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Hydrodynamic study of Anaerobic Reactor for domestic wastewater treatment

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Abstract
The anaerobic reactor (AR) is a very important element in integrated algal ponding systems. The proper functioning of the AR directly influences the quality of treatment in the High Rate Algal Pond. Thus the control of hydrodynamics will both improve the design of such a structure and optimize its performance. This study aims to simulate the flow and distribution of temperature for different residence times (1.5 day, 2 days, 3 days) in the anaerobic reactor. The resolution of the flow equations and the energy equation is required .Obviously the software Fluent. This study is divided into two parts:

- Flow modeling
- The Temperature

The results show that:

- The mixture in the AR is not completely mixed
- A temperature stratification in AR

Keywords: Anaerobic Reactor, Channel high-output algal, Hydrodynamic, Flow, Temperature, residence time.

1. Introduction
Besides the safeguarding of the environment and considerable improvement of the sanitary arrangements of the Man, the treatment of waste waters allows the safeguarding of the hydrous potential by recycling this water, in particular for agriculture [1]. The conventional methods of treatment are physical, chemical, biological or the combination of the three process [2]. When the climate allows it, the integrated system engine anaerobe-channel high-output algal is an interesting alternative which supplants the conventional systems of purification [3, 4], and this taking into account the advantages which it presents. Besides a much reduced energy cost this system presents a simple construction, an elimination of the odours besides a possible exploitation of the biomass algale [5]. The channel high-output algal in a sewage treatment plant of the standard integrated system "engine anaerobe-channel high-output algal" its function is to remove a great fraction of the dissolved pollution contained in the effluent to treat [6]. Its effectiveness depends primarily on its hydraulic characteristics.
The anaerobic engine is placed upstream channel high-output algal. Its main function is to support the radial forces which the (Channel high-output algal) cannot resist. Indeed in absence of the anaerobic pond at the top of the system of treatment, the channel high-output algal, cannot react to these variations and we obtain what is called a destabilization of the system [7], characterized by a tanning of the contents of the channel algal, extremely probably due to an excess of organic matter and suspended matter [7, 8]. During the passage of waste waters through the anaerobic engine, the suspended matter will form a deposit and form muds at the bottom of the basin. The organic matters will undergo transformations to lead to the formation of a recoverable gas: methane [9]. Key element of the integrated system, the anaerobic engine allows the safeguarding of the balance of the CAHR, which is rather fragile, by avoiding the shocks of load to him and by delivering an easily biodegradable substrate to him. A good performance of the anaerobic engine influences directly the output of

the channel algal. This operation includes the kinetic aspect as well as the hydraulic aspect. Thus it proves to be imperative to develop the performances of this engine.

2. Materials and methods

2.1. Study area

The sewage treatment plant which is subject of this research is of the same type as that which was conceived by Oswald at the University of California in the United States [10, 11]. It is located at the Veterinary Institute Hassan II (Rabat- Morocco) with coordinates (latitude 32°N, longitude 6°30W) with an average luminous intensity of 500 W•m^{-2} in wintry time.

The station of the Veterinary Institute Hassan II contains two anaerobic engines of cylindrical form, they ensure the anaerobic treatment, they have a diameter of 3 meter each one and a depth of 5 meter . The separate design of these engines makes it possible to vary the residence time in the channel during tests. The two engines are similar we concentrate on the study of the R2 engine.

2.2. Description of the system

One considers the engine as a vertical roll in which runs out a Newtonian and incompressible fluid in turbulent flow [12]. At the entrance of cylinder, the fluid is characterized by a speed and temperature constants. Inside the cylinder, the treatment of waste waters by heterotrophic bacteria [13], generates a Temperature superior than that at the entry. The Thermophysical properties of the fluid in competition are: Thermal conductivity, viscosity and the density we supposed the parameters are constant. One considers also the presence of a source of heat in the cylindrical air-gap given by the enthalpy of methanization reaction.

2.3. Governing equation

The main aim of this study is to model the Anaerobic engine like unit of domestic waste waters purification. For that one we used the equations of continuity, momentum and the equation of the energy balance [14], written in the cylindrical frame of reference.

Conditions of the problem:

- The mode is stationary: d/dt = 0
- The fluid is incompressible: The density is constant
- The cylindrical contact with: ϴ = 0

Table 1: Hydraulic data

Residence time (days)	Flows (l/s)	Mean velocities of entry (m /s)
1,5	0,24	0,030
2	0,18	0,023
3	0,12	0,015

2.3.1. Conservation equations of the mass (or equation of weight breakdown)

The equation of continuity makes it possible to trace the profiles radial speeds and is expressed then by:

$$\frac{1}{r}\frac{\partial rU}{\partial r} + \left(\frac{\partial W}{\partial z}\right) = 0$$

With:
W: Axial speed (m/s)
U: Radial speed (m/s)
r: Coordinate in the radial direction (m)
z: Coordinate in the axial direction (m)

2.3.2. Equation of Momentum

The conservation equation of the momentum makes it possible to trace the profiles axial speeds; this equation is translated as follows:

$$\rho U\frac{\partial W}{\partial r}+\rho W\frac{\partial W}{\partial z}=-\frac{\partial P}{\partial r}+2\mu\,\frac{\partial^2 W}{\partial z^2}+\mu\frac{\partial}{\partial z}\left(\frac{\partial U}{\partial z}+\frac{\partial W}{\partial r}\right)+\frac{\mu}{r}\left(\frac{\partial U}{\partial z}+\frac{\partial W}{\partial r}\right)+\rho g_z$$

With:
ρ: Density density (kg/m3)
g_z: Acceleration of gravity ($m.s^{-2}$)
P: Pressure (Pa)

2.3.3. Equation of the Energy balance
The conservation equation of energy makes it possible to calculate the variation in the temperature by taking account of the term source, this equation is expressed by:

$$\rho C_p\left[U\frac{\partial T}{\partial r}+W\frac{\partial T}{\partial z}\right]=K\left[\frac{\partial^2 T}{\partial r^2}+\frac{1}{r}\frac{\partial T}{\partial r}+\frac{\partial^2 T}{\partial z^2}\right]+q'+\mu\left[2\left(\frac{\partial U}{\partial r}\right)^2+\left(\frac{U}{r}\right)^2+\left(\frac{\partial W}{\partial z}\right)^2+\left(\frac{\partial U}{\partial r}+\frac{\partial W}{\partial z}\right)^2\right]$$

With:
C_p: Heat-storage capacity (KJ/kg*K)
µ: Dynamic viscosity (kg m/s)
T: Temperature (K)
q': Heat flow ($J.m^{-2}.s^{-1}$)
R: Raduis of the cylinder (m)
L: Length of the cylinder (m)
R_e: Reynolds number
F_r: Number of Froude
G_r: Number of Grashof

The dimensional analysis makes it possible to represent the physical phenomenon using the previous equations:

2.4. Dimensionless problem
To obtain the dimensionless form of the previous equations, the following characteristic sizes are defined:

$$P^* = \frac{R_0^2}{LUW_0} \qquad U^* = \frac{UL}{W_0R_0} \qquad \frac{W_0}{L}\,\frac{R}{U_0}=1 \qquad \mathrm{Pr}=\frac{P}{P^*} \qquad W_0\in=\frac{U}{U^*}$$

$$W^* = \frac{W}{W_0} \qquad r^* = \frac{r}{R_0} \qquad z^* = \frac{Z}{L_0} \qquad T^* = \frac{T}{T_0}$$

2.4.1. Dimensionless form of the equations
The adimensional form of equation 1 is written:

$$\frac{1}{r^*}\frac{\partial(r^*U^*)}{\partial r^*}+\left(\frac{\partial W^*}{\partial z^*}\right)=0 \qquad 1$$

The adimensional form of equation 2 is written:

$$\epsilon\, R_e\left(U^*\frac{\partial W^*}{\partial r^*}+W^*\frac{\partial W^*}{\partial z^*}\right)=-\frac{\partial P^*}{\partial z^*}+\epsilon\frac{\partial}{\partial z^*}\left(\frac{\partial w^*}{\partial r^*}\right)+\frac{1}{r^*}\left(\frac{\partial w^*}{\partial r^*}\right)+\frac{R_e}{F_r} \qquad 2$$

The adimensional form of equation 3 is written:

$$U^*\frac{\partial T^*}{\partial r^*}+W^*\frac{\partial T^*}{\partial z^*}=\frac{1}{Gr}\left[\frac{\partial T^*}{\partial r^*}+\frac{\partial^2 T^*}{\partial r^{*2}}\right]+\frac{Br}{Gr}\left[\left(\frac{\partial W^*}{\partial r^*}\right)^2\right]+q\,\frac{L}{W_0T_0} \qquad 3$$

2.5. Method of resolution
The final form of the mathematical model is a system of differential equations to the partial derivative of the second order nonlinear strongly coupled which cannot be solved analytically but rather by digital methods.
We choose this end the method the finite differences. The equations (1,2 and 3) obtained previously are discretized by using a centered space [15].

2.6. Process of resolution
Calculations of the model will be initiated by an initial profile which makes it possible to provide the boundary conditions of system. This last is adapted in order to represent the real profile suitably, with the aim of reduce the computing time. The results of the model make possible to determine the type of flow and the values of the temperature within the engine.

2.7. Digital simulation
Digital modeling makes it possible to identify, to have more information on the type the behaviour of flow and to make it possible to make a comparison with the results found by mathematical modeling. Indeed, the results got by the digital simulation are in the form of images 3D giving a description of the profiles speeds, contours amongst Reynolds and of the profiles of the temperature within the anaerobic Engine.

2.7.1. Tally of the study
Our study consists in modeling a three-dimensional flow within an anaerobic engine of cylindrical form as seen on the following figure (description Eulerian with a Cartesian reference mark centered on the cylinder [16].

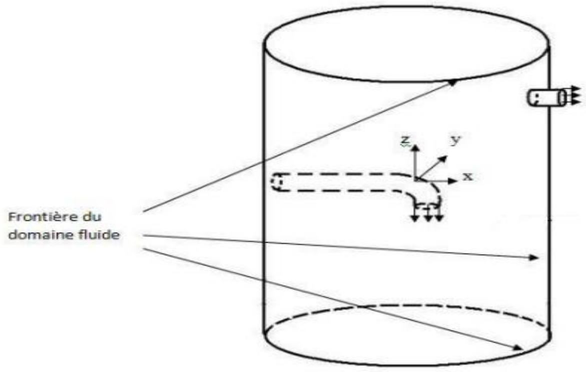


Figure 1: Geometry of the anaerobic engine

We used for modeling 3D and the digital simulation, the FLOWING computer code which is a software of the type CFD (Computational Fluid Dynamics) used for complex multiphase calculations. The equations used in the software highlight the behaviour of the fluids (waste waters). They are founded according to the physical laws: of conservation of mass (continuity), of energy and momentum (Navier-Stokes), [17].

2.7.2. Grid
Considering the complexity of the geometry, one divided up the engine into several zones which will be with a grid each one except, for simulating the points speeds well on all the geometry. A very particular care was granted to the grid which has a considerable influence on the exactitude of the anticipated results.

2.7.3. Boundary conditions
To be able to carry out simulation, some boundary conditions in the elaborate geometries must be given in agreement with the basic information of the software. The conditions relate to the exit, the walls and the bottom of Anaerobic Reactor.
One imposes the boundary conditions following on the various faces of the border:

Table 2: Boundary conditions

Element	Boundary condition
Entry	Velocityinlet
Exit	Out flow
Fund	Wall
Free surface	Symmetry
Walls	Wall
Conduite+ Bends	Wall

One will vary various parameters of which the Reynolds number, density of grid, models of turbulence and convergence criteria in order to consider their respective impact on the problem.

3. Results and discussion

3.1. The results of the model mathematic

The figures 2 and 3 show that:

- Lower speeds close to the walls.
- Radial speed is an increasing function of the radius.
- Low radial speed in the engine supports the growth of the micro-organisms
- The rate of the flow is important on the level of the center; this can be due to the type of the plane flow.
- By examining the curve attentively above one can also notice that because of geometrical symmetry, speeds are symmetrical compared to the center.

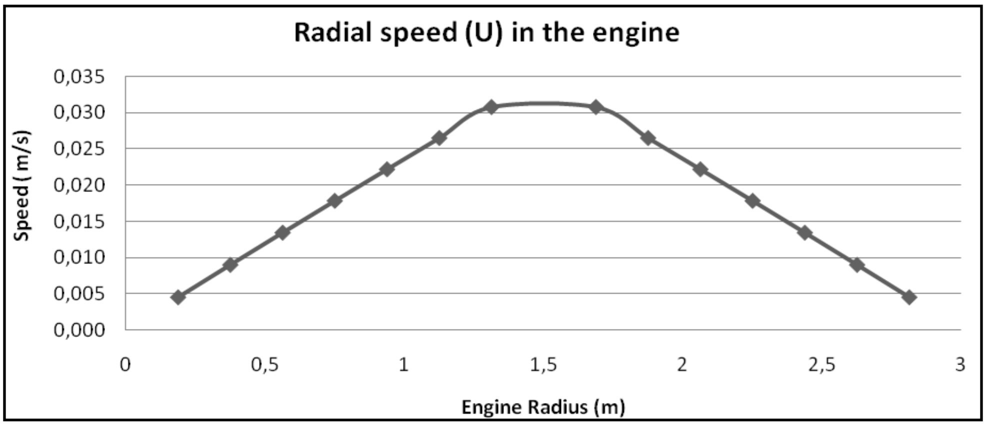


Figure 2: Profile radial speed, Height = 0, 5

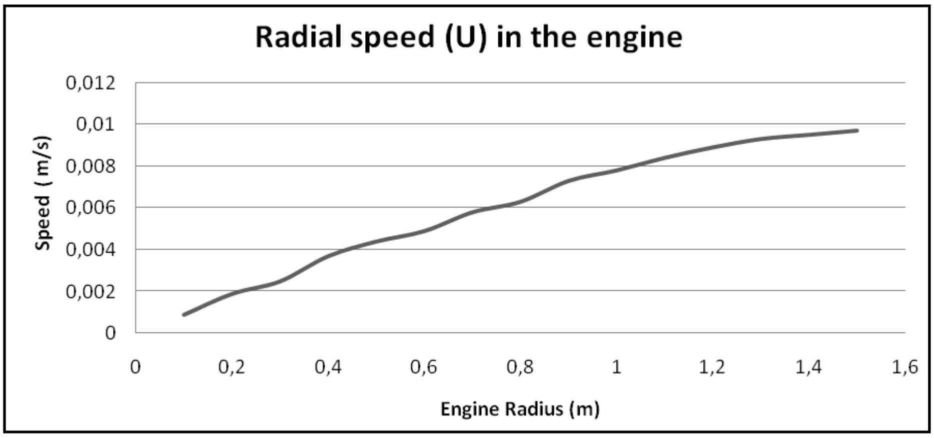


Figure 3: Profile radial speed, Height = 3

The figures 4 and 5 show that:

- Presence of turbulence on the level of the entry of the effluent of the liquid within the engine due at the speed of the jet in the exit of the elbow.
- At the height equals 2.5 was a disturbance seen at the input of the water in this point.
- Axial speed is a decreasing function height.
- The axial flow is not uniform; this phenomenon is always present in this kind of flow, led by an effect of damping on the one hand and on the other hand by the type of flow.
- The distribution speeds is identical for any point in the same level, It is clear that symmetry reigns in the distribution axial speeds.

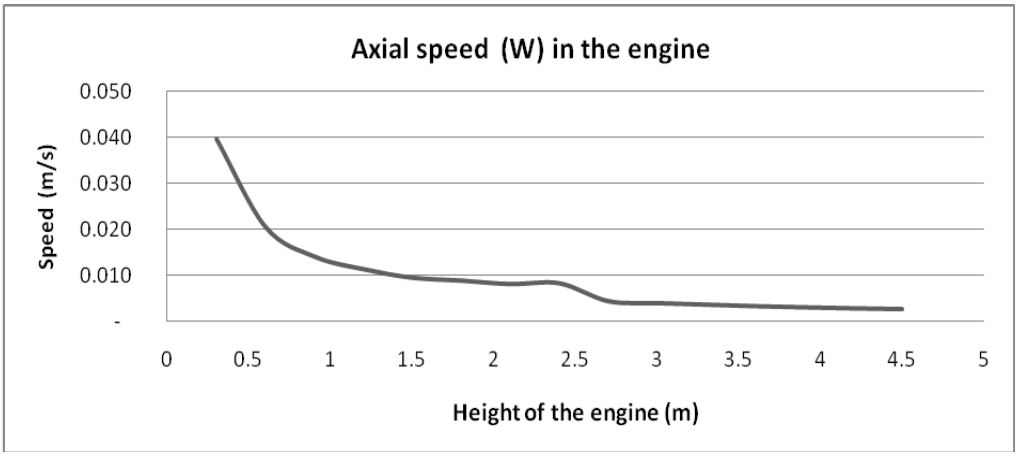


Figure 4: Profile axial speed, Radius =1,5

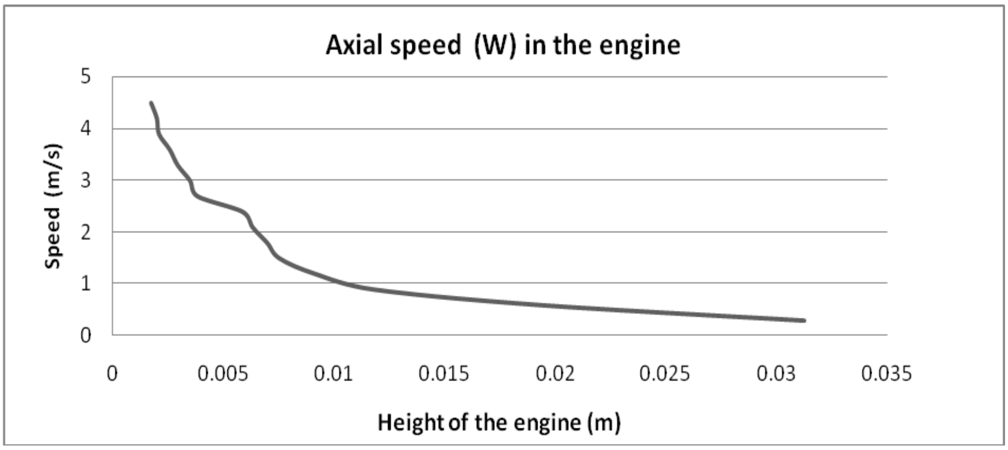


Figure 5: Profile axial speed, Radius = 0,75

According to these curves one can formulate that:

- The hydrodynamic conditions adapted in the engine show that the flow within the engine is not a piston flow.
- The profiles of velocities obtained in our study are generally weak; this confirms the performance of the biological treatment within the anaerobic engine because the excessive values can lead to the scrubbing of active muds and the reduction of the concentration of it.

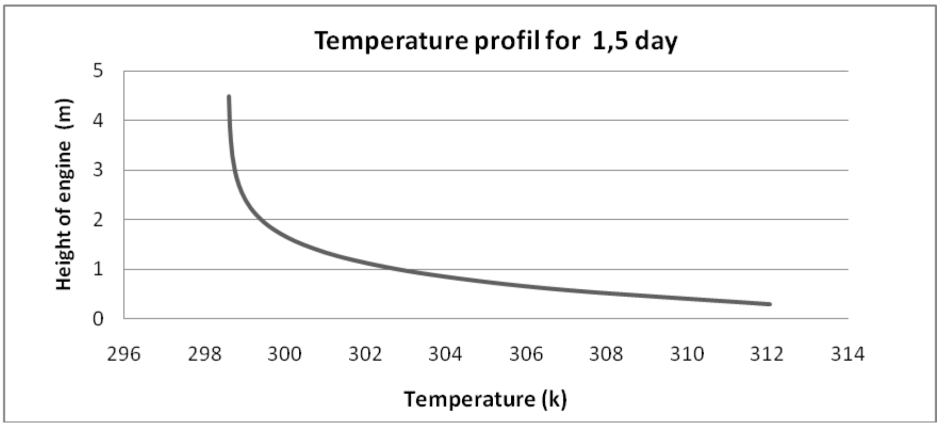


Figure 6: Temperature Profil, Radius =1,5

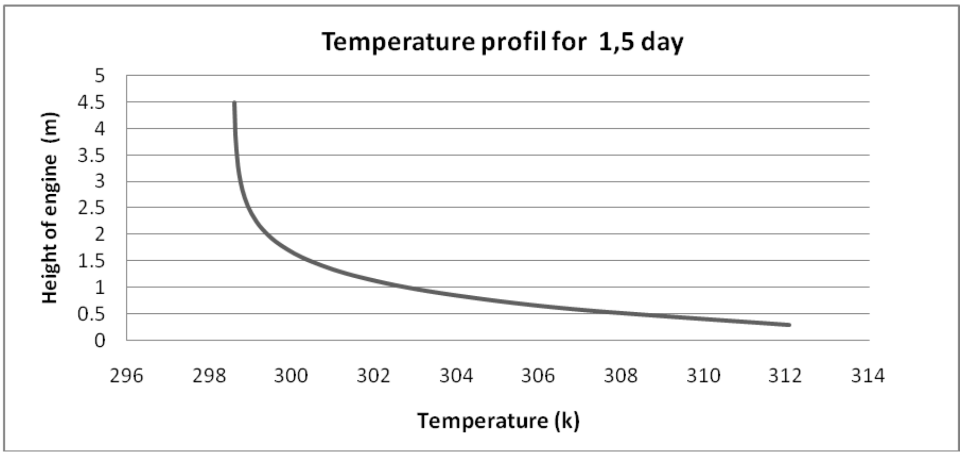


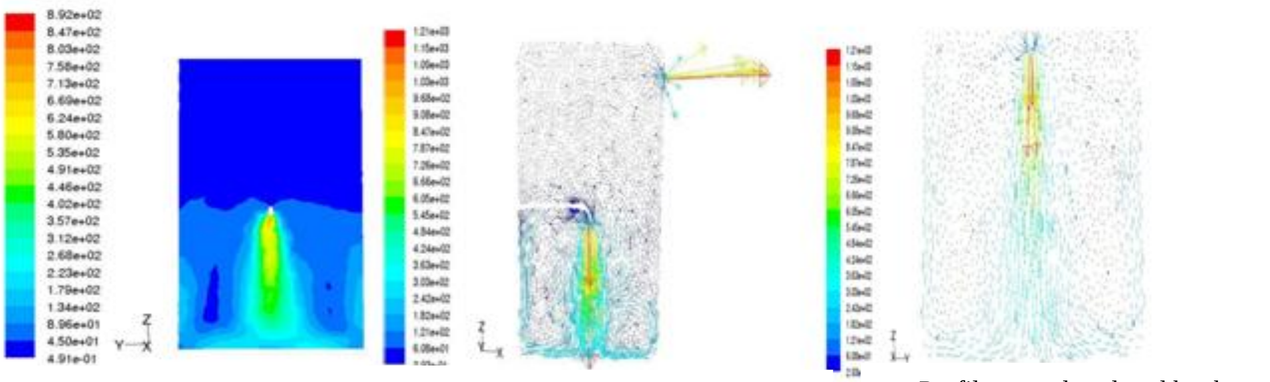
Figure 7: Temperature Profil, Radius =0,75

The graph 6 and 7 above shows that:

- The temperature is a decreasing function height. This can be explained by the concentration of the phenomenon of methanization at the bottom of the RA seen with the concentration of biomass which undergoes a reduction in bottom to the top.
- The results show that the effectiveness of the anaerobic engine for a local temperature about 25°C and a residence time of 1.5d is better and favorable for the culture of the mesophilic bacteria and consequently creates a warming of the unit.
- The figure shows that the temperature produced by the micro-organisms is a significant factor for good kinetics of transformation of organic pollution in the engine. This makes it possible to save energy. This confirms the results got in 2005 in occurrence (El hamouri B and al WST, 31(12)(1995) 67-74): The profile must upwards allow the formation of the mud mattress in the content of the engine followed by a gradient of mud concentration being decreasing by bottom.

3.1. The results of Digital simulation
3.1.1. Simulation of the flow
The basic information for Flowing
One carries out simulation for three different residence times: 1,5d – 2d – 3d.
The flows and the mean velocities of entry correspondents at the residence times are summarized in the previous table (Fact of the case).
The results which we present are in the form of images. They describe the behaviour of the liquid in Anaerobic Engine.

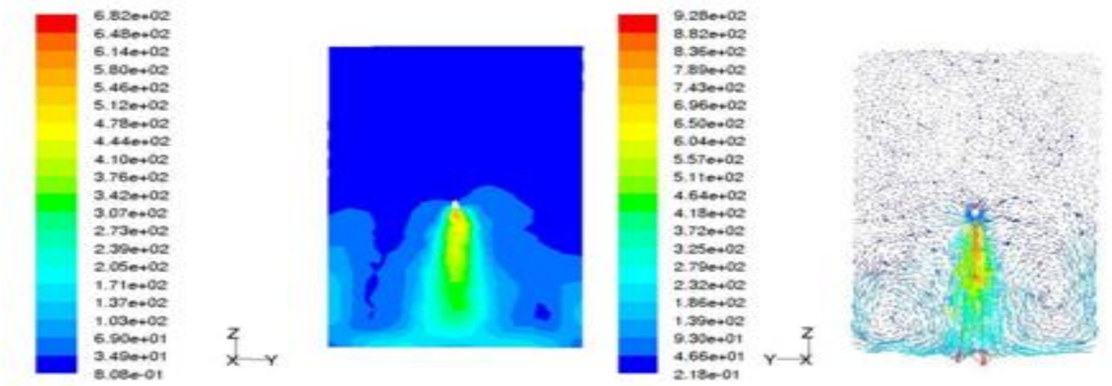
The 1st Simulation: Residence time: 1.5 days



Contours amongst Reynolds in the plan (y, Z) | Profiles speeds colored by the Reynolds number in plan (X, Z) | Profiles speeds colored by the Reynolds number in the plan (y, Z)

Figure 8: The simulation of the flow for a residence time: 1.5 days

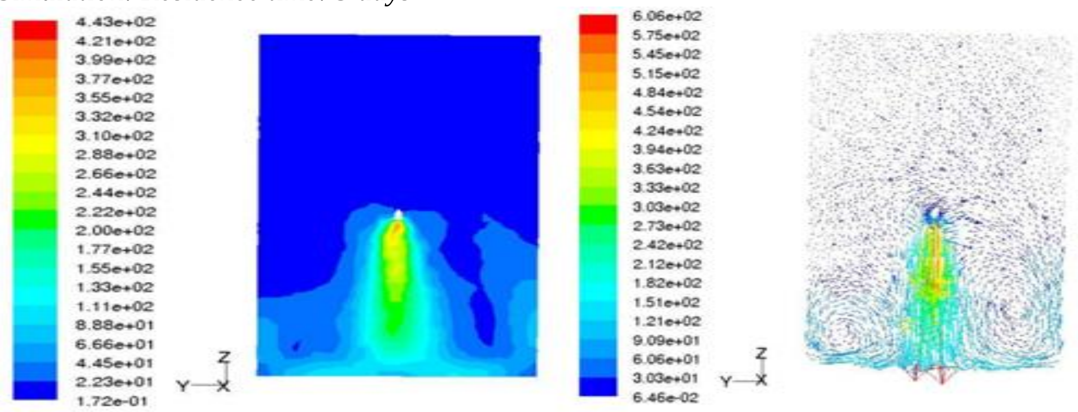
The 2nd Simulation: Residence time: 2 days



Contours amongst Reynolds in the plan (y, Z) Profiles speeds colored by the Reynolds number in the plan (y, Z)

Figure 9: The simulation of the flow for a residence time: 2 days

The 3rd Simulation: Residence time: 3 days



Contours amongst plane Reynolds in the (y, Z) Profiles speeds coloured by the Reynolds number in the plan (y, Z)

Figure 10: The simulation of the Flow for a residence time: 3 days

Discussion of the results

The simulation of the flow highlighted:

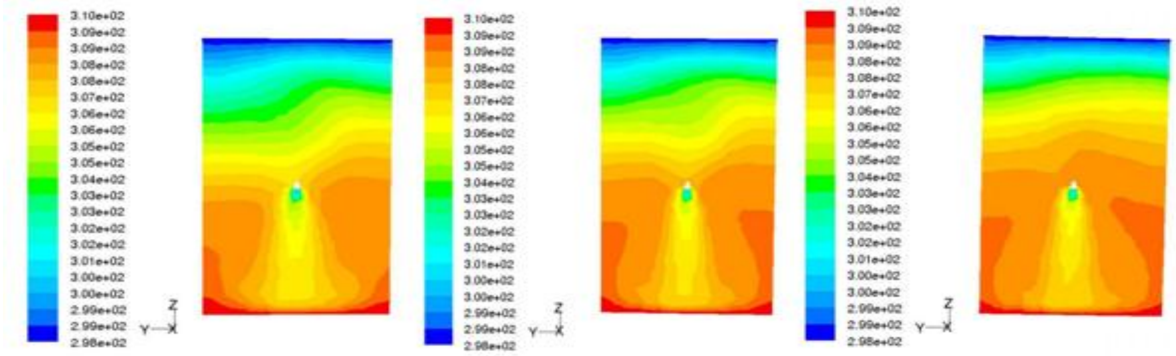
- Turbulence around of the entry and exit which appears by a peak amongst Reynolds.
- A symmetry of the flow compared to plan (O, X, Z).
- Higher speeds close to the walls.
- The phenomenon of the boundary layer close to the walls.
- A limiting separation of layers.
- The influence of the residence time on the turbulence of the flow: when the residence time increases, the turbulent character attenuates.

3.1.2. Simulation of the temperature

The setting in distribution equation of the temperature within the anaerobic engine is very difficult considering the complexity of the biological and thermodynamic phenomena which govern it.

In this part, one keeps the same data of previous simulations (simulations of the flow), while taking into account the equation of energy.

The results of these simulations are represented there after:



1, 5 days 2 days 3 days

Figure 11: Simulations of the distribution of the temperature for the three residence times (1.5, 2 and 3days).

Discussion of the results

The simulation of the distribution of the temperature highlighted:

- A stratification of the temperature within RA.
- A cooling on the level of the entry.
- The flow at the entry practically does not affect the optimum conditions for methanization.
- The distribution of the temperature in RA depends on the position of the entry.
- The influence of the residence time on the stratification of the temperature: more the residence time increases more the stratification is broad, and thereafter the optimum conditions for methanization, in term of temperature, are increasingly favorable.

These results confirm triples it connection between these two parameters. Indeed, the residence time has a triple effect on the temperature:

1st effect: By increasing the residence time, one supports methanization in the upper part of the engine, which makes increase the heat released by the reactions of methanization, thing which generates a warming of RA;
2nd effect: If one increases the residence time, the entering flow of waste waters decreases (because TRH= V/Q), cooling is not then important;
3rd effect: By decreasing the residence time, the turbulent character is accentuated (according to the hydrodynamic study) while attending a homogeneity of the temperature in the lower part of the engine.

The connection between the residence time and the temperature is very delicate, our study shows that for the three residence times, methanization is not obstructed by cooling by obtaining an interesting homogeneity.

Conclusion

This article can give a hydrodynamic study of the anaerobic engine, and the distribution of the temperature within this engine.
The results got by the digital simulation are in very good agreement with the results of mathematical modeling.

The results got for the study of flow showed the existence of the dead zones and turbulence within the engine.

The study showed, also, a strong dependence between the residence time and the temperature within the anaerobic engine, thus a good comprehension and control of this equation makes it possible to improve the performances of the operation of the work.

A residence time of 1, 5 day is then sufficient to obtain a degradation of the organic matter and a warming of the engine (70%).

The results of simulation could be confirmed in experiments at the laboratory by tests of tracing. We can as take temperature measurements for various depths of the anaerobic engine to show as the values obtained are fixed by the model of simulation. These tests are under development and will be the object of a future publication.
Other simulations could be possible for different position from the entry and the exit, In order to more improve the effectiveness of RA.

This process is a proper perspective in the sense that it is an extensive system with low energy cost, requiring small areas, it can be for small and medium-sized agglomerations.
It remains to say that the treatment of the integrated system engine anaerobe-channel high-output algal is an adequate perspective for development pathways in countries seen at: Low energy cost, low areas and climate conditions.

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