CONTRIBUTION TO OPTIMIZING THE PERFORMANCES OF ANAEROBIC REACTOR

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Abstract

The Integrated System: Anaeorobic Reactor – High Rate Algal Pond (AR-HRAP) is new approach combining high-rate anaerobic/aerobic units for wastewater treatment.
In this combination, the anaerobic reactor plays a crucial role. Thus, control of hydrodynamics will both improve the design of such a structure and optimize its performance.
According to several researchers, the hydrodynamic flow modeling is as important as the kinetic modeling of reactions.
This study aims to elaborate flow simulations for different residence times (1.5 d, 2 d, 3 d) in the anaerobic reactor, using software FLUENT.
This study has allowed us to have interesting results regarding hydrodynamic of anaerobic reactor.

Keywords: Hydrodynamic, simulation, anaerobic wastewater treatment

Introduction:

The potential of wastewater in Morocco is very high: nearly 700 Mm^3 nowadays and 900Mm^3 expected in 2020. The climatic context of Morocco is characterized by recurring droughts which had lead to less than 1.000 m^3/year of water per habitant. Therefore, wastewater treatment and reuse become a priority.

The success of any sanitation project is to be analysed in the context of limited funding capabilities, increasing resource depletion and greater environmental protection measures. The main requirements to be fulfilled by any chosen system are (El Hamouri, 2004):

- Low investment cost (avoiding equipment purchase and import)
- Low land area requirement,
- Simplicity of construction and operation,
- Minimization of sludge production,
- Transformation of organic matter into useful energy,
- Recycling of nutrients for crop production,
- Water conservation through agricultural reuse and/or urban purposes,
- Minimization of wastewater collection and conveying costs.

A research project aimed at the development of adapted technologies for wastewater treatment and reuse in small rural communities was initiated at the *Institut Agronomique et Vétérinaire Hassan II* (IAV) of Rabat. A new approach combining high-rate anaerobic/aerobic units is used to treat a daily flow of 63 m^3.

In the field of wastewater treatment, the study of reactor performance requires mastery modeling of the main factors that govern the functioning of these reactors. As such, the hydrodynamic flow modeling is as important as the kinetic modeling of reactions. (Villermaux, 1993).

The anaerobic reactor is a very important element in a sewage treatment plant system integrated type: Anaerobic Reactor - High Rate Algal Pond (RA-HRAP)
The proper functioning of RA directly affects the quality of treatment in the HRAP. Control of hydrodynamic will both improve the design of such a structure and optimize its performance.

This study aims to simulate the flow for different residence times (1.5 d, 2 d, 3 d) in the anaerobic reactor.

I- Materials and methods

I.1- The two-step upflow anaerobic reactor

The city of Rabat, capital of Morocco, is located in the North-West of the country (latitude 30°03' N, longitude 6°46' W). Its altitude is 73 m above sea level. The average temperature in the site is 14°C in the cold season and 24°C in the hot season.

The plant occupies 1,200 m^2 and receives a daily average flow of 63 m^3. It includes a preliminary treatment (screening and grid removal) followed by a TSUAR (Two-Step Upflow Anaerobic Reactor), for pre-treatment, and then by a post-treatment line, which includes a HRAP (High Rate Algae Pond) flanked with one MP (Maturation Pond) (Figure 1).

Figure 2 shows the pre-treatment configuration at the IAV plant.

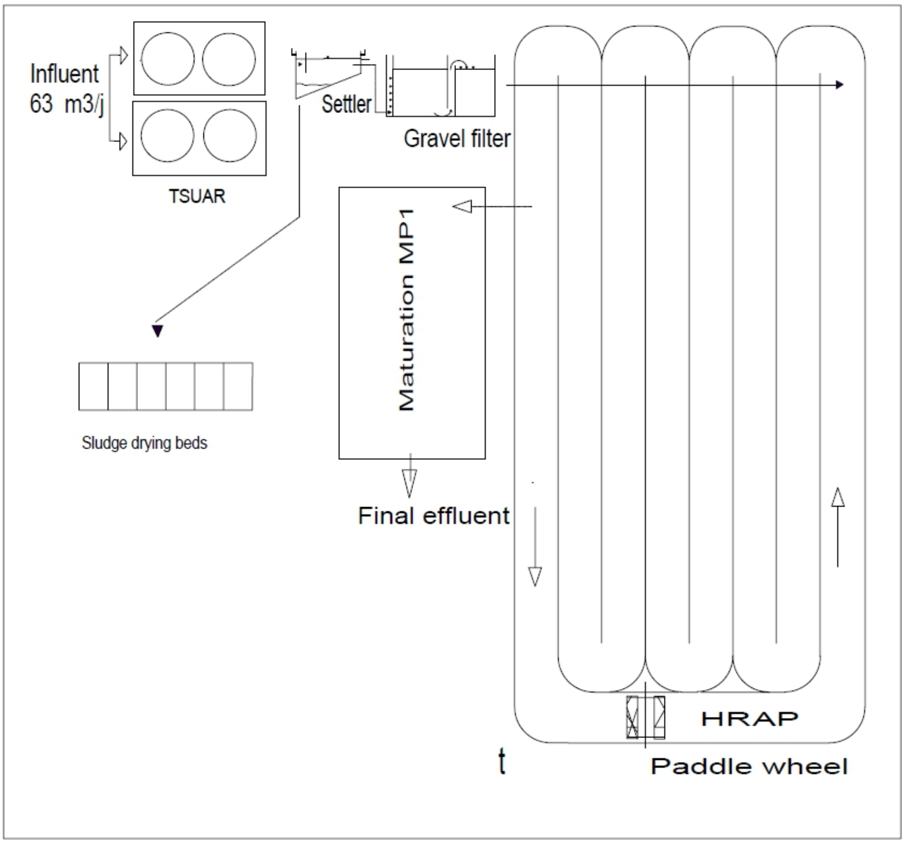


Fig. 1: Layout of the IAV treatment plant

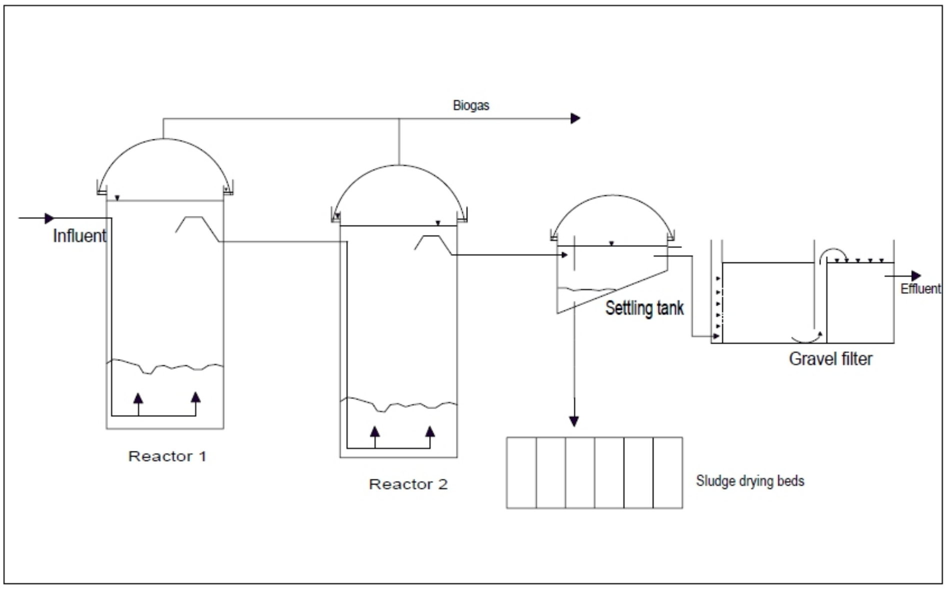


Fig. 2: The pre-treatment unit of the IAV treatment plant

Anaerobic unit located upstream of the station consists of two similar paralleled channels. Each channel consists of two anaerobic reactors in series (R1 & R2) followed by an outer separator (D). The set { R1 + R2 + D } is called "two-phase anaerobic system" (SADP)

Dimensions and key operational parameters are presented in Table 1 . These reactors are completely covered and each provided with a biogas collection system.

In both reactors, upflow velocity was maintained in the range of 0,1 to 0,6 m h-1 depending on the admitted flow, which varies during the day.

Table 1: Dimensions and operating parameters for reactors R1 and R2 of the TSUAR

	Reactor R_1	Reactor R_2
Depth (m)	5,30	5,00
Area (m^2)	7,06	7,06
Diameter (m)	3,0	3,0
Volume (m^3)	33	31
Average HRT (h)	24	23
Average solid retention time (d)	32	32
Over flow (m h^{-1})	0,1 – 0,6	0,1 – 0,6
Number of inlets	2	2
Number of outlets	1	1
Average HLR (kg COD m^{-3} d^{-1})	0,76	0,40

HLR: hydraulic loading rate
Source: El Hamouri, 2004

I.2- Introducing FLUENT

To perform our simulations, we used the FLUENT software.

Like any CFD software , it is composed of three elements: the pre- processor, solver and post- processor.

The definition of the problem is done using the preprocessor GAMBIT . It allows to represent the geometry of the system , defining the type of limits on domain boundaries conditions, specify the type of material (liquid or solid) . It also provides the ability to discretize the field , offering several algorithms following mesh geometry.

The numerical solver is used to define the operating conditions (gravity , pressure) of the simulation and the specification of the boundary conditions. Finally, it allows us to choose the iterative process, in particular by proposing several numerical schemes for spatial and temporal discretization , and for coupling the velocity and pressure . It also provides an interface to monitor at any time the status of calculations.

The post- processor allows to visualize the geometry and meshing of the domain , but also to display the results. It is thus possible to display the velocity vector field , the pressure field , the Reynolds and all other quantities calculated on a segment, a section of the area or over the entire volume . It also provides the ability to draw curves and visualize streamlines or particle trajectory .

Fluent software widely used in a variety of areas, offers a sophisticated interface that facilitates its use. These reasons have motivated our choice to use this software.

II- Theoretical approach:

II.1- Flow caracteristics

Data flow and medium properties are summarized in the following tables:

Tab. 2 : data flow

Residence time (d)	Flow rates (l/s)	Inlet average speeds (m/s)
1,5	0,24	0,030
2	0,18	0,023
3	0,12	0,015

Tab. 3 : medium properties

Medium	wastewater
Density (kg/m^3)	998
Kinematic viscosity (m^{2}s^{-1})	10^{-6}

The Reynolds number of the flow is expressed by : $\text{Re} = \frac{\rho V L}{\mu}$

V: The flow velocity at infinity (output speed),

L: The characteristic length of the RA (RA diameter),

ρ : The density of the fluid,

μ : The dynamic viscosity of the medium.

This number defines the ratio of inertial forces to viscous forces and thus characterizes the behavior of the fluid for a given geometry.

The values of Reynolds number corresponding to different residence times are shown in the table below:

Tab. 4 : values of Reynolds number for different residence times

Residence time (d)	Average exit speeds (m/s)	Re
1,5	0,030	1210
2	0,023	928
3	0,015	606

These values give to the flow laminar character which increases with residence time. To verify that there is no phenomenon of tourbillon we use the following expression of Reynolds number:

$$Re = \frac{nL^2}{\vartheta}$$

ϑ : kinematic viscosity m^3/s. (1,0087.10^{-6} m^3/s)

n: rotating speed of the fluid (t/s).

From the Reynolds number values previously obtained, the rotational speed of the fluid for different residence times are deduced :

Tab. 5: Rotational speed of the fluid for different residence times

Residence time (d)	Re	n (t/s)	n (t/min)
1,5	1210	0,00021	0,0127
2	928	0,00016	0,0097
3	606	0,00011	0,0063

The results show that there is no tourbillon phenomena.

The figure below outlines the boundaries of the domain, the configuration of the input and the output.

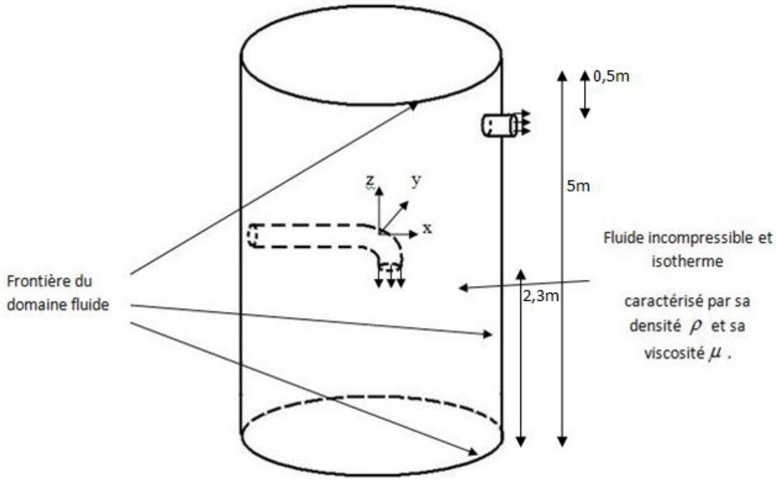


Fig. 3

II.2- Setting equations

To study the flow, we will use the Navier-Stokes equations in cylindrical coordinates for a potential flow given the geometry of the reactor:

This is an irrotational flow, and $\vec{V}$ derives from a potential gradient $\vec{V} = \nabla\varphi$

φ: Velocity potential

Whence: $\vec{\omega} = \overrightarrow{\mathrm{rot}}\vec{V} = \nabla \times \vec{V}$

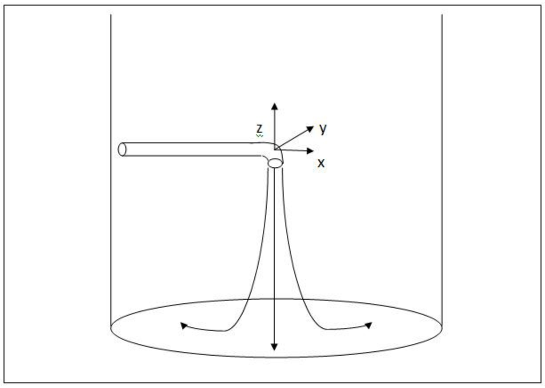
According to the continuity equation : $div\vec{V} = 0$

So : $div(\nabla\varphi) = 0 \longrightarrow \nabla^2\varphi = 0 \longrightarrow \Delta\varphi = 0$

Whence the Laplace equation in cylindrical coordinates (r, θ, z):

$$\Delta\varphi = \frac{\partial^2\varphi}{\partial r^2} + \frac{1}{r}\frac{\partial\varphi}{\partial r} + \frac{\partial^2\varphi}{\partial\theta^2} + \frac{\partial^2\varphi}{\partial z^2} = 0$$

The flow in the RA is plane, as shown in the figure below:



So our problem boils down to a source uniformly distributed over the OZ axis.

If Q is the volume flow per unit width:

$\overrightarrow{rot}\vec{V} = 0 \longrightarrow \begin{cases} V_\theta = 0 \\ V_r = f(r) \\ V_r = Q/2\pi r \end{cases}$

$dQ = r.d\theta.V_r \longrightarrow$ (1)

$$\nabla\varphi = \vec{V} \longrightarrow \begin{cases} \frac{\partial\varphi}{\partial r} = V_r \\ \frac{\partial\varphi}{\partial\theta} = 0 \\ \frac{\partial\varphi}{\partial z} = 0 \end{cases}$$

$$\frac{\partial\varphi}{\partial r} = Q / 2\pi r \longrightarrow \varphi = \frac{Q}{2\pi}\ln r$$

So: $div\vec{V} = \frac{V_r}{r} + \frac{\partial V_r}{\partial r} + \frac{1}{r} . \frac{\partial V_\theta}{\partial\theta} = 0$

Thus there exists ψ such that: $\begin{cases} \frac{1}{r}.\frac{\partial\psi}{\partial\theta} = V_r = Q / 2\pi r \\ \frac{\partial\psi}{\partial r} = - V_\theta = 0 \end{cases}$

$$\psi = \frac{Q}{2\pi}\theta$$

$$f(z) = \varphi + i\psi$$

$$f(z) = \frac{Q}{2\pi}(\ln r + i\theta)$$

Can be defined in the complex plane a "Potential Complex" f (z) such that: f (z) is an analytical function that depends only on the complex variable z = x + i y.

$$z = re^{i\theta} \longrightarrow \ln z = \ln r + i\theta \longrightarrow f(z) = \frac{Q}{2\pi} lnz$$

$$z = x + i\,y \longrightarrow \frac{df(z)}{dz} = \frac{Q}{2\pi}\frac{1}{(x+iy)} = \frac{Q}{2\pi}.\frac{x-iy}{(x^2-y^2)} = V_x - iV_y$$

$$V_x = \frac{Q}{2\pi}\frac{x}{x^2+y^2} \quad \text{and} \quad V_y = \frac{Q}{2\pi}.$$

$$z = re^{i\theta} \longrightarrow f(z) = \frac{Q}{2\pi} lnz = \frac{Q}{2\pi}\ln(\sqrt{x^2+y^2}\,e^{i\theta}$$

$$\longrightarrow f(z) = \frac{Q}{2\pi}\left(\ln\left(\sqrt{x^2+y^2}\right) + i\theta\right)$$

$$f(z) = \varphi + i\psi \longrightarrow \varphi = \frac{Q}{2\pi}\ln(\sqrt{x^2+y^2}) \quad \text{and} \quad \Psi = \frac{Q}{2\pi}\arctan(\frac{y}{x})$$

$$V_x = \frac{\partial\varphi}{\partial x} = \frac{Q}{2\pi}\frac{x}{x^2+y^2} \longrightarrow \frac{dx}{V_x} = \frac{dy}{V_y},$$

$$V_y = \frac{\partial\varphi}{\partial y} = \frac{Q}{2\pi}\frac{y}{x^2+y^2} \longrightarrow \frac{dx}{x} = \frac{dy}{y},$$

Whence the stream function: $\Psi = \frac{Q}{2\pi}\arctan(\frac{y}{x})$

And the equation of the current lines: $\frac{y}{x} = C$

III- Simulation

III.1- Meshing

The meshing structure is studied in the following order: Meshing surfaces, meshing volume controls andverification of meshes.

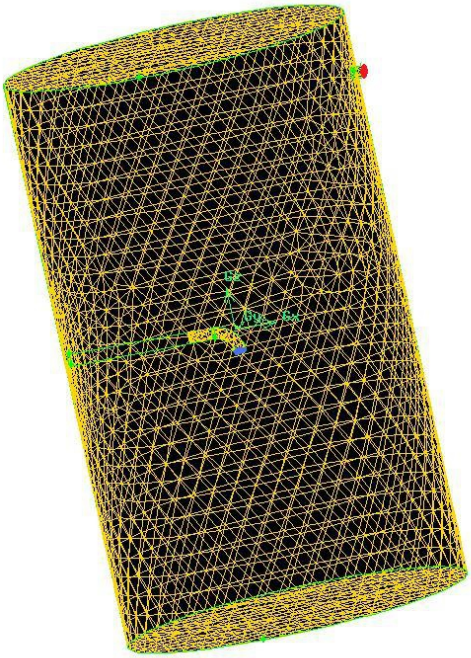


Fig. 4 : Meshing with Gambit

III.2- Boundary conditions

To perform the simulation, certain boundary conditions must be determined in accordance with the data of the software.
These conditions concern exit, sides and bottom of the RA.

Tab. 6: Boundary conditions

component	Boundary conditions (FLUENT)
entry	Velocity inlet
output	Out flow
background	Wall
free surface	Symmetry
walls	Wall
Elbow + pipe	Wall

III.3- Data bases for Fluent

Simulation is performed for three different residence times: 1.5 d - 2d - 3d.
Inlet flow rates and average speeds corresponding to residence times are summarized in the following table:

Tab. 7: Simulation data

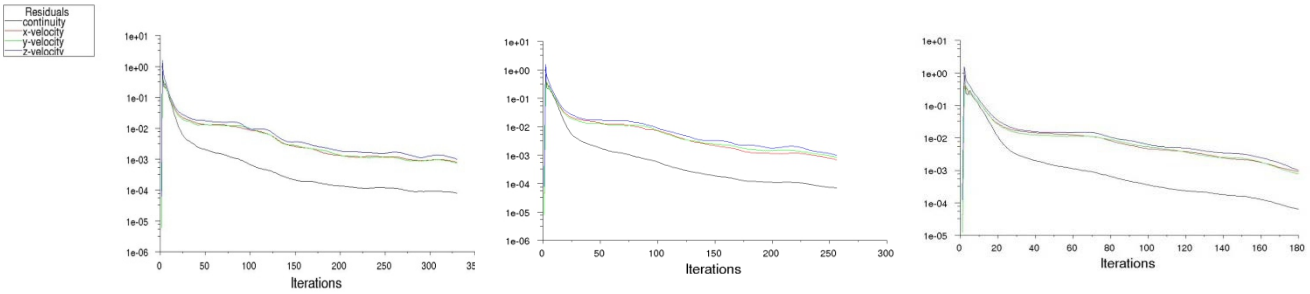
Hydraulic Retention Time (HRT) (d)	Inlet flow rates (l/s)	Inlet average speeds (m/s)
1,5	0,24	0,030
2	0,18	0,023
3	0,12	0,015

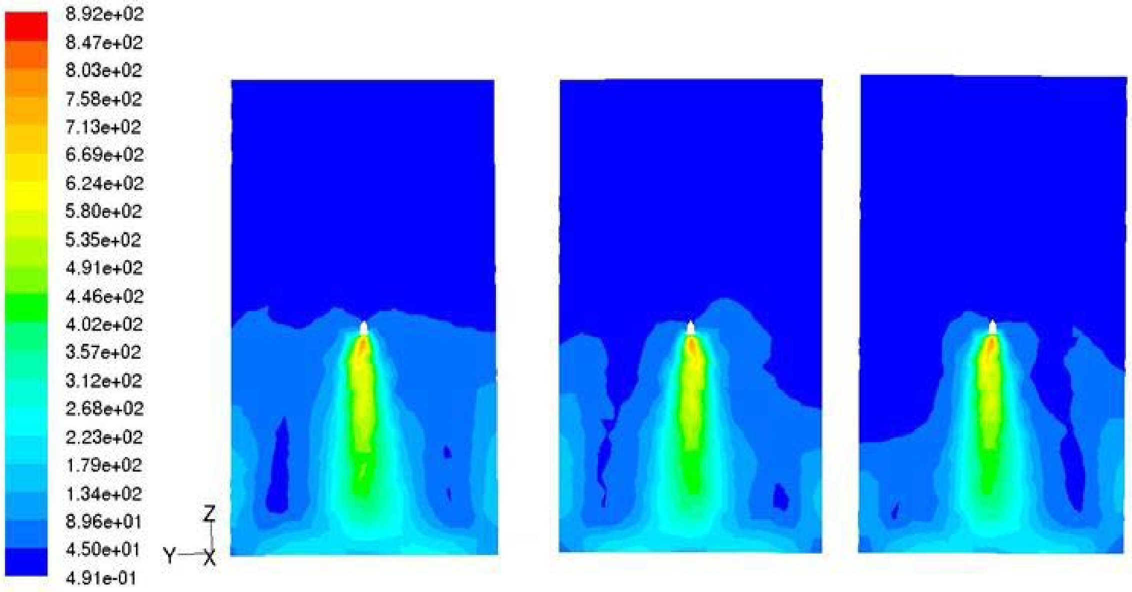
We consider for the resolution a single phase, the wastewater.

IV- Results

<u>Convergence</u>

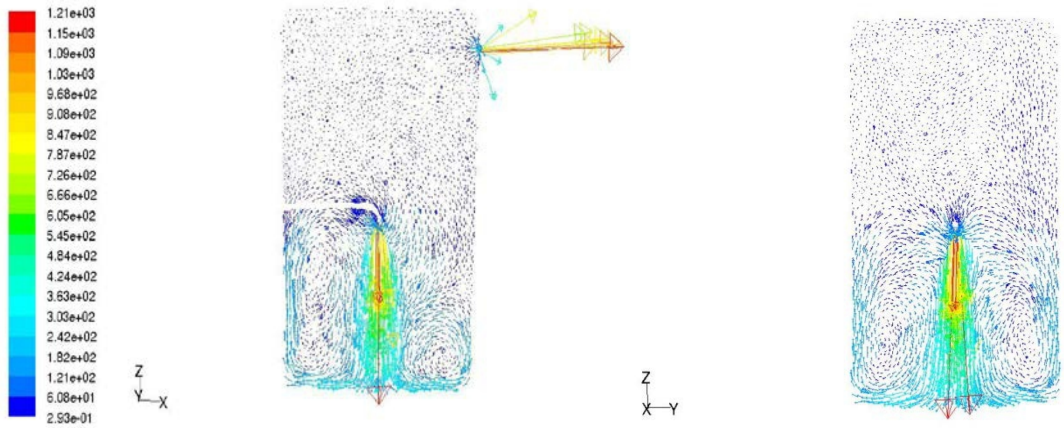
To ensure the convergence of the calculations, we help two visual criteria. The first is to look at the curves of the residues, the second is to follow the evolution of the velocity fields during the iterations. When not changing, it means that the calculation has converged.



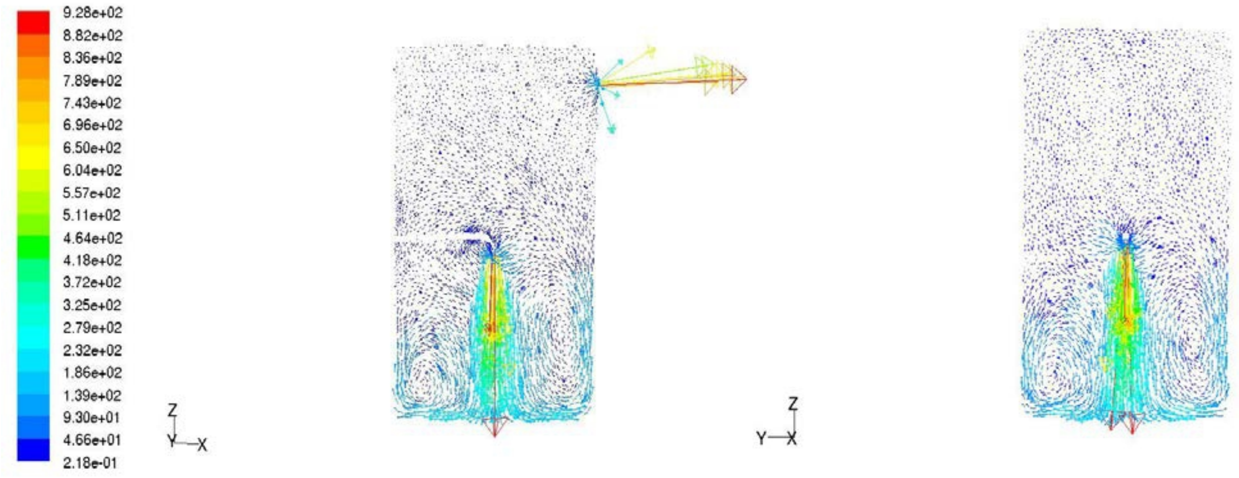


Contours of cell Reynolds Number

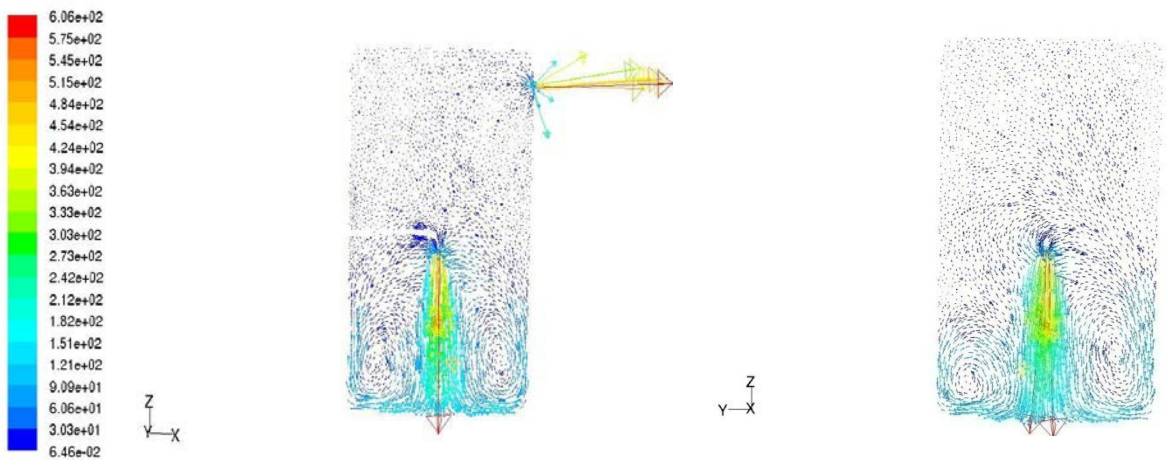
<u>Velocity vectors</u>



Velocity vectors colored by cell Reynolds Number for HRT = 1.5 d



Velocity vectors colored by cell Reynolds Number for HRT = 2 d



Velocity vectors colored by cell Reynolds Number for HRT = 3 d

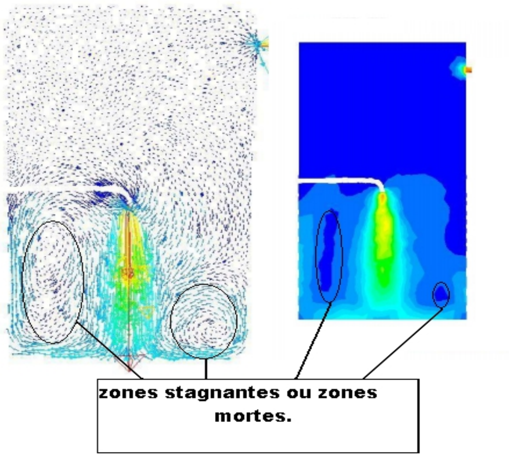
V- Discussion

The flow simulation showed:

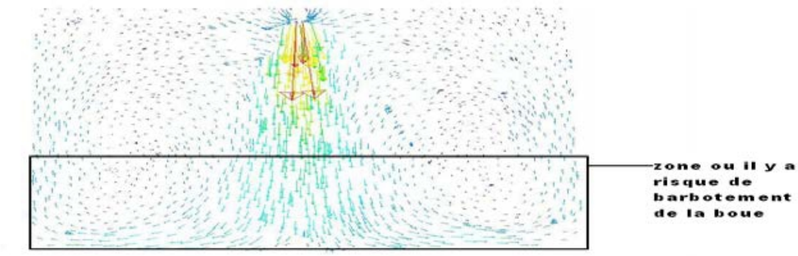
- A turbulence at the inlet and outlet leading to a peak Reynolds number.
- A symmetry of the flow relative to the plane (O, x, z).
- Speeds greater near the walls.
- The phenomenon of the boundary layer near the walls.
- A separation of the boundary layer.
- A piston flow above the inlet.
- The influence of the residence time on the turbulence of the flow: when the residence time increases, the turbulent nature diminishes.

The simulation also revealed some shortcomings related to the design of RA:

- Presence of stagnant zones and dead zones



- Greater velocities at the bottom wall of the reactor (zone where the sludge is located) can lead to the phenomenon of separation of the boundary layer velocity at said wall. There is therefore a risk of bubbling of the sludge that it is at the bottom of the reactor



- A fairly random stratification of Reynolds number below the entrance reveals a real flow away from the plug flow coveted for optimizing the operation of such reactors.

Conclusion:

This study has allowed us to have interesting results regarding hydrodynamic of anaerobic reactor. It was helped us, among other things, to update the existence of dysfunctions that certainly affect the performance of the reactor and are directly related to the choice of design parameters such as the position and geometry of the wastewater entry or inlet and outlet velocities.

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