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ANALYSIS OF THE ACTIVATED SLUDGE REACTOR OF THE FOVISSSTE V ETAPA TREATMENT PLANT IN CHETUMAL, QUINTANA ROO

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Abstract: The activated sludge reactor at the Fovissste plant was characterized by measuring the concentrations of organic matter and estimating kinetic parameters using the Extant respirometric method. During the characterization, variations in the concentrations of organic matter in the reactor were detected. These are caused by the interruption of the reactor residual water feed. These interruptions are applied randomly because the average inflow flow is less than the design flow. Additionally, it was detected that aeration is carried out continuously with a 5 hp blower without considering the process conditions, which affects operating costs. To establish a process optimization strategy, the estimated kinetic parameters and a material balance in the reactor were used. The reactor was modeled and it was found that the air supply was exceeded, thus increasing operating costs. Additionally, the operation of the activated sludge reactor was analyzed simulating its operation as a sequenced batch reactor with the estimated kinetic parameters and an optimal operation of 3 cycles of 8 hours with an aeration time of 2.0 hours with a required power of the blower was determined of 2 hp.
Keywords: Activated Sludge, Respirometry, Kinetic Parameters, Oxygen Consumption, Sequenced Batch Reactor, Blower Power.

INTRODUCTION

In Mexico, according to the National Inventory of municipal drinking water treatment plants and wastewater treatment of CONAGUA (December 2020), there are 2786 municipal wastewater treatment plants built, which treat 73.5% of the water waste generated in the country. This problem has been present for several years, since since 2013 Roberto Olivares, president of ANEAS, declared that, according to data from the federal government, in Mexico only 48% of the wastewater generated in the country was treated and of the 1700 plants built in that year in the country, 50% were white elephants (Maldonado, 2013). Additionally, for the year 2014, the Inter-American Development Bank mentioned that 16% of the plants in the country were inoperative (Sánchez M., 2014). In the specific case of the State of Quintana Roo, according to the same Inventory there are 29 plants which treat 68.8% of the municipal wastewater and of these 20 have activated sludge systems as a secondary treatment system with a capacity to treat 1387.6 $l\ s^{-1}$. The "Fovissste V Etapa" water treatment plant is located in the municipality of Othón P. Blanco in Chetumal. This plant has a fully mixed aerobic activated sludge system, which consists of a reactor with a volume of 166 m^3 air fed by a positive displacement blower with a 5 hp motor and a rectangular type secondary settler. This plant was designed to treat a flow of 5 $l\ s^{-1}$ municipal wastewater. However, the influent flow is less than the design flow, which causes the plant workers to perform residual water interruptions and sludge recirculation, thus modifying the treatment process. On the other hand, the aerobic activated sludge process has been widely used in the removal of soluble organic matter and nitrogen from municipal wastewater. In the activated sludge process, a consortium of microorganisms known as mixed liquor grows in a reactor under an aerobic environment, consuming organic matter and ammoniacal nitrogen. The prediction of the effluent concentration in this type of process is carried out using mathematical models that incorporate the reactions of substrate consumption and bacterial growth. These reactions are described by various equations, the Monod equation being the most widely used. This equation contains two kinetic parameters, the maximum specific growth rate and the substrate affinity constant. The correct estimation of these parameters allows a precise analysis of the activated sludge process and its consequent control and optimization. In recent years, the Extant respirometric technique (Duchain and Vanrolleghem, 2001, Johnson, 2006) has emerged as a potential tool for estimating these kinetic parameters, since it is a simple and direct technique in which a consumption profile of oxygen of the microorganisms which is adjusted to a mathematical model to estimate the kinetic and stoichiometric parameters of the process. Considering the aforementioned with respect to the activated sludge reactor, the objective of this work is to estimate kinetic parameters of the activated sludge to establish a proposal for the optimization of the organic matter removal process together with the characterization of the removal efficiency.

MATERIALS AND METHODS

To perform the respirometric tests, a Corning respirometer with a working volume of 5 l (Figure 1) equipped with a variable speed stirrer was used. For the air supply, an aerator with a porous diffuser was used, placed in the lower part of the respirometer. Dissolved oxygen was measured with a dissolved oxygen meter, Hanna and her readings were stored on a computer using a data acquisition system attached to the meter.

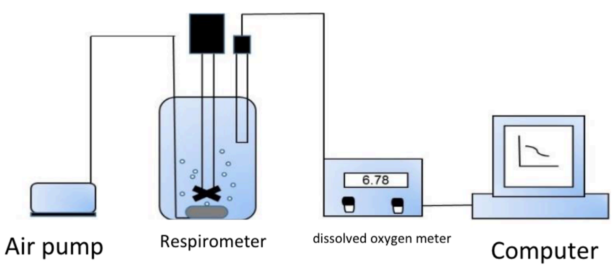

Figure 1. Experimental setup used for the estimation of kinetic parameters.

ANALYTICAL DETERMINATIONS

The concentration of organic matter was measured as Chemical Oxygen Demand (COD) by the Closed Reflux method according to the methodology described in Standardized Methods (APHA, 1995) and using Hach commercial analytical kits and a Hach UV-Visible spectrophotometer. The biomass concentration in the activated sludge reactor was measured as Volatile Suspended Solids (VSS) by the gravimetric and calcination method (APHA, 1995). three samplings were carried out in a period of one month, the residual water samples were collected from the plant influent and from the activated sludge reactor effluent at 30-minute intervals, from 6:00 a.m. to 5:00 p.m. until 9:00 p.m.

ESTIMATION OF KINETIC PARAMETERS BY THE EXTANT METHOD

The kinetic parameters of the plant's activated sludge reactor were estimated using the Extant method (Johnson, 2006). 5 L of sludge were taken from the activated sludge reactor, which were added to the Respirometer shown in Figure 1. Pulses of sodium acetate were added, at the same time that aeration in the respirometer was interrupted. The theoretical model that describes the substrate degradation process in the respirometer is the following:

$$\frac{dS}{dt} = -\mu_{max} \frac{1}{fs} \frac{S}{Ks+S} Xb \quad (1)$$

$$\frac{dX}{dt} = \mu_{max} \frac{S}{Ks+S} Xb \quad (2)$$

$$\frac{dOU}{dt} = \mu_{max} \frac{1-fs}{fs} \frac{S}{Ks+S} Xb \quad (3)$$

Where μ_{max} is the maximum specific growth rate (d^{-1}), *Ks is the affinity constant of the substrate* (mg L^{-1}), S *is* the concentration of organic matter (mg DQO l^{-1}), *Xb* is the concentration of microorganisms in the respirometer (mg *SSV* l^{-1}), *OU is the oxygen consumed (mg l-1) and fs is the cell performance coefficient. kinetic parameters* μ_{max} and *Ks were estimated by minimizing the sum of the squared residual errors (SERC) of the consumed oxygen data with the predictions of the theoretical model:*

$$\boldsymbol{SERC} = \sum_{i=1}^{n}[(\boldsymbol{OU_{obs}})\boldsymbol{i} - (\boldsymbol{OU_{teo}})\boldsymbol{i}]^2 \quad (4)$$

Where OU_{obs} is the observed oxygen consumed and OU_{teo} is the theoretical oxygen consumed from a total of observations. The differential equations (1), (2) and (3) were numerically integrated using the Runge-Kutta method and the estimation of the kinetic parameters was performed using the Marquardt method with the help of the ModelMaker program (Cherwell Scientific, USA). fs was calculated using the following equation:

$$fs = \frac{S_{0p} - OU_f}{S_{0p}} \quad (5)$$

where Sop is the initial pulse concentration of sodium acetate in the respirometer (mg DQO l^{-1}) and OU_f is the final oxygen consumed (mg O_2 l^{-1}).

MATERIAL BALANCE IN THE ACTIVATED SLUDGE REACTOR

An analysis of the activated sludge reactor was carried out by means of a material balance in the reactor. The equations that describe the degradation of organic matter, biomass growth and the oxygen requirement (Ro) are the following:

$$\frac{dS}{dt} = \frac{Q+Qr}{V}Sa - \frac{Q+Qr}{V}Se - \left(\frac{\mu_{max}}{fs}\frac{Se}{Ks+Se} - K_d\right)X \quad (6)$$

$$\frac{dX}{dt} = \frac{Qr}{V}Xr - \frac{Q+Qr}{V}X + \left(\mu_{max}\frac{Se}{Ks+Se} - K_d\right)X \quad (7)$$

$$Ro = \frac{1-fs}{fs}\mu_{max}\frac{Se}{Ks+Se}XV \quad (8)$$

where Q is the inflow (m^3 d^{-1}), *Qr is the recirculation flow rate to the activated sludge reactor* (m^3 d^{-1}), Sa and Se are the concentrations of organic matter in the influent and effluent respectively (kg *DQO* m^{-3}), *Kd* is the decay coefficient (d^{-1}), *X* y *Xr* are the concentrations of microorganisms in the reactor and in the recirculation respectively (kg SSV m^{-3}) and V is the volume of the reactor (m^3). The coupled differential equations (6) and (7) were solved numerically using the Runge-Kutta method with the help of the ModelMaker program.

CALCULATION OF THE REQUIRED POWER OF THE BLOWER

The required Power of the blower was calculated using (Tchobanoglous, 2003):

$$Pw = \frac{w\,R\,T_1}{(29.7\,)0.283\,e}\left[\left(\frac{P2}{P1}\right)^{0.283} - 1\right] \quad (9)$$

Where *Pw* is the required blower power (kW), w is the air mass flow (kg/s), R is the gas constant equal to 8.314 J mol^{-1} K^{-1}, 29.7 is a conversion factor, e is the efficiency usually between 0.7 to 0.90 and P1 and P2 are the inlet and outlet pressures respectively (atm). The required air mass flow was calculated using the methodology described in Tchobanoglous (2003) considering a temperature of 25 °C and a standard oxygen transfer efficiency of 15% and the oxygen requirement estimated with equation (8).

RESULTS AND DISCUSSION

As a first stage of this work, the concentrations of soluble organic matter in the influent residual water of the Plant were measured. The average concentration of organic matter was 653.9 mg COD L-1 ± 138.5. The residual water that reaches the Plant is stored in a tank with a capacity of 15,500 liters. The estimated average influent wastewater flow was 1.7 L s-1. This fact means that the plant cannot work continuously since the residual water pump feeds the activated sludge system with a constant flow of 4.6 L s-1, where the flow fed to the system is greater than the influent flow, the Plant workers operate the activated sludge system in three types of operation during the day. In the first type they feed residual water to the system with sludge recirculation, in the second type they interrupt the supply of residual water and interrupt sludge recirculation (batch operation) and in the third type they interrupt the supply of residual water and recirculate the sludge. These types of operation are applied daily without there being an established schedule for the three types of operation. This causes variations in the concentrations of soluble organic matter in the activated sludge reactor, as can be seen in Figure 2, where the concentrations of organic matter measured in a period of 15 hours are presented at intervals of 30 minutes for the first sampling. It can be observed that the feeding and the interruption of residual water do not present an application pattern, where the decreases and increases in the concentration of organic matter are not similar.

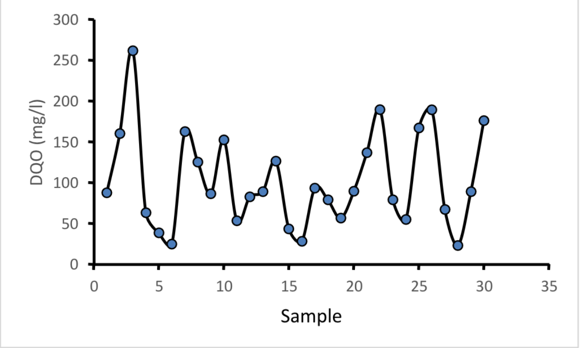

Figure 2. Organic matter concentrations measured in the activated sludge reactor for the first day of sampling.

In the case of this sampling, the average concentration of organic matter in the reactor was 102.4 ± 58.5 mg l^{-1}. Figure 3 presents a respirogram obtained from a sample of sludge from the treatment plant reactor. The solid line corresponds to the adjustment to the experimental values made with Model Maker. The values obtained for the kinetic parameters were: $\mu_{max} = 0.079\ h^{-1} \pm 0.024$, Ks = 53.17 mg $l^{-1} \pm 12.29$ y fs = 0.54 ± 0.07.

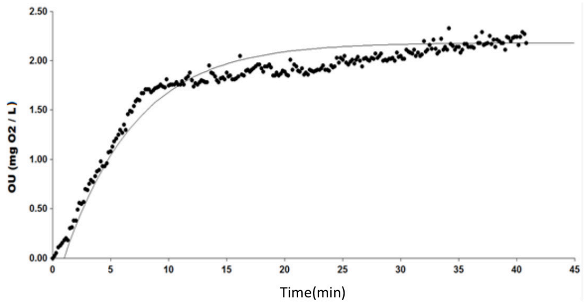

Figure 3. Respirogram obtained from a sample of activated sludge from the treatment plant.

With the values of the estimated kinetic parameters and through equations (6) (7) and (8) the organic matter removal process in the reactor was modeled considering the type of batch operation. Figure 4 presents the organic matter concentrations measured corresponding to samples 3, 4, 5 and 6 (black circles); The solid line in this Figure corresponds to the concentrations of organic matter in the reactor, predicted by the equations described by the material balance considering a decay coefficient of $0.088\ d^{-1}$.

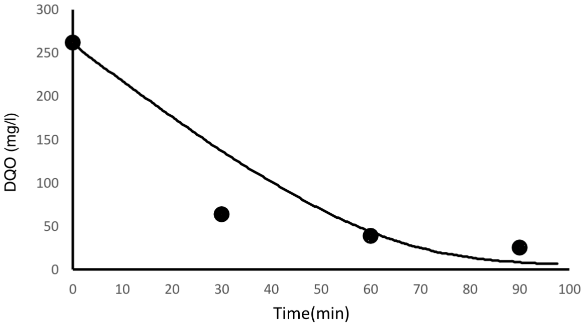

Figure 4. Organic matter concentration predictions in the reactor (solid line) at four concentrations measured during the batch type of operation.

Additionally, the reactor was modeled under the type of continuous operation with sludge recirculation through equations (6), (7) and (8), using the estimated average flow rate of 1.7 l s-1, a concentration of microorganisms in the recirculation of 10000 mg l-1 SSV, a recirculation flow of 36.8% of the average flow and with the initial conditions: S equal to 654.3 mg l-1 COD (average concentration of organic matter measured in the influent) and X equal to 2567 mg l-1 SSV (concentration measured in the reactor). Under stationary conditions, the model predicts a concentration of organic matter in the effluent of 8 mg l-1 COD and a Ro of 94.6 kgO2 d-1. Based on the estimated Ro, the required power of the blower would be 2 hp, which implies that for a continuously fed flow of 1.7 l s-1, only 40% of the power currently supplied to the reactor (5 hp) would be required. This would imply a decrease in the costs of aeration to the reactor with a considerable improvement in the quality of the effluent. To carry out this type of operation, it would be necessary to acquire a pump that supplied the estimated average flow (1.7 l s-1) and a variable speed controller for the blower motor. However, in the State of Quintana Roo, like other parts of the Republic, treatment plants face problems mainly due to the abandonment of the public sector. This problem is evident in the lack of resources for maintenance of the plants as mentioned by Roberto Olivares in 2013. Due to the lack of resources, another more economical option was worked on for the operation of the activated sludge reactor of the treatment plant. Fovissste. Considering the current operation of the plant, the operation of the reactor was analyzed as a sequenced batch reactor. Using the estimated kinetic parameters, the estimated influent flow and the average concentration of organic matter, it was determined that for the operation of the reactor as a sequenced batch, a filling time of 3.5 hours, an aeration time of 2 hours, a sedimentation time of 1 hour and emptying time of an hour and a half, which implies three cycles of eight hours a day. Therefore, the required aeration of the reactor would be 6 hours per day, reducing operating costs where the 5 hp blower that the plant has is currently operated 24 hours a day.

CONCLUSIONS

The operation of the activated sludge reactor of the Fovissste V stage plant was analyzed and variations in the concentrations of organic matter in the reactor were detected due to interruptions in the feeding of residual water and sludge recirculation. It was detected that the air supply is exceeded, for which the best treatment option for the reactor was analyzed, being the sequenced batch mode. It was found that the operation with 3 cycles of eight hours per day would imply savings in operating costs since only 6 hours of aeration per day would be required to obtain a good quality effluent.

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