Master Project

Water Sterilizer Optimization

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January 2008

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The beginning

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The steriliser

Award winner of most innovative technologies for environment

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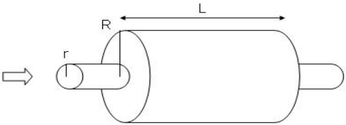
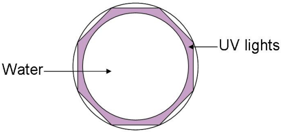
Definition

- **Context:** To model water sterilization by UV radiation with this device :





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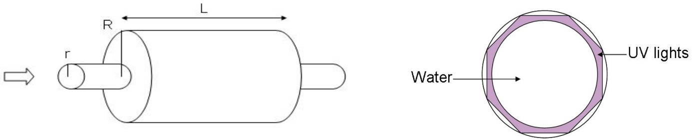

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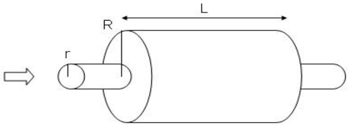

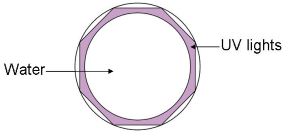

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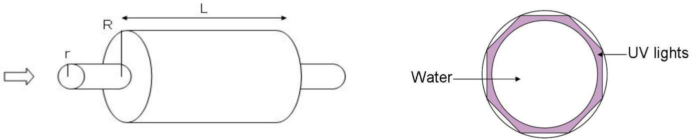

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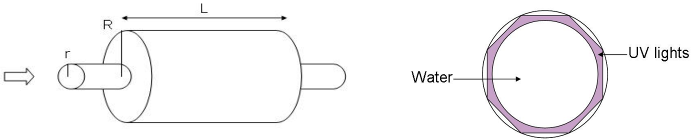

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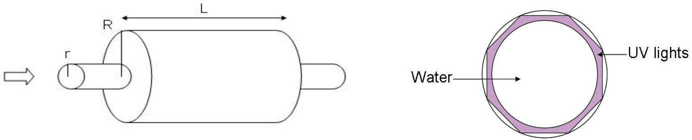

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- **Expected Result:** To create a computer program to search these radius.

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Methodology

Different concerned domains:

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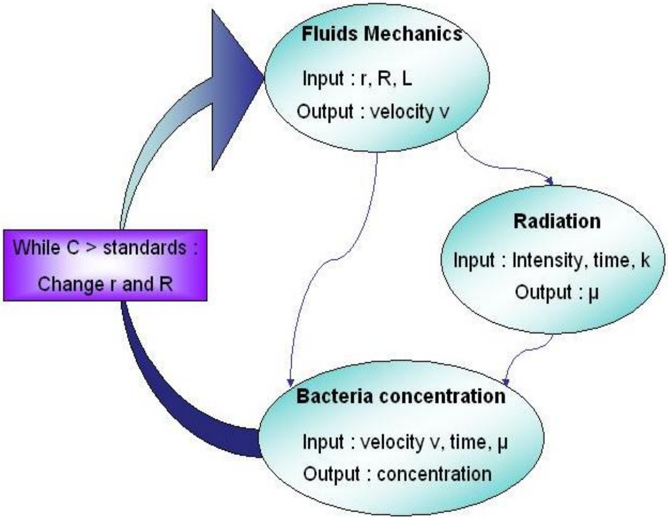
- 2D axisymmetric with simplified Navier-Stokes' equations

Methodology



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Objectives

First:

$\Rightarrow$ To complete the 0D model before mid-February.

$\Rightarrow$ To finish the 2D model and give representative results for r and R to obtain sterilised water.

If miracle:

$\Rightarrow$ To do the same with the 3D model.

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General Case

Incompressible fluids velocity are governed by Navier-Stokes equations. We look for the velocity $\vec{u}$

The Navier-Stokes Equations

$$\begin{cases} \frac{\partial \vec{u}}{\partial t} + \vec{u} \cdot \nabla \vec{u} - u \Delta \vec{u} + \nabla p = f \\ \\ div(\vec{u}) = 0 \end{cases} \tag{1}$$

where : $\vec{u}$: the fluid velocity
p: the pressure

0D Case

- RC-Lux gives us: the pressure loss Δp
- We look for: the velocity v

The Darcy-Weisbach Equation (version 1)

$$h_l = f \cdot \frac{L}{D} \cdot \frac{v^2}{2g} \tag{2}$$

where :
h_l: the head loss due to friction
f: a Darcy friction factor
L: the length of the pipe and D: the diameter of the pipe
g: the gravitational constant

The Darcy-Weisbach Equation (version 2)

Since $\Delta p = \rho g h_l$, where ρ is the flow's density, we have :

$$\Delta p = f \cdot \frac{L}{D} \cdot \frac{\rho v^2}{2} \tag{3}$$

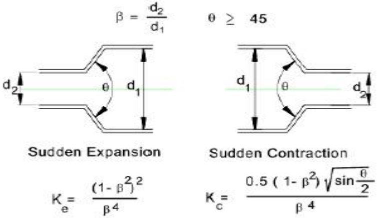
0D Case

$$\Delta p = \left(\sum_{p=1}^{3} f_p \frac{L_p}{D_p} + K_e + K_c \right) \cdot \frac{\rho v^2}{2} \tag{4}$$

Swamee-Jain Equation

$$f_p = \frac{0.25}{[\log(\frac{\varepsilon}{3.7 D_p} + \frac{5.74 \cdot \nu^{0.9}}{(v.D_p)^{0.9}})]^2} \tag{5}$$

And :



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General Case

Single Stage Exponential Decay Equation

$$S(t) = e^{-kIt} \tag{6}$$

Where
S: the surviving ratio of the initial population $\frac{c}{c_0}$
t: the exposure time
I: the UV radiation intensity
k: the sensitivity coefficient of the microorganisms to UV exposure.

Beer-Lambert Law

$$I(x) = I_0 \cdot e^{-\alpha x \rho} \tag{7}$$

Where
I_0 is the intensity of the incident light
α, the absorption coefficient
ρ the density of water.

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General Case

We are interested in solving this equation in order to know concentration at the end of the sterilizer.

Bacteria's Concentration Equation

$$\frac{\partial c}{\partial t} + \underbrace{\vec{u} \cdot \nabla c}_{advection} + \underbrace{\mu \cdot c}_{reaction} = f \tag{8}$$

Where,
c: the bacteria concentration
u: the fluid velocity
μ: a constant which represents the bacteria's destruction

0D Case

In a first approximation:

Simplified Bacteria's Concentration Equation

$$\begin{cases} \frac{\partial c}{\partial t} = -\mu \cdot c \\ c(t=0) = c_0 \end{cases} \tag{9}$$

The solution of this problem is so:

$$c(t) = c_0 \cdot e^{-\mu t} \tag{10}$$

Using the formula about radiation explained earlier, we obtain:

The Concentration at time t:

$$c(t) = c_0 \cdot S(t) = c_0 \cdot e^{-kIt} \tag{11}$$

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Problem Formulation

Constrained optimisation problem

$$\begin{cases} \underset{(r,R)\in\mathcal{D}}{Min} \ \alpha C(r,R) + \beta Vol(r,R) \\ C(r,R) \leq C_s \\ 2 \leq Q(r,R) \leq 4 \end{cases} \tag{12}$$

- $\mathcal{D} = [2,6] \times [7,20]$
- *Vol* represents the volume of the device
- α and β weights on concentration and volume
- The dimension of the radius is the millimetre.
- We use $\Delta p = kQ^2$ to have the constraint on the flow.

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First Approximation : $\beta = 0$

Our optimisation problem

$$\begin{cases} \min\limits_{(r,R)} c(r,R) & = c_0 \exp\left(-kl \frac{z}{U(r,R)}\right) \text{ under the constraints} \\ Q_1(r,R) & = 2 - \pi r_{exit}^2 U(r,R) \leq 0 \\ Q_2(r,R) & = \pi r_{exit}^2 U(r,R) - 4 \leq 0 \end{cases}$$

$$\frac{2}{\pi r^2} \leq U(r,R) \leq \frac{4}{\pi r^2}$$

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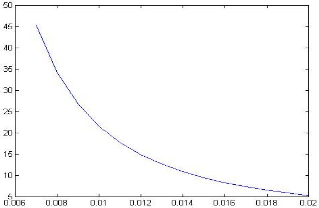
Second Approximation : $\beta = 0$ and $r = 2mm$ $\Rightarrow \underset{R \in [7,20]}{Min} \; C(R)$

Formula

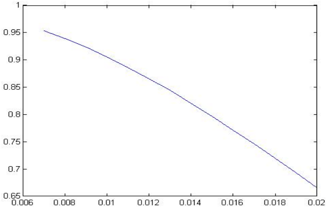
$$\left(f_1(v) \frac{L_1 + L_3}{2r} + f_2(v, R) \frac{L_2}{2R} + K_e + K_c \right) \cdot \frac{\rho v^2}{2} - \Delta p = 0 \qquad (13)$$

$$c(R) = c_0 \cdot e^{-kI \frac{L_2}{v(R)}} \qquad (14)$$

1^{st} Step : $v(R)$



2^{nd} Step : $C(R)$



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In the Future

- 0 Space Dimension :
  - * To find the minimum bacteria concentration with r and R.
  - * To optimize with the volume
- 1 Space Dimension
- 2 Space Dimension

Conclusion

Difficulties:

- Delay in our schedule.
- More complex than we expected.
- Almost no communication with the RC-Lux company.

Positive Points:

- Very interesting and concrete subject with different scientific domains.
- Learning of many things.
- Participation to an industrial project.

Thank you for your attention