ACTIVATED SLUDGE DISPERSION IN THE BIOREACTOR

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The dispersion and concentration of the activated sludge depends on the presence of an optimum concentration of dissolved oxygen in the bioreactor.

For this study there were made microscopic analysis on the samples from Mioveni WWTP, and theoretical modeling based on thorough literature research for the MLVSS and experimentally determined concentration for DO. The results are showing that a value for DO between 0.5 and 2 mg/L is optimum for the microorganisms to maintain the metabolic activity.

Keywords: heterotrophic, activated sludge, bioreactor, mathematical modelling.

1. Introduction

Activated sludge process consists in mixing the influent with aerobic bacteria, protozoa, metazoa and oxygen for a period of time necessary to metabolize and to flocculate a large part of the organic material in the bioreactor [1].The most frequent species that participate to the biodegradation of organic matter in the biological system are bacteria, protozoa and metazoa [2][3].

Over the years, the microbial diversity in the bioreactor has been analyzed by many authors[4-7], but the most important reference is from Curds and Cockburn(1970b)[4] that established a relationship between some species and sludge loading, meaning that the quality of the effluent depends on the biological oxygen demand(BOD)[8]. Also, it has been concluded that protozoa have an important role in the bioreactor because they eliminate the excess bacteria, stimulate growth and promote flocculation [9]. When protozoa are consuming the free bacteria in the mixed liquor, the turbidity decreases, as well as BOD concentration and suspended matter content [10].

Richard (1991) [11] (Table 1) made a study on the predominant protozoa and the organic loading. This relationship between protozoa and organic loading is an indicator of the efficiency of an activated sludge system.

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Table 1

Predominant protozoa groups depending by organic loading

Organic loading	*Predominant groups*
Low	Stalked ciliates, rotifers and higher invertebrates, especially nematodes.
Optimum	Good diversity of organisms, dominated by free-swimming and stalked ciliates.
High	Flagellates, amoebae, and small, free-swimming ciliates

Heterotrophic bacteria are consuming nutrients in presence of dissolved oxygen to obtain energy and to sustain metabolic activity. They represent a major fraction in the bioreactor that uses as a substrate organic carbon.But the activity of the bacteria is conditioned by other parameters such as amount of biomass, substrate, temperature and pH[12].

The model that describes the biological process with activated sludge used for this paper is ASM1.

In ASM1 the process of wastewater treatment with activated sludge considers the growth of heterotrophic bacteria in an aerobic environment with use of soluble substrate for energy. Therefore, two fundamental processes occur: biomass increases by cell growth and decreases by decay[13]. In addition to these two fundamental processes, oxygen consumption and substrate removal occur, but are not considered fundamental, rather are consequences because they result from biomass growth and decay and are connected to the process through the system stoichiometry.

The efficiency of the activated sludge treatment depends on the flocculation and settling properties of the microorganisms. The flocculation properties of the inactive microorganisms it allows them to form a solid mass with settling properties [14].

2. Mathematical modeling and estimation of kinetic parameters

The basic activated sludge process scheme (Fig.1) was adapted to Mioveni WWTP conditions, with five diffusers.

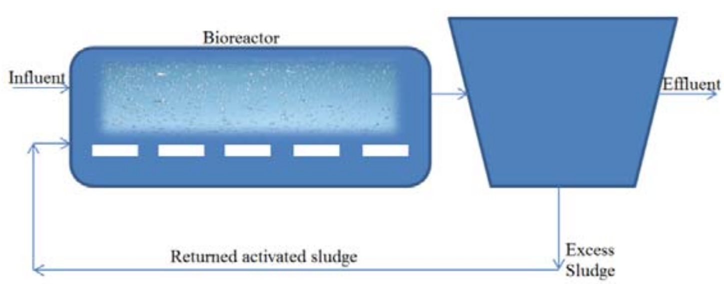

Fig. 1 – Basic activated sludge process

The results from the microscopic analysis of the samples from Mioveni WWTP concluded that in the bioreactor the most abundant species are heterotrophs (Fig.1, fig.2, fig.3, fig.4).

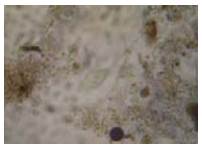
Fig.2- Vorticella sp. (200x)


Fig.3 -Epistylis sp. (200x)

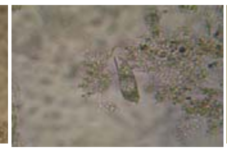
Fig.4 - Peranema sp. (200x)


Fig.5 -Rotifer (100x)

From the category of bio-indicators in the activated sludge were observed the following species:

- solitaire fixed ciliates – *Vorticella sp.*(Fig.2), colonial fixed ciliates – *Epystilis sp.*(Fig.3), flagellate – *Peranema sp.* (Fig.4), rotifers (Fig.5).

In this case, the most appropriate model to use for microbial dispersion in the bioreactor is ASM1.But this model has to be adapted to the existing conditions, so the following assumptions were made:

- The readily biodegradable substrate that is the source of carbon and energy for the heterotrophic bacteria is present and accessible;
- In the bioreactor is maintained optimum aeration to achieve good mixing of the mixed liquor;
- The biomass has an exponential growth phase;
- The substrate is consumed by all species present in the bioreactor.

Mathematical simulation of the biological treatment using activated sludge system has to be based on mass balance, kinetics of substance and microorganisms mass increase. In FlexPDE program are introduced the customized equations for general dispersion and cell growth [15].

The specific growth rate equation from Monod [16] is:

$$\mu = \frac{\mu_m S}{K_S + S} \tag{1}$$

whereμ is the specific cell growth (h^{-1}), $\mu_m$is the maximum growth rate of the cells(h^{-1}), and S is the substrate concentration (g/L) and Ks is the saturation constant. The growth of microbial cells [17] is the first mechanism of the viable cells to remove the nutrients, and for this is used μ, measured in h^{-1}:

$$\mu = \frac{1}{X}\frac{dX}{dt} \tag{2}$$

The two equations (1) and (2) can be merged, resulting equation (3):

$$\mu = \frac{1}{X}\frac{dX}{dt} = \frac{\mu_m S}{K_S + S} \tag{3}$$

Taking into account the changes in the substrate, the following two equations are describing better variations of S and X though another coefficient, $Y_{X/S}$ that is the cell mass yield.

$$X-X_0= Y_{X/S}*(S_0-S) \tag{4}$$

$$S=S_0+ X_0/Y_{X/S} - X/Y_{X/S} \tag{5}$$

where $Y_{X/S}$ is the cell mass yield (g cell mass/g S consumed) and X_0, S_0 - are the initial concentrations of the cells and substrate.

Substituting equations (4) and (5) into equation (3) results:

$$\frac{dX}{dt} = \frac{\mu_m (S_0 Y_{\frac{X}{S}} + X_0 - X)}{(K_S Y_{\frac{X}{S}} + S_0 Y_{\frac{X}{S}} + X_0 - X)} X \tag{6}$$

Equation (6) is introduced in FlexPDE for the evaluation of dispersion of the cells in the bioreactor.

The general equation for dispersion (7) in water is also taken into consideration for the numerical modeling:

$$\frac{\partial C}{\partial t} + \frac{\partial}{\partial x}(uC) + \frac{\partial}{\partial y}(vC) + \frac{\partial}{\partial z}(wC) = \frac{\partial}{\partial x}\left(\varepsilon_x \frac{\partial C}{\partial x}\right) + \frac{\partial}{\partial y}\left(\varepsilon_y \frac{\partial C}{\partial y}\right) + \frac{\partial}{\partial z}\left(\varepsilon_z \frac{\partial C}{\partial z}\right) + D_m\left(\frac{\partial^2 C}{\partial x^2} + \frac{\partial^2 C}{\partial y^2} + \frac{\partial^2 C}{\partial z^2}\right) + S(x, y, z, t) \tag{7}$$

where C= oxygen concentration, ε_x,ε_y, ε_z are dispersion coefficient on x,y,z axis in 3D and D_m is diffusion coefficient of the substrate.

Because is very hard to predict all the parameters in the equation (7), some simplifications are required as following:

- the dispersion equation it will be reduced to two dimensional space because it is considered that the axial movement is reproduced identical in all the transversal sections [18].
- it will be assumed that there are no interactions between the dispersed constituents and mixed liquor, and this fact leads to canceling the expression for mass diffusion.
- the dispersion coefficients in z and y axis are constant in time, resulting equation (8):

$$\frac{\partial C}{\partial t} + \frac{\partial}{\partial x}(uC) + \frac{\partial}{\partial y}(vC) = \frac{\partial}{\partial x}\left(\varepsilon_x \frac{\partial C}{\partial x}\right) + \frac{\partial}{\partial y}\left(\varepsilon_y \frac{\partial C}{\partial y}\right) - k * C \tag{8}$$

The kinetic coefficients that are describing this process are experimentally determined and identified after the microscopic analysis of the activated sludge.

According to G.C. Okpokwasili and C.O.Nweke [19] the values for saturation constant, cell mass yield and microbial growth coefficient can be obtained from literature and calibrated to the situation of the bioreactor geometry and microbial composition. The values used for numerical model simulated with FlexPDE were selected from the typical parameter values table at 20°C [20] in ASM1: $\boldsymbol{K_S} = 20$, $\boldsymbol{Y_{X/S}}$= 0.67 and $\boldsymbol{\mu} = 0.8$.

The results are showed in two dimensions because it was assumed that the axial movement is reproduced identical in all the transversal sections.

3. Materials and methods

The study was conducted at the Mioveni WWTP. On the 24th of July from the bioreactor were taken four samples (Fig.7) of activated sludge using specific tools. First two samples were taken from the middle of the tank, from the surface (Fig. 6). The last two samples were taken from the same point of the tank, only lower with approximately 15 cm from the surface to highlight the differences in layers of concentration in the bioreactor.

Fig.6 – Tool used for sampling from the surface

Fig.7- Samples

The samples were analyzed at a microscope to obtain information on the species present in the bioreactor. Based on the identification of the species, there was made a thorough literature research to obtain the best model for distribution of the species in the bioreactor. ASM1 was chosen because it has the kinetic and stoichiometric coefficients that fitthe heterotrophic species in the bioreactor.

4. Results

The microscopic analysis of the samples from Mioveni WWTP concluded that the quality of the activated sludge is almost identical in all samples indicating a good homogenization on different layers in the bioreactor. The structure of the activated sludge is composed by flocs with an irregular shape and opened structure (Fig. 6a and Fig. 6b).

Fig. 6a – Microscopic image of the activated sludge – general image (40x)

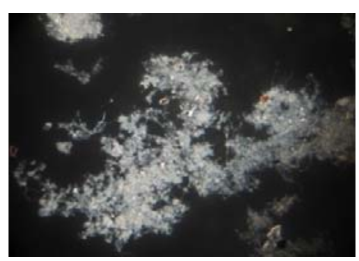

Fig. 6b - Microscopic image of the activated sludge – detailed flocs (100x)

4.1. Mathematical modeling conditions

In the bioreactor the concentration of mixes liquor suspended solids is approximately equal to the concentration of the microorganisms [21].

Assuming that the range of MLVSS concentration in Mioveni WWTP bioreactor is between 2000 and 3500 mg/L [22], the optimum choice for modeling is 2750 mg/L.

The concentrations of DO were experimentally determined for each month of 2014, and the values used for modeling were chosen to represent each season: January, 0.66 [mg O_2/l]; March, 3 [mg O_2/l], July, 1.2 [mg O_2/l] and October, 1.7[mg O_2/l].

There have been made four simulations to show the distribution of the microorganisms in the bioreactor at different values of the DO.

Assuming that activated sludge settles in the bioreactor the boundary condition was put for the bottom of the tank where the biomass concentration does not go lower than 1800 mg/L. The concentration of biomass is higher on entrance in the bioreactor, and lower at exit. The oxygen only enters on the surface of the diffuser. For a detailed view of the parameters concentration distribution there have been made a zoom to one of the diffuser.

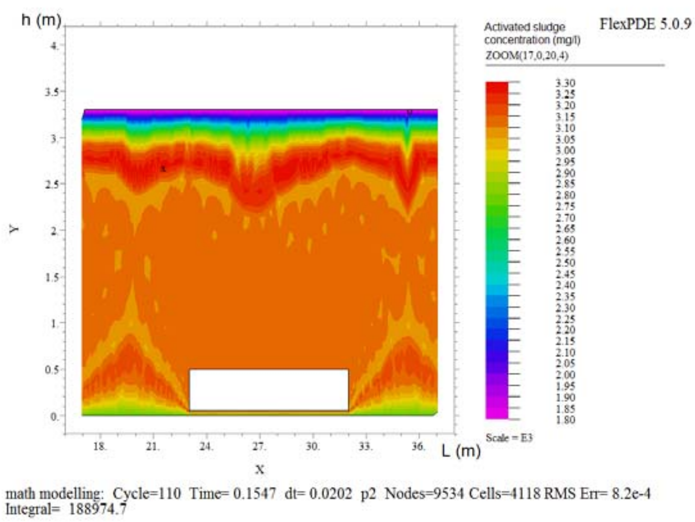

Fig 8a -Distribution of the activated sludge concentration in the bioreactor in January. The maximum concentration of activated sludge reached 3300 mg/Lof biomass related to a maximum concentration of oxygen of 0.66 mg/L. In the center of the bioreactor it is observed that the concentration of biomass is homogenous at a concentration of 3100-3150 m/L, grows to 3300 mg/L, and as it reaches the surface decreases to 1800 mg/L.

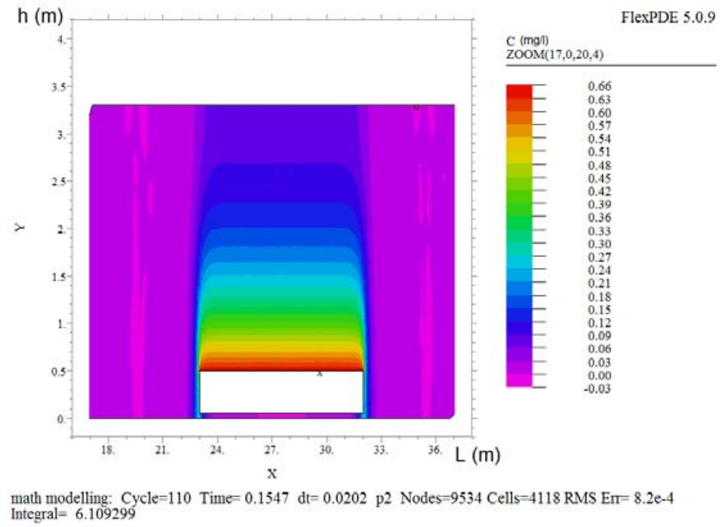

Fig. 8b - Distribution of theDO concentration in the bioreactor in January
The oxygen has the concentration of 0.66 mg/L at the entrance of the diffuser, and get consumed by biomass reaching 0.09 mg/l.

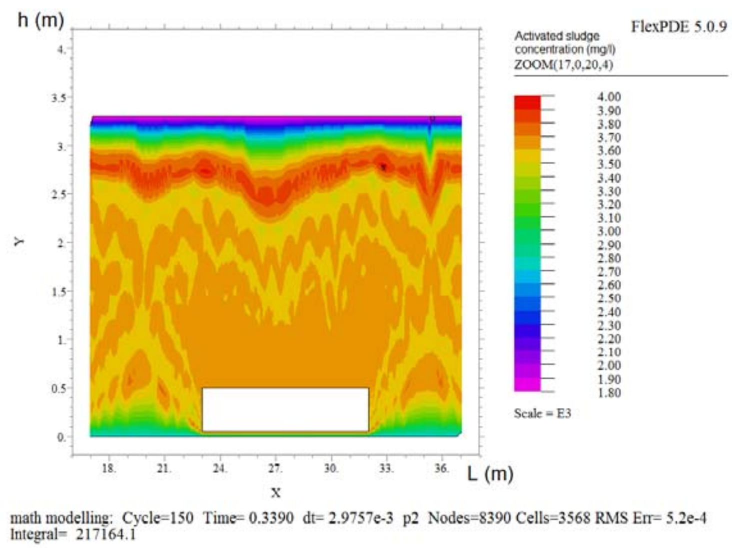

Fig 9a -Distribution of the activated sludge concentration in the bioreactor in March.
Related to a concentration of 3mg/L, the activated sludge distribution concentration gets higher than the optimum concentration, reaching to 4000 mg/L. In the center of the bioreactor the concentration variates between 3600 and 3700 mg/L.

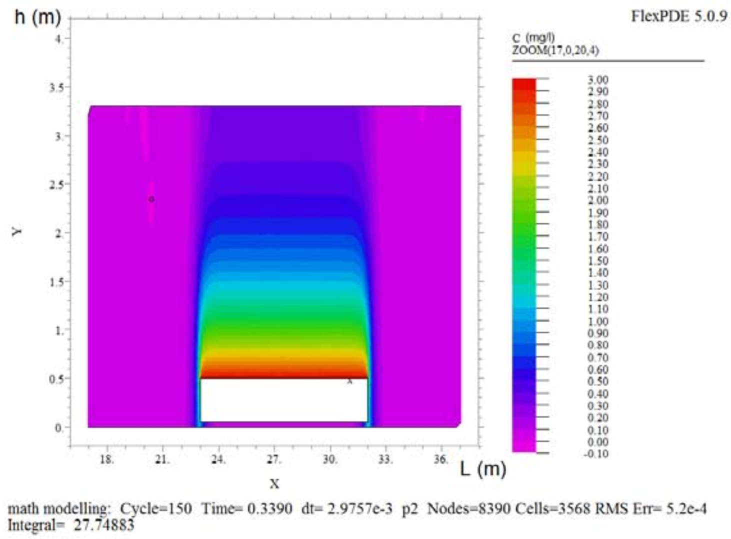

Fig. 9b - Distribution of theDO concentration in the bioreactor in March

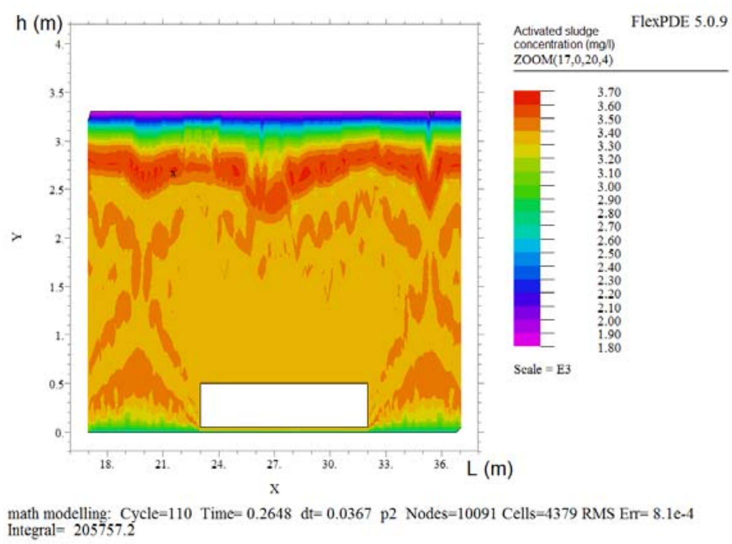

Fig 10a -Distribution of the activated sludge concentration in the bioreactor in July. The concentration of activated sludge in July has a maximum of 3700 mg/L, with a value of concentration for oxygen of 1.2 mg/L.

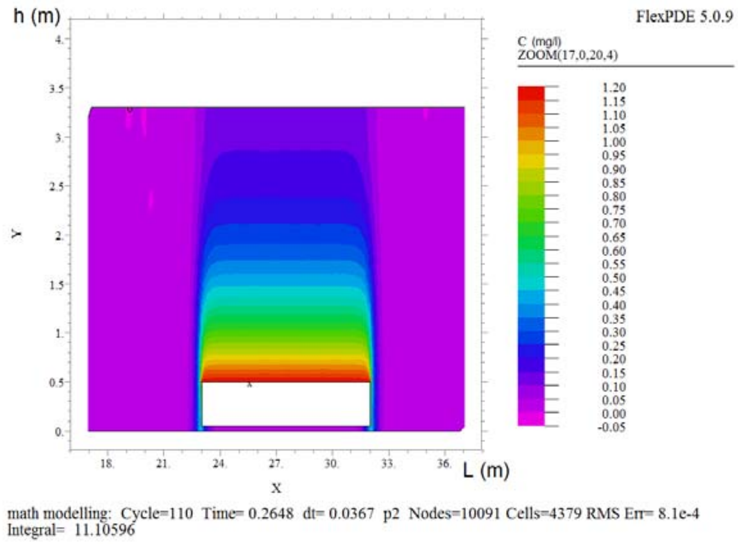

Fig. 10b - Distribution of theDO concentration in the bioreactor in July

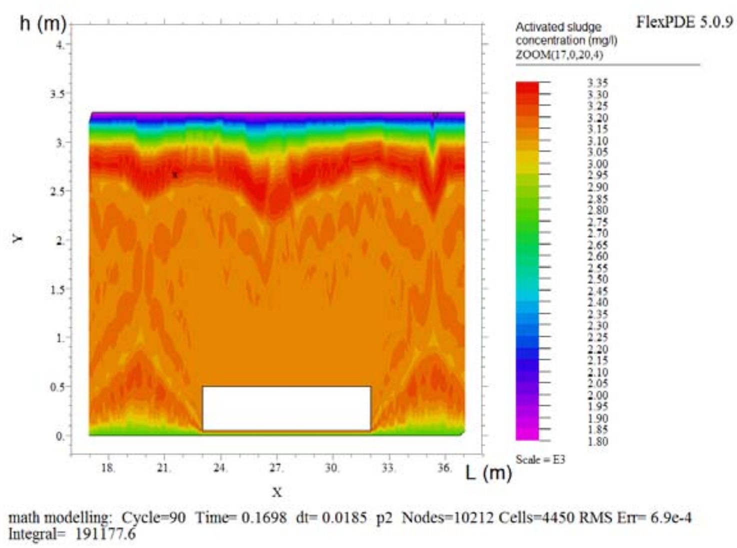

Fig 11a -Distribution of the activated sludge concentration in the bioreactor in October. The maximum concentration of activated sludge has a value of 3350 mg/L related to a value of oxygen between 1 and 2 mg/L.

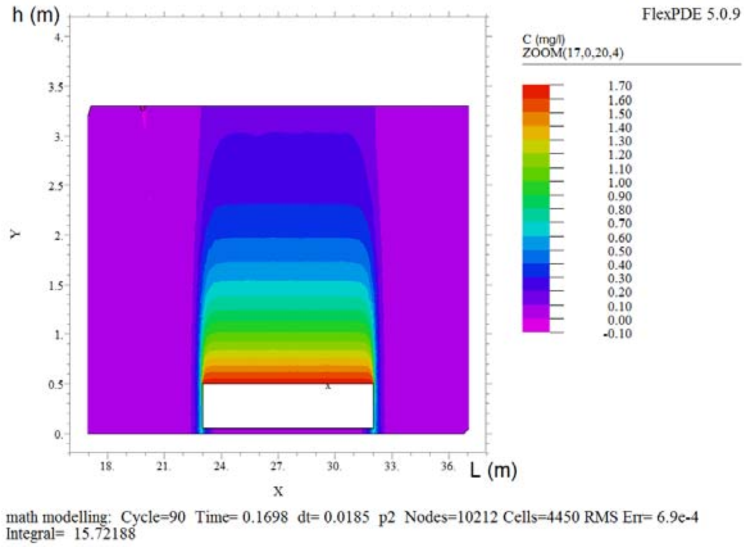

Fig. 11b - Distribution of theDO concentration in the bioreactor in October

The analysis of the images 8a, 8b, 9a, 9b, 10a, 10b, 11a, 11b reveals the distribution of the concentration of activated sludge in the bioreactor.

For January, July and October, the values for the activated sludge are in the range recommended by literature for an optimum treatment of the wastewater. But for March, the modeling have shown that for a concentration of 3 mg/L of oxygen, the activated sludge concentration gets to 4000 mg/L, a higher value that could cause development of filamentous species resulting in bulking and an inefficient treatment of the wastewater.

8. Conclusions

The microscopic studies have revealed that in the bioreactor exists an abundance of heterotrophic species, and the quality of the activated sludge is good in correlation with the presence of a good diversity of organisms, dominated by free-swimming and stalked ciliates.

The model chosen for the mathematical modeling is ASM1, consisting with the fact that in the bioreactor from Mioveni WWTP were found heterotrophic species and the kinetic coefficients were determined based on experimental data.

Analyzing the numerical results the recommended DO concentration should be maintained between 0.5 and 2 mg/L for an efficient treatment of the wastewater with activated sludge process at Mioveni WWTP. Similar results were observed in literature consisting with the correlation between MLVSS concentration and DO concentration profile in the bioreactor for substrate removal efficiency [23].

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