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STUDY OF A CABLE CONTACTOR IN ULTRA-VIOLET DISINFECTION.

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SUMMARY.

This preliminary study investigates the possible use of a cable contactor for the sterilization of micro-organisms suspensions in water by ultra-violet radiation. The influence of some of the most important operating parameters has been analysed and a kinetic model of UV disinfection in the "AMAZONE" contactor is proposed. The technical feasibility of the process is seemingly demonstrated.

INTRODUCTION.

Sterilization techniques are used in many fields for disinfecting microbiologically contaminated liquids (food industries, swimming-pools, public water supplies, cooling water supplies, electronic industries, etc.).

In these applications, chemical disinfectants continue today to be the most widely used (chlorine and derivatives, ozone, etc.). Despite of their high efficiency and low cost, these techniques also present some well-known drawbacks such as potential production of environmentaly hazardous compounds, modification of the colour, taste, pH of the treated water, loss of efficacy against some resistant germs.

In this frame, ultraviolet light (UV) is being considered as an interesting alternative to chemical disinfection. Nevertheless, it should be remembered that the light intensity and consequently its germicidal action, is attenuated exponentially with the penetration depth in the medium (Lambert's law). The liquid film presented to the UV lamps must therefore be as thin as possible, dead angles and obstacles shoud be avoided and the distance between the liquid film and the lamp is to be minimized. Moreover, for industrial purposes, sterilization units must be able to treat very large flow rates while remaining compact.

Considering all these characteristics, it was decided to study the potential use of the "AMAZONE" cable contactor in UV disinfection of liquids.

The basic element of the "AMAZONE" contactor, preliminary designed for gas-liquid heat and mass transfer, is series of textile cable curtains vertically stretched (16500 cables/m^2 of horizontal surface) forming a highly porous lattice (about 80 %). The liquid distributed at the top of the curtains forms around the cables thin pipes falling at uniform outer velocity. The exposed liquid surface is high (about 100 m^2/m^3 of contactor)

and large liquid flow rates can be treated (40 $m^2/h.m^3$ of horizontal surface) (Anonymous, 1987).

MATERIALS AND METHODS.

This work is essentially devoted to investigate the possible use of the "AMAZONE" contactor as a UV disinfection unit.

In this aim, it was proceeded in two steps : first, with a one-cable equipment fitted with a single UV lamp and, in a second step, with a pilot-scale apparatus containing many lamps and more than 1000 cables.

Choice of the main experimental parameters.

A great number of parameters may influence the efficiency of a UV disinfection unit. Let us namely quote : the distance between the lamp and the liquid film, the liquid flow rate, the turbidity of the liquid, the nature and concentration of micro-organisms, the physicochemical characteristics of the liquid.

Among these parameters only the supposed most important ones were retained in this preliminary study : the liquid flow rate, the distance between the liquid film and the lamp and the nature of the micro-organism.

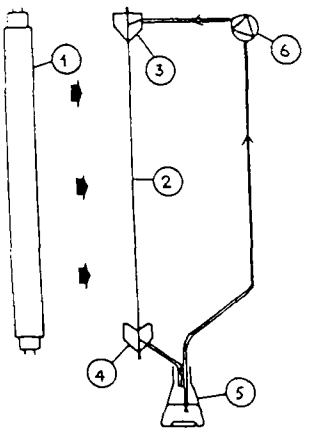
Micro-organisms suspensions and enumeration after irradiation.

In all runs, the densities of micro-organisms in the test water ranged from 100000 to 300000 micro-organisms/ml.
Culture age may eventually influence the sterilization kinetics. Therefore cultures of the same age were used in all runs. Each sample taken during irradiation was duplicated to enhance precision. Samples were diluted in sterile physiological water in order to obtain countable plate agar.

One-cable experimental equipment.

The experimental equipment shown in Figure 1 is constituted of a single cable (polyethylene terephthalate textile yarn - 0.85 m long).

A Philips TUV 30 Watt germicidal lamp (UV-254 nm irradiance at a distance of 1 m = 830 mW/m^2) (Anonymous, 1979) is placed vertically, parallel to the cable.



1. TUV LAMP, 30 W, L=1 METER
2. MULTI-THREAD TWISTED TEXTILE CABLE
3. AND 4. SOLUTION DISTRIBUTER AND RECUPERATOR
5. ERLENMEYER FLASK : 50 ML STIRRED SOLUTION
6. PERISTALTIC PUMP

Figure 1. Experimental installation with a single cable.

Due to the great efficiency of UV light in the air, no contamination of airborne germs was found in preliminary runs. Therefore no special protection of the cable against the environment was taken.
About 50 ml of test water was circulated on the cable by a peristatic pump. In order to compensate the liquid evaporation during runs, the volume of test water was maintained constant by regular additions of sterile water.

Pilote-scale apparatus "AMAZONE".

The pilot-scale apparatus was designed to be representative of a future industrial UV sterilization unit based on the "AMAZONE" system.
It is composed of two "AMAZONE" modules (0.168 m^2 of horizontal section and 1.2 m in height) placed side by side (Figure 2).
Between the two modules is inserted a frame formed of metallic sections supporting 4 Philips TUV 15 W lamps (UV-254 nm irradiance at a distance of 1 m = 370 mW/m^2) horizontally placed and regularly spaced in height.

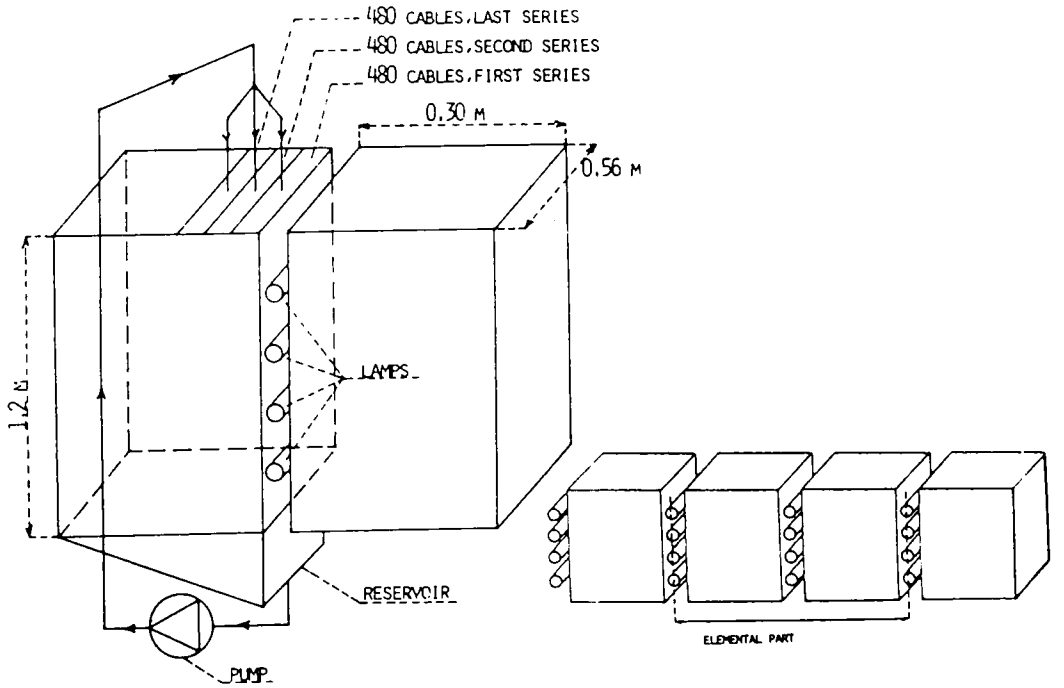


Figure 2. Diagram of the pilot-scale apparatus.

This equipment structure was chosen because it corresponds to the elementary pattern of a future battery of sterilization units. Owing to the system symetry, only the inside half of a module was irrigated in all runs (24 nets of 60 cables). As in the experimental apparatus, a batch of liquid stocked in a tank below the module was continuously circulated on the cables.

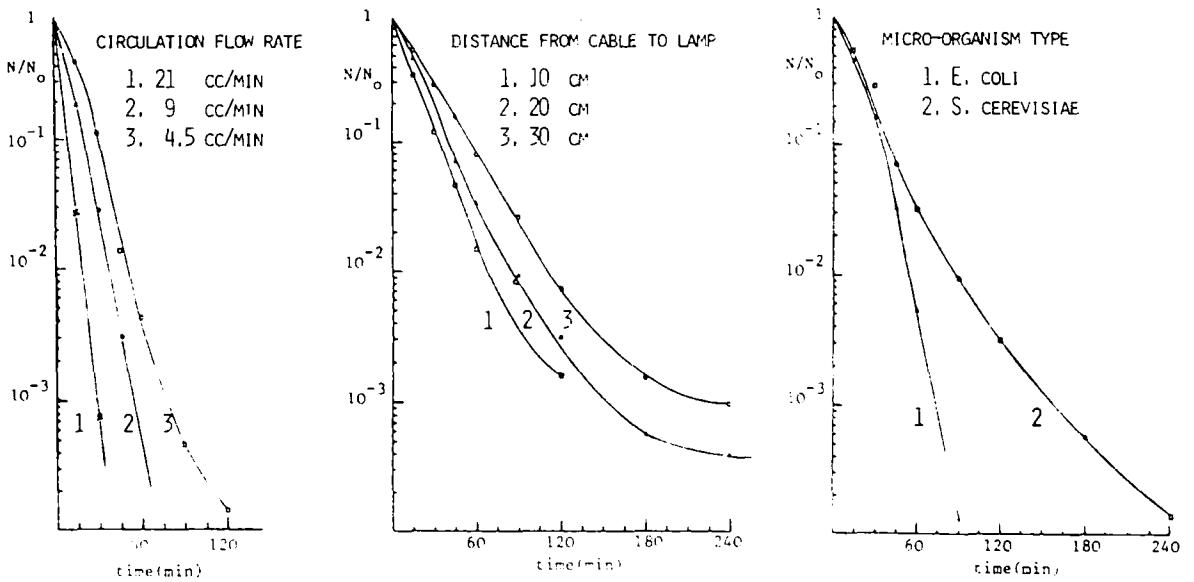
In order to limit evaporation during the runs, the pilot-scale equipment is enclosed in a box realised with polypropylene plates. Inside lateral faces are coated with aluminium sheets in order to increase the efficiency of the installation (aluminium presents a high reflectance to 254 nm UV - 60 to 80 %). Conversely, the two other faces are non-reflecting.

RESULTS AND DISCUSSION.

Results obtained on the one-cable apparatus.

Effect of the circulation flow rate.

The effect of an increase of the circulation flow rate is complex. It is known that an increase of the flow rate thickens the liquid pipes around the cables and diminishes the falling time (Onyejekwe, 1978) and therefore the potential exposure time of the micro-organisms to UV radiations. Nevertheless, the number of passages of micro-organisms per unit time passing in front of the germicidal lamps is also statistically increased. Three circulation flow rates were used : 4.5, 9 and 21 cm^3/min.
Results are presented in Figure 3. It appears that sterilization efficiency increases with an increase of the flow rate.



Figures 3, 4 and 5. Influence of several parameters on the sterilization kinetics.

Effect of the distance between the cable and the lamp.

As expected, the sterilization efficiency decreases with the distance between the lamp and the cable. Runs were performed for three distances : 10, 20 and 30 cm (Figure 4).

Effect of micro-organism species.

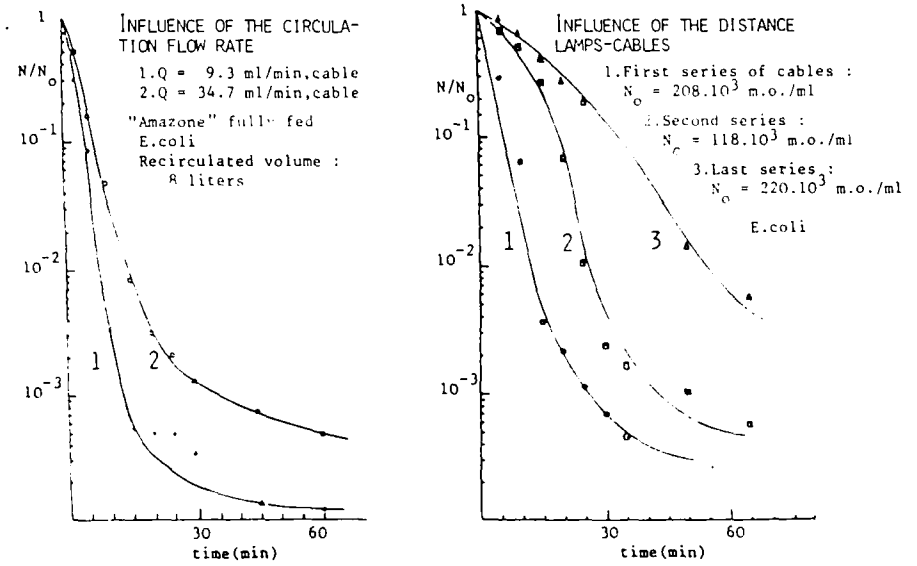
The UV resistance of micro-organisms may vary considerably with the species. The UV resistance generally increases with the shape and complexity of cells. Two micro-organisms whose resistance to UV are known to be different were chosen : Saccharomyces cerevisiae and Escherichia coli.

As shown in Figure 5, the yeast appears more resistant than the bacteria, this result is in agreement with literature data (Anonymous, 1979).

Results obtained on the pilot-scale apparatus.

The results obtained on the pilot-scale apparatus are presented in Figures 6 and 7. These results confirm those obtained on the one-cable apparatus.

It will be seen that the number of micro-organisms decreases more sharply in the pilot-scale apparatus than in the experimental one. The mean residence time of the liquid in the tank was shorter in the pilot-scale apparatus (0.2 min in this equipment, 2.4 min in the one-cable one).



Figures 6 and 7. Results obtained on the pilot-scale apparatus.

Discussion.

It was attempted to model the evolution of the number of surviving micro-organisms as a function of the time, taking into account the sterilization kinetics and the liquid residence time distribution in the equipment.

The pilot-scale apparatus can be considered as a perfectly mixed volume (the tank) in series with a piston reactor (the cables). Neglecting the volume of the piston zone with respect to the volume of the perfectly mixed zone, the internal age distribution of the micro-organisms which passed j times on the cables, at time t, is given by :

$$N_j = N_0 \frac{(t/\tau)^j}{j\,!} e^{-t/\tau}$$

Coupling this residence time distribution with a mixed-second order kinetics of sterilization leads to a model which cannot explain the initial shoulder usually observed in experimental runs.

On the other hand, a suitable model is obtained by coupling the residence time distribution with the series events kinetics developped by Severin.

The number of surviving micro-organisms at time t is given by the following relation :

$$N_S = N_0 \, e^{-t/\tau} \sum_{i=0}^{\infty} \left[\frac{(t/\tau)^j}{j\,!} \, e^{-kITj} \sum_{i=0}^{n-1} \frac{(kITj)^i}{i\,!} \right]$$

This model is in good agreement with the experimental results, at least for short irradiation times. Nevertheless, it cannot explain the final shoulder also observed. This latter could be attributed to the presence of clumps of micro-organisms. Micro-organisms inside a clump are protected by the shield formed by the more external ones.

The effect of the distance between the lamps and the cables cannot be easily theoretically analysed in the pilot-scale apparatus, owing to its complex geometry. This effect will be investigated in a further study by an actinometric method.

CONCLUSIONS.

The objective of this work was to study the use of the "AMAZONE" cable contactor as a UV sterilization unit.
Among the numerous operating parameters, the influence of the distance between the lamps and the cables, the liquid circulation flow rate and the micro-organism species were investigated.

Two experimental installations were developped and worked : an apparatus fitted with a single cable and a pilot-scale equipment containing more than 1000 cables.

Runs performed on these two equipments show the technical feasibility of UV sterilization in "AMAZONE" cable contactors.

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NOTATIONS.

I : UV light intensity (W/m^2)
j : Number of passages on the cables
k : Kinetic parameter
n : Kinetic parameter (m^2/J)
N_0 : Initial number of m.o. (m.o./ml)
N_S : Surviving m.o. at time t (m.o./ml)
τ : Mean residence time = V/Q (s)
Q : Liquid circulation flow rate (m^3/s)
t : Time (s)
T : Mean residence time of the liquid on the cables (s)
V : Holding tank volume (m^3)

REFERENCES.

- Anomymous, The Amazone Contactor, Technical notice, Ateliers Toussaint-Nysenne, B 4820 Dison, Belgium, 1987.
- Anonymous, Germicidal lamps and applications, Philips technical notice, Lighting division, 1979.
- Onyejekwe F.O., Ph. D. thesis, Faculté Polytechnique de Mons, 1978.
- Severin B.F., Kinetic modeling of microbiological inactivation by ultraviolet light, Ph. D. Thesis, University of Illinois, 1982.