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# Optimization of Two Stage-High Rate Algal Pond for the purification of wastewater has a large organic charge.

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## Abstract

The goal of this study is to develop the optimal model based on the kinetics of organic matter removal in an integrated system anaerobic reactor-high rate algal pond in two stage (AR-TS-HRAP), and this to have a sizing tool adapted to the Moroccan context. Contrary to Oswald's approach, which is based on the algae energy balance, this model has been developed according to an engineering concept that takes into account the design parameters of the reactors (flow, charge and residence time). .

The tests of the modeling of the organic matter diffusion for an important organic charge of 750 mg / l for different residence times in the high and low channel, allowed us to find the optimal residence time to have a total yield very interesting also win half a day. So we can consider that the combination of a residence time of 1.5 days in the high channel and 2 days in the low channel using the CFD FLUENT tool, would be a good basis for sizing these systems in Morocco. In order to treat twice of the rate by the same area and to adapt the system to large agglomerations.

## Keywords

High rate algal pond (HRAP), The Two Stage High rate algal pond (TS-HRAP), Wastewater, Residence time, Purification, Organic matter. Diffusion, Simulation, optimization, ANSYS, CFD FLUENT.

## 1. INTRODUCTION

Morocco is a country facing the problem of water scarcity. Indeed, it will soon reach in 2020 the critical threshold of 500 m3 per inhabitant per year, a threshold commonly accepted as the threshold of absolute water scarcity, the country should then face a permanent lack of water. Currently, the resources are under increasing pressure, they are increasingly polluted, the purification sector has a serious delay. Indeed, a significant difference has been unsaturated


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between the rhythm of implementation of water supply networks and that of investments reserved for sanitation and wastewater treatment.

The wastewater treatment has become a necessity that should not be neglected, it should not be considered just as a means of pollution control, but also as a means of recycling of wastewater after purification, in order to relieve the water deficit that Morocco will face in the future.

It is therefore imperative to develop the purification processes that offer this possibility, and answer to the recycling requirements dictated by the WHO, such as the integrated system Anaerobic Reactor-High Rate Algal Pond, which is an extensive system requiring low energy costs and small areas.

The High Rate Algal Pond (HRAP) process is known as a real reactor for intensive algae cultivation. It is based on the symbiotic interaction between heterotrophic bacteria and algae produced in this lagoon (OSWALD, 1977) where the goal is to accelerate the purification process by promoting algal production. HRAP seems to be an interesting technique for the treatment of wastewater because of the high efficiency of assimilation of nitrogen and phosphorus by microalgae (EL HALOUANI et al., 1993). However the integrated system AR-HRAP is intended for small and medium-sized agglomerations.

To overcome this problem, the idea of adding a second stage to the high rate algal pond has been chosen to make the extensive system an intensive system to treat twice of the flow by the same area and to adapt it to large agglomerations. The Two Stage-High Rate Algal Pond (TS-HRAP) came into being as a result of research work initiated at “Institut Agronomique et Vétérinaire Hassan 2” in Rabat. For this purpose, the main objective of this study is to optimize the performance of the Two Stage-High Rate Algal Pond (TS-HRAP) in the elimination of organic matter for the wastewater treatment of the large agglomeration.

## 2. Material and Methods

### *2.1.Hydrodynamics of the TS-HRAP*

The High Rate Algal Pond in stage mode consists of two identical channels, so the hydrodynamic study that will be established later is valid for the high channel and the bottom channel.

The fluid within the channel is a mixture of waste water and microscopic algae, the concentration of algae is too low to influence the liquid’s physical characteristics. Therefore, the fluid will now be considered **Newtonian**.

For an average flow velocity of **15 cm / s**, corresponding to the velocity recommended by OSWALD for optimum and economical functioning, hydraulic flow parameters are shown in the following table:


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**Table 1:** The hydraulic parameters of the TSHRAP

| Parameter | Value | Observation |
|---|---|---|
| **Number of Mach** | 0.0001 | Incompressible mixture |
| **Number of Reynoldes** | 56250 | Turbulent flow |
| **Number of Froude** | 0 .005 | River flow |

According to these parameters, the fluid nature is incompressible and the flow regime is turbulent and fluvial.

### *2.2.Equation setting:*

The equations ruling over the TS-HRAP's hydrodynamics are:

*2.2.1. The continuity equation or the mass conservation equation:*

$$\frac{\partial \rho}{\partial t} + \operatorname{div}(\rho\vec{v}) = S$$

**ρ** : fluid's density (kg.m-3) ;
$\vec{v}$:: fluid's velocity (m.s-1) ;
**S**: term wells / source (kg.m-3.s-1).

*2.2.2. The equation of momentum :*

$$\frac{\partial(\rho\vec{v})}{\partial t} + div(\rho\vec{v}\vec{v}) = -\overrightarrow{grad}\, p + div\, \bar{\bar{\tau}} + \vec{f}$$

- $\rho\vec{v}\vec{v}$ : the momentum tensor;
- $div(\rho\vec{v}\vec{v})$: the flow balance input/output of momentum for the elementary volume;
- $\bar{\bar{\tau}}$: the stress tensor due to the viscosity of the liquid (Pa)

*2.2.3. The equation of energy :*

$$\frac{\partial(V_i(\rho E+p))}{\partial x_i} = \frac{\partial}{\partial x_i}\left[k_{eff}\frac{\partial T}{\partial x_i} - \sum_j h_j\vec{J_j} + V_i\left(\tau_{ij}\right)_{eff}\right] + S_{\mathrm{h}}$$

- **K eff** : the effective conductivity defined by:

$$K_{eff} = K_{moy} + K_{tur}$$

As $K_{moy}$ : the average conductivity; $K_{tur}$ : the turbulent conductivity.

- **Jj** : the specific diffusion flow of the species j.
- **E :** is the result of the formula:

$$E = h - \frac{p}{\rho} + \frac{v_i^2}{2}$$

**h**: the sensitive enthalpy, for an incompressible fluid.


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*2.2.4. The transport equation :*

$$\frac{\partial}{\partial t}(\rho Y_j) + \frac{\partial}{\partial t}(\rho V_i\, Y_i) = \frac{\partial}{\partial x_i}\vec{J}_i + R_i$$

- Vi : component of the velocity along an axis;
- Yi : mass fraction of each species;
- Ri : Reaction rate or Production rate of the species i;
- Jj : The diffusion flow of species i due to the concentration gradient.

After the equation, simplifying assumptions are required for the numerical resolution by the software, namely:

- The flow regime is permanent, so *:* $\frac{\partial}{\partial t} = 0$
- The mixture is considered to be a homogeneous and incompressible fluid, so the variation of ρ is negligible regarding time and space:

ρ = constant;

-The mixture is considered to be a Newtonian fluid, so the fluid's viscosity: = *constant;*

- The mixture is subjected to a single volume force which is its weight:

$$\vec{f} = p.\vec{g}$$

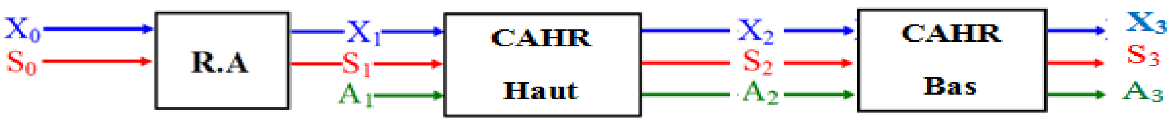
Where:

$\vec{g}$: the acceleration of gravity

### *2.3.Balance of organic matter:*

During TS-HRAP's operation, the organic matter balance is written as follows:

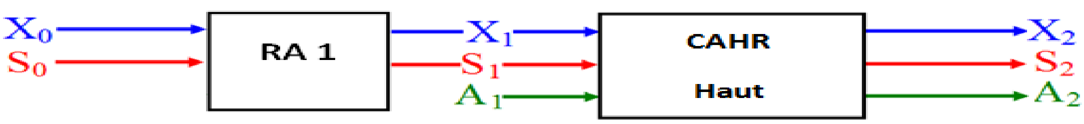
*2.3.1.In series*




$$S_0 - S_3 = \frac{\alpha_a \times b}{D_a + a} + \frac{\alpha_h}{\gamma_h} \times \frac{b_h}{D_c + a_h} + \frac{\alpha_b}{\gamma_b} \times \frac{b_b.D_c + a_h.b_b - a_b.b_h}{(D_c + a_h).(D_c + a_b)}$$

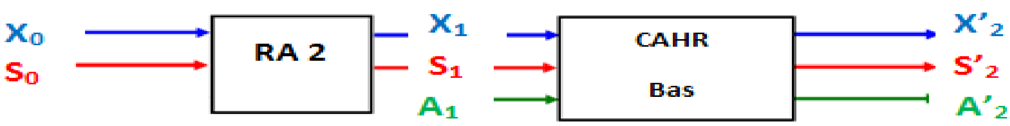
*2.3.2. In parallel :*

*2.3.2.1. High channel*




$$S_0 - S_2 = \frac{\alpha_a \times b}{D_a + a} + \frac{\alpha_h}{\gamma_h} \times \frac{b_h}{D_h + a_h}$$

*2.3.2.2. Bottom channel*





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$$S_0 - S'_2 = \frac{\alpha_a \times b}{D_a + a} + \frac{\alpha_b}{\gamma_b} \times \frac{b_b}{D_b + a_b}$$

With:

- X: the bacterial biomass concentration (mg / l)
- S: the substrate concentration (mg / l)
- $\alpha_a$: the biomass-substrate conversion rate
- $a_h$ and $b_h$: the kinetic constants of the high channel
- $a_b$ and $b_b$: the kinetic constants of the bottom channel
- $D_a$: the dilution rate of TS-HRAP
- a: coefficient that has the characteristic of a growth rate
- b: coefficient that has the characteristic of a speed
- γ: the factor connecting the bacterial and algal biomasses, in which: $\gamma = \frac{dA}{dt} \Big/ \frac{dX}{dt}$

### *2.4. Numerical simulation*

The numerical simulation of the diffusion of organic matter in TS-HRAP was done by a Calculation Code FLUENT, which is a CFD (Computational Fluid Dynamics) type software used for complex multiphase calculations. The latter will give 3D images illustrating the profiles of the diffusion of the organic matter according to the geometry of the channel.

*2.4.1. Geometry :*

To present the geometry of TS-HRAP it is not necessary to represent the two channels, up and down, in GAMBIT, because they have the same geometry.


**Figure 2:** The geometry of HRAP

It defines the configuration of the problem to be analyzed. It involves:
-Creating the system's geometry in ANSYS Design Modeler;
-Editing and improving the created geometry while making the necessary readjustments.
-Explicitly identifying all fluid and solid areas of the model.

The dimensions of our channel are as follows:

**Table 2:** Geometric data of the algal channel.

| Straight section | | Curved section | |
|---|---|---|---|
| Length (m) | 50 | Ray (m) | 30 |
| Width (m) | 3 | curvature angle (m) | 180 |
| Height (m) | 0,5 | Width (m) | 0,5 |


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*2.4.2. The meshing*

The mesh used in this study is of refined type which makes it possible to have results of good precision.

*2.4.3. Boundary conditions*

The simulation program requires the definition of certain boundary conditions, concerning the free surface, the stirring wheel and the contact surfaces between the different materials.

**Table 3:** Boundary conditions for each element

| Items | Boundary conditions (fluent) |
|---|---|
| enter | Velocity inlet |
| exit | Out flow |
| background | Wall |
| wall | Wall |
| free surface | Symmetry |

*2.4.4. Setting and solution (FluentSolver)*

The setting component helps to specify the physical and chemical phenomena to be modeled and the types of used materials (fluid or solid) and their properties. As for the solution component, it allows to choose the iterative process, proposing in particular several numerical schemes for the spatial and temporal discretization, and for the velocity/pressure coupling as well.

*2.4.5. Results (Post Processeur)*

This component allows visualizing the field's geometry and mesh, displaying the required results with the post-processor tools that are integrated in "Fluent solver" such as: Graphics and Animation, Plots and Reports.

*2.4.6. Convergence*

At every iteration, Fluent helps to judge the convergence's state by calculating the residues, which corresponds to the imbalance of the equation (the general discretized equation) summed on all the cells of the field.

## 3. Results and discussion

At present, the studies that have been done on the TS-HRAP for low organic charge have shown that the TS-HRAP in serial mode can have significant yield compared to the parallel mode, keeping 1.5day residence time in the Anaerobic Reactor, the time enough to purify the domestic wastewater similar of Rabat.

In order to find the TS-HRAP optimal residence time in series mode for an important organic charge. according to the correlations and the results of the modeling of organic matter


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diffusion, we choose to purify an organic charge effluent of 750 mg / l for a large agglomeration, a coupling of residence time:

$$T_{high} = 1.5\ day \quad \text{et} \quad T_{bottom} = 2\ day$$

By ANSYS have obtained the following contours illustrate the distribution of the substrate in both high and low channels.

- The Higher Channel :

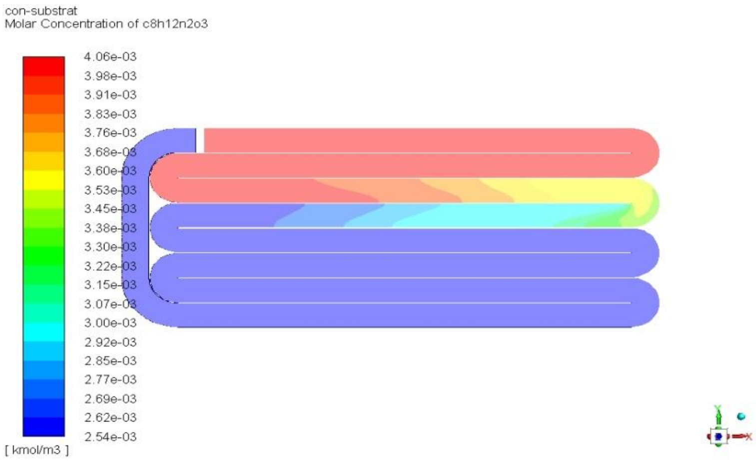


**Figure 3:** Profile of the concentration of OM, in the high channel, 1st day (Ts = 1.5days)

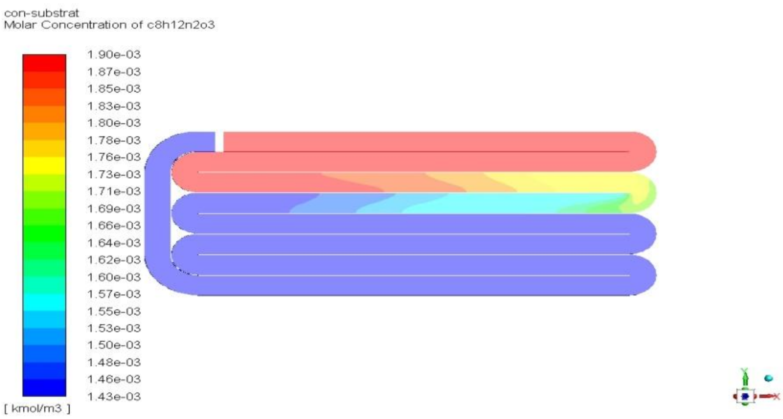


**Figure 4 :** Profile of the concentration of the MO, in the high channel, 2nd day (Ts = 1.5day)


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- Bottom channel :

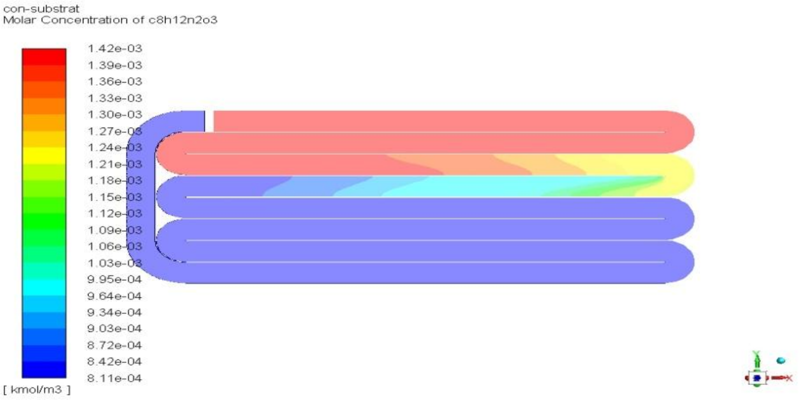


**Figure 5**: Profile of the concentration of OM in the low channel (Ts = 2day)

- **Summary Table** :

**Table 5:** Summary of the case in series T = 1.5day at the high, T = 2day at the bottom

| (1.5day ; 2day) | Higher channel | | Bottom channel | |
|---|---|---|---|---|
| | input | output | input | output |
| COD (mg/l) | 750 | 263.12 | 263.12 | 149.22 |
| yield (%) | 64.92 | | 43.29 | |
| Total yield (%) | 80.1 | | | |

## Discussions

- The relationship between yield in the higher channel (R1), yield in the bottom channel (R2) and total yield (R) is as follows:

$$R = (R1 + R2) / 2$$

- The substrate concentrations decrease along the channels; we think this is due to the bacterial activity within the basins.

- It is noted that the rate of degradation of the upper basin substrate is greater than that of the lower basin, because the sunlight, in the latter, is unfavorable and also because the input charge is lower.

- The numerical results obtained by FLUENT allowed us to know the yield of each channel for 750mg/l organic charge. these results led us to find the optimale residence time.


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- For an important charge, we could reach a very important yield (80%), and at the same time we win half a day in the total residence time in both channels (3.5 days, instead of 4 days ). Thus, we gained in terms of the population served and in terms of the half-day stay.

- These results show that TS-HRAP is an effective solution that makes this system intensive, and thus to adapt to larger agglomerations.

## 4. Conclusion

RA-TS-HRAP integrated system technology can be recommended for large agglomerations, It can also be part of collective sanitation schema, in which small wastewater treatment plants can be built in the urban fabric and integrate perfectly with the landscape without occupying a large area.

Therefore, we have contributed to modeling the integrated system TS-HRAP with the kinetics of elimination of organic matter by the calculation code FLUENT in its version ANSYS, Inc. Products 18.0 (academic version). It was based on experimental and theoretical studies already established on the high rate algal pond of “Institut Agronomique et Vétérinaire Hassan 2”. Then we developed a model on Fluent, on which we applied several couplings of residence time, staying in the total of 4 days in the TS-HRAP.

Furthermore, the results obtained have revealed the possibility to improve the performance and the operation of integrated system TS-HRAP in series mode. Indeed, we thought to decrease the residence time in the high channel in order to keep some of the material easily biodegradable to degraded them in the bottom channel also to improve the performance of the bottom channel. So we can apply a larger organic charge and have an important yield (80%) with a 3,5day residence time and win a half day in residence time. Instead of treating an organic charge at a residence time of 4 days.

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