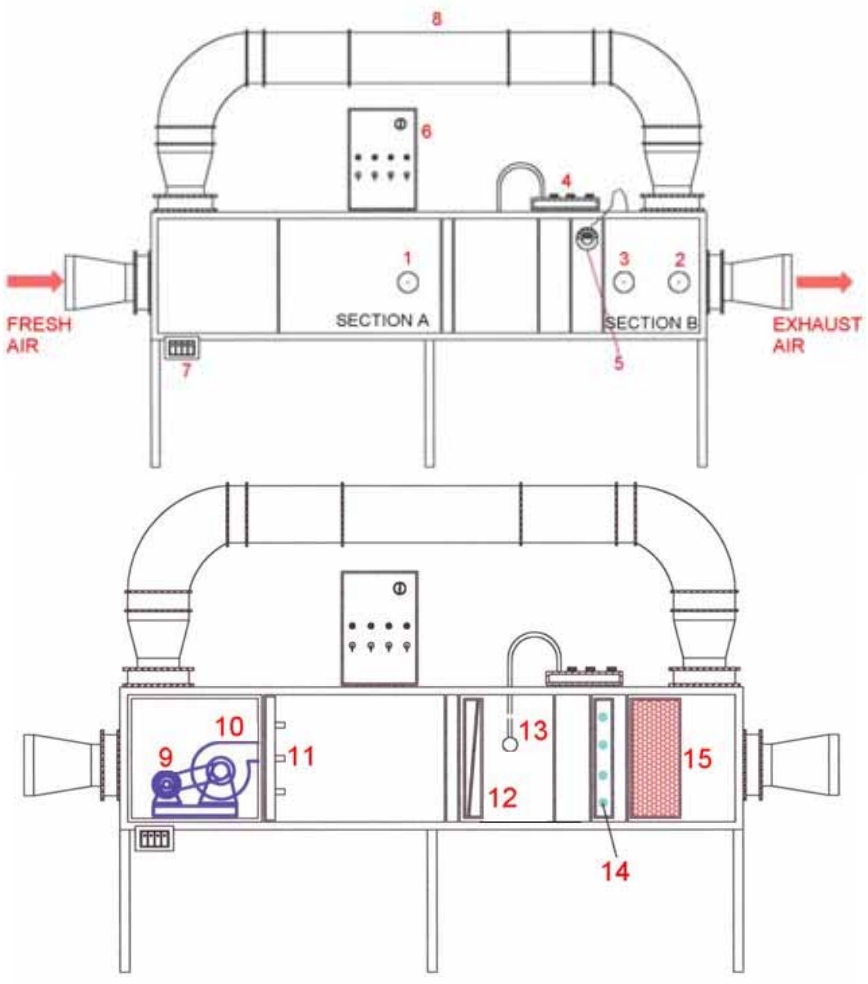
METHODS

Experimental Facility

The experimental apparatus is an air conditioner unit for air treatment (Figure 2), composed by

- A section including the fan together with his electric motor;
- A zone for microbiological charge (Colony Forming Units CFU);
- A section containing the air heating resistor and the steam humidifier with drops separator;
- A section containing the germicide lamps;
- A section containing the filtering media.

For each section there is the possibility of air sampling through an opening equipped with special butterfly valves, in order to avoid losses during the sampling. The box containing the Air Conditioning Unit (ACU) is made by galvanized steel sheets with finished surface; this is to avoid the growth of bio-film on the surfaces and to obtain a good reflection coefficient to increase the germicide action of the UV-C lamps installed.



Figures 2 - Experimental facility schemes. At top lateral view, at bottom lateral section. 1 air sampling intake A, 2 air sampling intake B, 3 inspection intake, 4 humidifier, 5 thermometer, 6 general electric panel, 7 UV-C lamps control, 8 air recirculation duct, 9 electric motor, 10 fan, 11 CFU plates, 12 heaters, 13 humidifier distributor, 14 germicide lamps UV-C, 15 HEPA filter

In the first section of the air conditioner unit ACU, along the air circuit, there is a fan with a static prevalence of 100 Pa and a capacity of 1,500 m^3/h, driven by a monophase electric motor fed at 220V.

In the second section are included

- Three armoured electric resistors, fed at 220 V, as heating device for the temperature control. They are regulated through a temperature probe and can absorb power up to 5000 W.
- The steam distribution for the relative humidity (RH) control of the circulating air into the ACU. It is an inox steel linear distributor which introduces steam obtained by a submersed electrodes humidifier that can reduce the water pollution by 99.8%. The humidifier is controlled by a humidity probe with modulating signal and absorbes a power of 5.8 kW supplied by an electrical transformer providing 8 kg/h of sterile steam. The humidifier with submersed electrodes is fed by the water line of the laboratory. This type of humidifiers operates through the Joule effect using as electrical resistance that of the water which is heated and evaporates. An anti foaming system (AFS) can detect and discard the foam produced in the cylinder. Due to the fact that the steam produced inside the ACU can condensate, the pipe of the distributor is positioned sub-horizontally, with a slope of 2-3% in order to avoid biological growth.

The third section houses the germicidal lamps mounted, with their standard supports for fluorescent lamps, on supports built ad hoc, standing on a squared frame. Four lamps (PHILIPS TUV UV - C G15T8 LONG LIFE, 15 W each) are used. They are tubular quartz lamps, 450 mm long, 26 mm diameter, fed at 220 V, with a specific UV-C emission of 40 $\mu W/cm^2$ and they are located on the air flow.

The last ACU section houses the aluminium sledges containing the HEPA filter employed during the experiments, with efficiency DOP of 99.995%**,** mounted at a distance of 150 mm away from the germicidal lamps.

MEASUREMENT PROTOCOLS

The objectives pursued during the experiments with UV-C as air disinfectant are the following:

- To verify the efficacy of the association of mechanical filters and UV-C apparatuses.
- To verify the microbial growth on the mechanical filter surface is avoided.
- To evaluate the opportunity of irradiating a filtering medium at high efficiency.
- To prolong, if possible, the operative life of mechanical filters.

To perform the research phases and obtain correct conclusions, it has been necessary to plan correctly the different steps. Before of each measurement campaign detection of possible air leakages from the plant, clean-up and disinfection of inner surfaces, disinfection of inaccessible parts using “Fumispore” was performed. After the introduction of fungal dose by means of the Colony Forming Units CFU and the start up of plant, three air samples was drawn in order to determine the initial situation. The air sampling was performed by means of a SAS device.

- PRELIMINARY PHASE: empty plant. Determination of the right dose of fungi to introduce into the ACU. Quantification of the natural decay of the microbial concentration due to three simultaneous events: (a) microdispersion outside the ACU, (b) deposit of fungi onto the internal surfaces, (c) lysis of the fungi due to the mechanical collision against the hard surfaces of the plant.
- FIRST EXPERIMENTAL CONDITIONS: plant operated with UV-C only.
- SECOND EXPERIMENTAL CONDITIONS: using Hepa filter inside the plant with UV-C not operating;
- THIRD EXPERIMENTAL CONDITIONS: using Hepa filter and operating UV simultaneously.

During the first, second and third phases, air sampling and sampling from the inner surfaces of ACU have been performed. For air we performed three samples for each sampling interval; the sampling interval was time 0, after 15 min, after 30 min, after 45 min, after 1, 2 4 and 6 hours. For the surfaces, several samples was drawn at the end of the single experiment.

RESULTS AND DISCUSSION

In this paper we report results regarding survival curves into the air samples, whereas those regarding the surface samples will be reported in future work. Also the opportunity of irradiating the filter at medium efficiency will be investigated in future work.

Figures 3, 4 and 5 report the inactivation curves toward time. The curves show the typical two stage shape with tail: it confirms what has been observed by many researchers, in particular Cerf 1977 [23], Smerage and Teixeira 1993 [24], Fujikawa and Itoh 1996 [25] and others ([26]). In general, in every microbial population there exists a small fraction resisting the UV-C radiations or other bactericidal agents. In that case, the mathematical model of inactivation can be represented by the relationship (3).

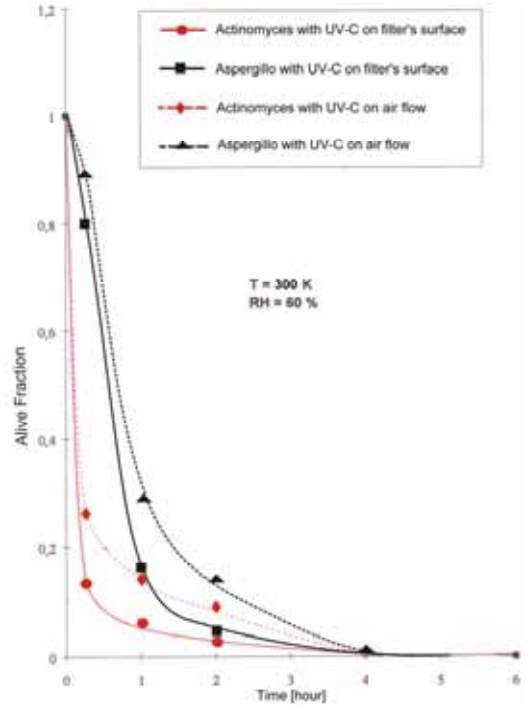


Figure 3 – Comparison of two radiation techniques for *Actinomices* and *Aspergillus niger*

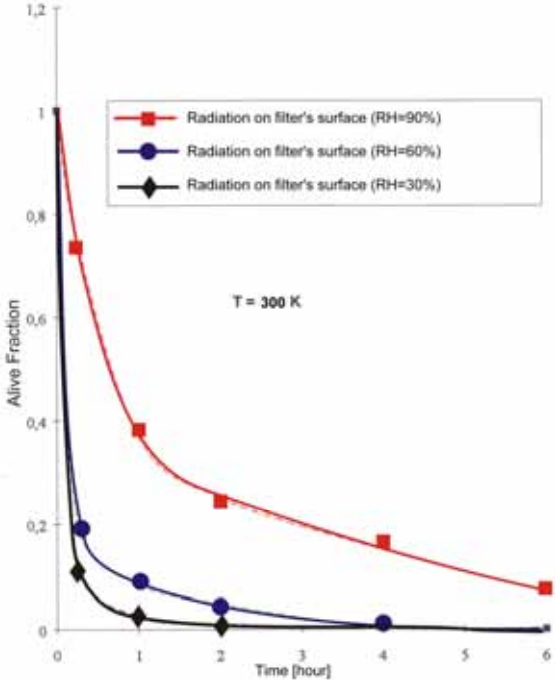


Figure 4 – Inactivation curves of *Actinomices*

Figure 3 shows the inactivation curves at 300 K and 60% RH for *Aspergillus niger* and *Actinomices.* It is clear that *Actinomyces* has a higher sensitivity compared to *Aspergillus niger*. Curves refer to measurements performed when irradiating the air stream and the HEPA filter surfaces respectively. The fraction of *Actinomyces* surviving 15 min later after irradiation of the air stream and of the filter results less than 25% and 15% respectively, whereas the fraction of *Aspergillus niger* it is still 90% and 80%. Irradiation of the filter surface gives better results than irradiating the air stream, as it appears evident from the much faster decay of the surviving population.

Decay curves of *Actinomyces* at 300 K temperature toward variation of RH are reported in Figure 4, while Figure 5 compares the decay curves of both microorganisms toward the variation of the test conditions, RH and modes of irradiation. When increasing irradiation, the fraction of surviving population increases neatly, and becomes much higher when RH is 90%.

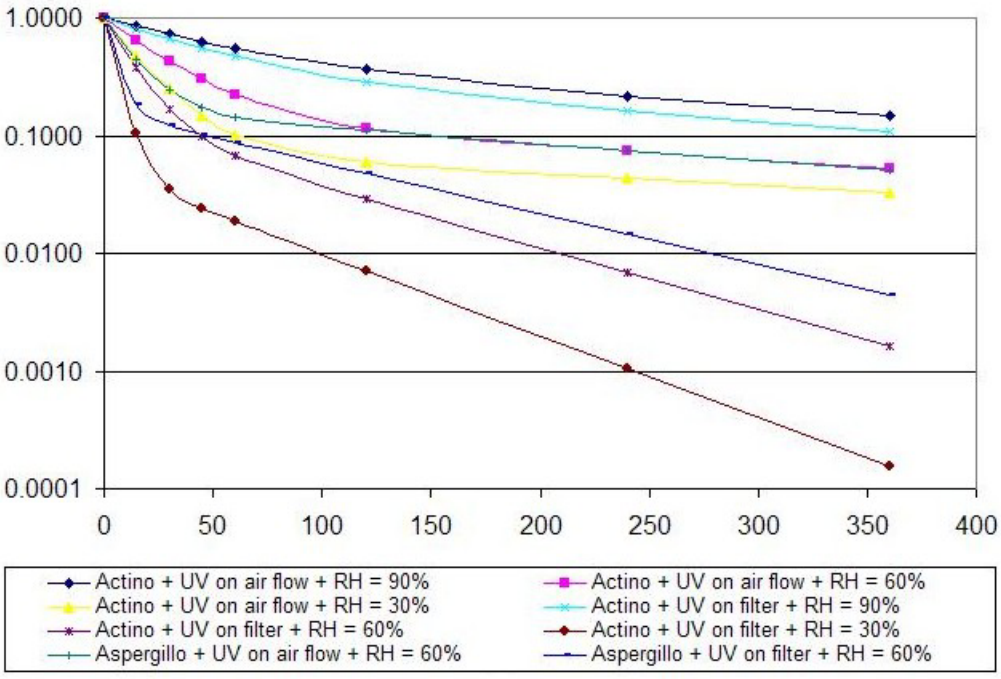


Figure 5 Decay curves of surviving Aspergillus niger and Actinomices fraction for different values of relative humidity and for two irradiation targets (air flow or filter surface)

At this value the differences observed in the decay curves with different irradiation procedures (irradiation of the air stream and irradiation on the filter surface) are quite small. Absorption of UV-C radiation by the steam becomes very high and, therefore, the effect of UV rays is reduced, especially for the more resistant population fraction. The tails do not differ significantly one from the other.

On the contrary, with low RH values (30%), the direct irradiation of the filter surface has amplifying effects on the decay of microrganisms, compared to the other irradiation procedure. Also the resistant population fraction decays faster, as it is demonstrated by the slope of the tail.

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