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BOD_5 removal kinetics and wastewater flow pattern of stabilization pond system in Birjand

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ABSTRACT

Wastewater stabilization ponds (WAPs) are one of the simplest techniques available for the treatment of municipal wastewater which eventually benefit from the simplicity and reliability of their operation. Although many WAPs have been established and made operational, but still the dynamics of pollutants in these systems are not well understood and this can lead to improper design and poor removal efficiency of pollutants and also operational problems. Since in the most used wastewater treatment stabilization ponds, the removal of organic matter (BOD_5) is the primary goal of design systems, so preliminary determination of BOD_5 removal kinetics and wastewater flow pattern is often required. In this study, to analysis of kinetic data, four kinetic models that can be used in the WAPs have been compared. The studied models combine the different kinetics of Monod and First order kinetic models with continuous stirred-tank reactor (CSTR) and plug flow regimes. Finally, the models were analyzed using statistical parameters. The combined model of the Monod's kinetic equation and plug flow pattern presented nearest mathematical relationship between theoretical and actual data of WAPs. In the three hybrid models except the Monod and plug flow, BOD_5 removal coefficients decreased with increasing BOD_5 loading. About the prediction of organic materials removal in WAPs, a significant relationship between the ratio of BOD / COD and removal coefficients was not found, suggesting that the decomposition of organic matter in the stabilization ponds are not susceptible rather than organic waste nature.

Keywords: wastewater stabilization ponds, wastewater treatment, modeling, Birjand.

INTRODUCTION

The main objectives of wastewater treatment is often producing an effluent suitable for discharging into receiving environments somehow complies with effluent standards and have no damages for the environment[1]. Therefore, the wastewater treatment not only would cause environment protection and public health improvement, but also return water to the consumption cycle directly or indirectly. Due to the water crisis in the last century, the importance of this issue has been even more apparent. Therefore, several treatment systems whether biological or chemical and or mixed one may be employed. Natural treatment mechanisms are considered as one of the most popular systems [1, 2].

Waste stabilization ponds (WSPs) as natural treatment systems are widely used in developing countries especially in rural areas because of their low cost and simplicity of construction, operation, and maintenance[3] and often consist of anaerobic, facultative and aerobic (maturation) ponds. The anaerobic pond, which is the initial treatment reactor, is designed to eliminate suspended solids and some of the soluble organic matter. The residual organic matter is further removed through the activity of algae and heterotrophic bacteria in the facultative pond. The final stage of pathogens and nutrients removal takes place in the maturation pond [4, 5]**.** Wastewater treatment in stabilization ponds mainly results from settling and complex symbiosis of bacteria and algae where the oxidation of organic matter is accomplished by bacteria in the presence of dissolved oxygen supplied by algal photosynthesis and surface reaeration [6, 7]. During the wastewaters storage, another different processes can also occur in ponds such as the water volume decrease under natural evaporation, organic and inorganic compounds degradation and mineralization by microbiological flora, volatilization of some compounds and finally infiltration of wastewaters through soil layers [8-10]. Thus, where land is somewhat inexpensive, the weather is good and there is a lack of equipments and skilled operations and also simple method is considered, the wastewater stabilization ponds are the best options[11, 12]. Although many ponds have been established and operated, but still the pollutants dynamics in these systems is not well understood[4]. To better perception of hydraulic conditions, many fundamental research and scientific debates on the wastewater systems and kinetics of decomposition of pollutants separately have been conducted[13]. For example, the pattern of a continuous tank flow in the Plug flow regime and the kinetics of first-order model versus the Monod equation kinetics have been reported.

The practical performance of WSPs systems is dependent upon several factors, including: the type of wastewater; the organic loading regime; the geometry and physical arrangement of the pond system; and ecological conditions such as air temperature and the amount of wind and incident sunlight to which the pond is exposed [14]. In addition to these influential criteria, the hydraulic behavior of wastewater within a pond system is also of principal importance in determining its overall treatment efficiency, since it controls the hydraulic residence time (HRT) and also the residence time distribution (RTD) which governs the dispersion (mixing) of waste substrates and chemical and biological entities within the reactor basin[15].

Meanwhile in majority of applied wastewater stabilization ponds, the removal of organic matter (BOD_5) is the primary goal to design systems. Miscomprehension of the dynamics of contaminants in the system can lead to incorrect design; it usually appears in improper shape of stabilization ponds, as results low pollutant removal efficiency and operational problems such as clogging and short circuiting.

In order to allow optimization, better understanding of BOD_5 removal kinetics and sewage flow pattern are needed, which can be achieved by using mathematical models [16]. Such developed studies potentially leading to that the models of removing contaminants are more accurate which results from the more correctly design. Gathering sufficient quality data for the accuracy of a kinetic model is often difficult and when the model is applied to complex environmental parameters and according to guesswork kinetic coefficients, it can only lead to incorrect design[11, 12].

In this study, a complete approach is detailed for a full-scale WSP system. The aim of this paper is analyze the flow characteristics in a WSP, develop and validate a kinetic pattern with data obtained from the influent and effluent analysis, and develop a methodology that uses the BOD5 pattern predictions to build a compartmental model.

MATERIALS AND METHODS

Data gathering

The research is a cross-sectional study that the wastewater treatment plant of Birjand city which its wastewater treatment system is WSPs was investigated. In this treatment plan, the wastewater, after passing through the screening and flow measurement, was entered into the anaerobic pond which the most portion of wastewater was treated into this section. Subsequently the sewage entered into a facultative pond. After this step, the effluent drains into a secondary facultative pond which acts as the ultimate unit. The chlorination unit has been built at the end of system but it is currently inactive.

Sampling was conducted as two times per each month and for 6 months duration. At every sampling time, all samples taken at three intervals during a day. Simultaneously, the flow measurements and data recording of treatment plant input and output were carried out. To enhance the range and accuracy of data, each of samples was analyzed separately twice and the averages were considered. All tests were performed in the water and wastewater laboratory of Birjand city.

The kinetic models

Figure 1 show simple design equations which relate the values of the input and output data of WSPs. These equations were developed from combination of CSTR or Plug flow kinetic models with first order or Monod's models.

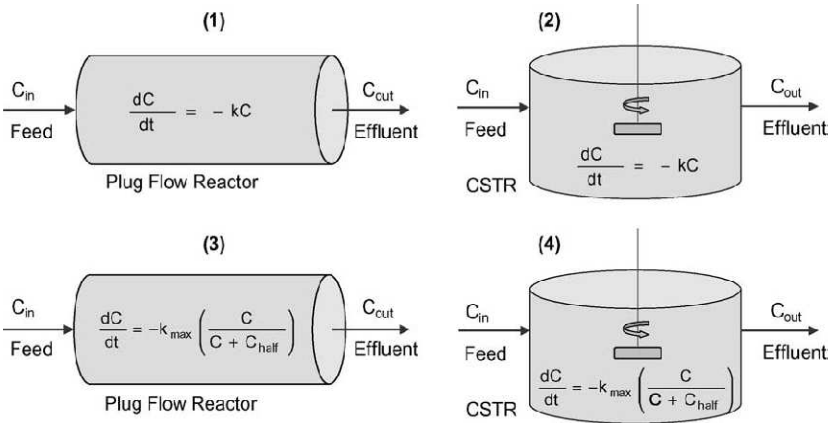

Figure 1: Four modeling methods for stabilization pond; (1): combined model of first-order and Plug flow, (2): combined model of First-order and CSTR regime, (3): combined model of Plug flow and Monod, (4): combined model of Monod and CSTR. [11, 12].

Combining of Plug flow regime and first-order reaction kinetic creates the first design equation (Equation Kickuth) which is the easiest and most useful equation commonly in designing of WSPs. [11, 12]

$$A_h = \frac{Q(\ln C_{in} - C_{out})}{K_1} \qquad \text{(Eq.1)}$$

A_h: pond area, m^2
Q: flow rate, m^3/d
C_{in}: input BOD_5 concentration, *mg/l*
C_{out} :output BOD_5 concentration, *mg/l*
K_1: velocity constant *(m/d)*

Also, the combination of CSTR flow kinetic equation with first-order reaction derived an equation that associated with simple values of input and output BOD_5 of WSPs. [11, 12].

$$\frac{dc}{dt} + \frac{1}{\tau}C_{in} = \frac{1}{\tau}C_{out} \qquad \text{(Eq.2)}$$

$$A_h = \frac{Q(C_{in} - C_{out})}{K_2 C_{out}} \qquad \text{(Eq.3)}$$

Where: τ represents a hydraulic retention time (d), and K_2 is the velocity constant (m/d) .

From the combination of simplified Monod's equation (Eq. 4) with Plug flow or CSTR, the equation 5 and 6 were obtained, respectively [11, 12].

$$\frac{dc}{dt} = -K_{\max}\frac{C}{C + C_{half}} \quad \text{(Eq.4)}$$

$$A_h = \frac{Q(C_{in} - C_{out} + 60\ln(C_{in}/C_{out}))}{K_3} \quad \text{(Eq.5)}$$

$$A_h = \frac{Q(C_{in} - C_{out})(C_{out} + 60)}{K_4 C_{out}} \quad \text{(Eq. 6)}$$

Where:
K_{max} is the maximum BOD_5 removed in WSPs regardless the effect of temperature, ($g/m^3.d$).
C_{half} is the amount of wastewater BOD_5 while the removed BOD_5 value is half of K_{max}; which in this study has been considered equal to 60 mg/l that is the common value used in Monod's Eq[11, 12] In wastewater. Also in a study done in 2009 by Guangzhi and et al. onto 80 WSPs, the C_{half} was considered 60 mg /l [11, 12].

Model Assessment
Although equation (1) is used in the design of stabilization ponds for more than two decades, but Eq 3, 5 and 6 were presented by Guangzhi et al. for the first time in 2009 and used in this study. The accuracy and reliability of the results can be evaluated by comparison with existing based practice data. Whatever the equations show closer mathematical calculation, they would be more accurate models. All equations of 1, 3, 5 and 6 can be come as the following general formula:

$$F(C_{in}, C_{out}) = K\frac{A_h}{Q} \quad \text{(Eq.7)}$$

For each stabilization pond, the value of K can be obtained from linear regression and F (C_{in}, C_{out}) and (A_h/Q) can be calculated using the average data.

RESULTS AND DISCUSSION

Matching design equations
The conformity of Equations 1, 3, 5 and 6 were evaluated by comparing the documented values F (C_{in}, C_{out}) with the equations and actual data of stabilization ponds. The values of K_1, K_2, K_3 and K_4 were obtained through data regression.

In each of four equations, when the data are placed in the general form of Equation 7, the value of K is obtained as following:

parameter	For:
$K_1=0.08\ d^{-1}$	(Eq.1)
$K_2=0.201\ md^{-1}$	(Eq.3)
$K_3=8.73\ g\ BOD_5\ m^{-2}d^{-1}$	(Eq.5)
$K_4=20.16\ g\ BOD_5\ m^{-2}d^{-1}$	(Eq.6)

In the equations 1, 3 and 6, the linear relationships between F (C_{in}, C_{out}) and (A_h/Q) are somewhat weak. Equation 1 (Equation Kickuth) which used typically in the design of stabilization ponds, showed lower mathematical relationship between theoretical and actual results. comparing of statistical parameters also indicated that the combination of two equations of 1 and 3 have generated closer mathematical relations, After that the coefficients of K_1 - K_4 obtained separately, the amounts of input BOD_5 were plotted vs. organic loading values. Also the coefficient of K_1 - K_4 resulted from the combined relationships were plotted vs. Subsequently, in order to investigate the relationship between the ratio of BOD / COD values and K_1 - K_4 obtained from combined equations, the BOD / COD vs. K_1 - K_4 were plotted in Figure 2.

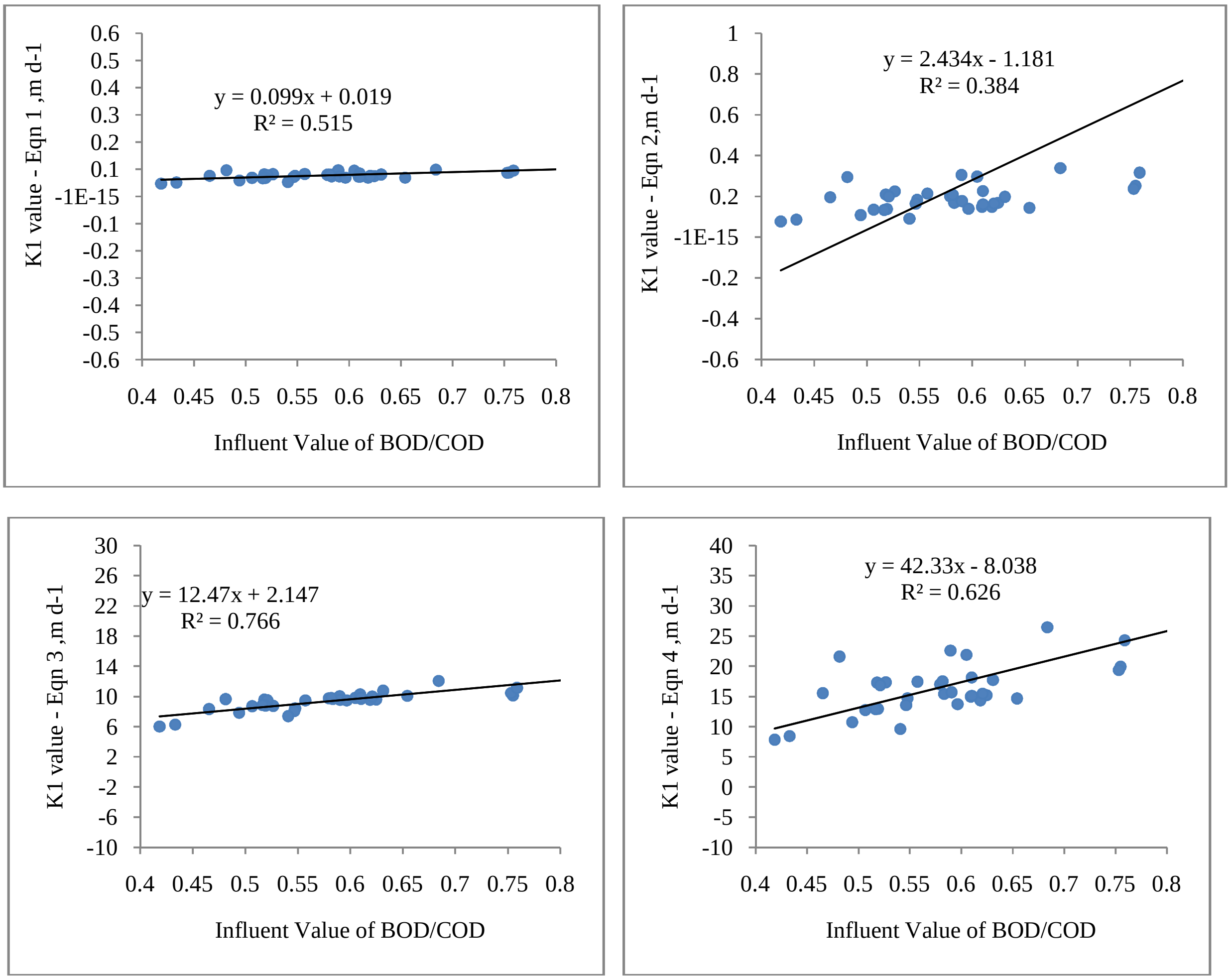

Figure2.Trend of Regression coefficients (K_1) of combined equations of 1-4 versus BOD/COD ratios

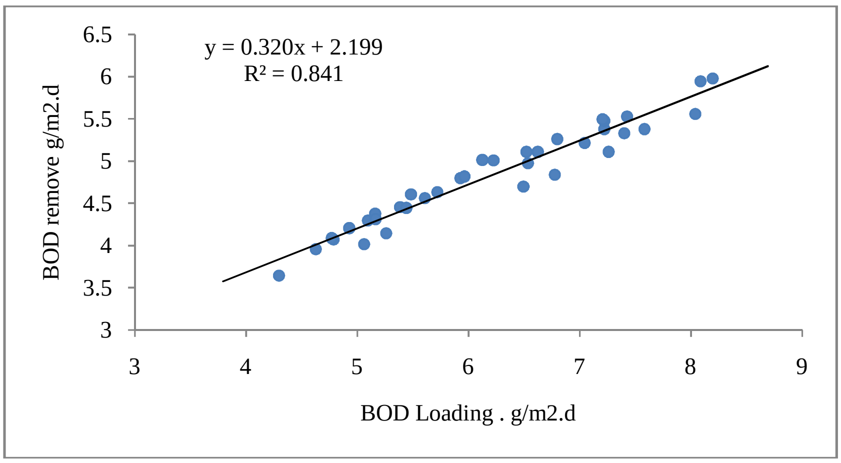

Figure3.Regression if BOD_5 amounts removal versus organic matter loading in studied stabilization ponds

CONCLUSION

According to statistical parameter of R^2 obtained from two hypotheses kinetic equation of the first order kinetics – Monod and Plug flow regime – CSTR, it was identified that the Plug flow regime showed the closer mathematical data than CSTR flow regime which confirms that the Plug flow is the dominant flow regime in wastewater stabilization ponds in Birjand. Also between the four used models, the combined model of the Monod and Plug flow provided the best mathematical relationship between the theoretical predictions and the actual data of stabilization ponds. In a study conducted in 2009 by Guangzhi and et al. using a combination of four models mentioned above, the combination model of Plug flow pattern and Monod's kinetics model provided the best mathematical correlation. From obtained results of previous conducted researches and current study, it can be concluded that the Monod's kinetics and Plug flow regime are dominance in stabilization ponds. Also, the resulted models for the COD data showed lower values of statistical parameters (especially R^2) and there was no significant correlation between the kinetic equations of the flow regime.

Variation of kinetic coefficients:

BOD_5 and flow rate data provided the possibility to assess changes of coefficients, pollutant loading and BOD / COD ratio. As the coefficients K_1 - K_4 of different substrates obtained, the organic loading values were plotted versus the amounts of input BOD_5 and it revealed that in combined equations of 1, 2 and 4, the greater input BOD_5 values was consistent with the slightly lower kinetic coefficients while this status was reversed in the combined equation (3)and the larger input BOD_5 values was consistent with slightly larger kinetic coefficients that in equations 1, 2 and 4, the speed of biological reactions was almost constant and has not changed with change of their input loading. Meanwhile Equation 3 indicates which the rate of biological reactions would be increasing by increasing in the input loading of system and this will confirm the applicability of predicted model of Monod and Plug flow regime for stabilization ponds of Birjand.

The first-order kinetics and Monod were able to predict the organic removal increasing with increasing loading rates. Also in many other studies, increased loading rates were consistent with slightly lower kinetic coefficients in each of four combined models. However, in the present study, only the Monod model would indicate this status.

The effect of Biodegradability

The BOD / COD ratio is generally used as an indicator of potential biodegradation of organic matter. If this ratio be 0.5 or larger, the organic materials are considered as simple biodegradable while if this ratio be 0.3 or less, they are considered as low biodegradable.

Figure 2 shows that there are no statistically significant relationship between the kinetic coefficients and the ratio of input BOD / COD. This has also been reported by Caselles-Osorio A and Guangzhi. The removal of organic matter in stabilization ponds is not sensitive to the nature of the organic matter, whether they are readily biodegradable or slowly. About the input loading to the system and the removal of organic matter, it was also determined that the removal of organic materials would increased with increasing organic loading, indicating the higher organic loading capacity of the system rather than its current state (see Figure 3).

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