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DETERMINATION OF KINETIC PARAMETERS IN ACTIVATED SLUDGE PROCESS FOR DOMESTIC WASTEWATER TREATMENT PLANT

The process was effectively used for the treatment of domestic wastewater known as the activated sludge process. To predict the biomass growth, the Monod rate equation was applied in a 30 liter(s) aerated and agitated vessel. The projected data for the kinetic model were used to estimate the large scale aeration tank for the efficient oxygen transfer rate. Food to microorganism ratio (F/M) and HRT were examined for the desired rate of COD removal. More than 52% yield of organic removal was obtained. Also, the endogenous decay coefficient of 0.06 d^{-1} was obtained. The growth rate constant (K_S) and rate constant (k) were determined as 85.5 mg/l and 1.71 d^{-1}, respectively. 90% COD removal was achieved with the eight–day–old sludge.

Key words: Kinetic Model, Activated sludge process, Aerated vessel, Biological treatment, Food to microorganism ratio

The biological wastewater treatment is primarily used to remove the dissolved organic matter from the wastewater. Some suspended organics are also metabolized, the natural flocculation and settling characteristics of the biosolids are formed and then the solids, along with other suspended matters, are removed.

The biological treatment is a "natural" process; organic matter in the wastewater will naturally decay in the presence of microorganism as receiving bodies in the wastewater. High organic loads in the wastewater will upset the biosynthesis of the receiving bodies and cause other undesirable effects. The biological treatment is engineered to accelerate natural decay processes and neutralize the waste before the discharge to receiving waters in the safe environment.

In an aerobic process, air or oxygen is supplied to microorganism which has the contact with the wastewater. The microorganisms utilize organic matters and stabilize the waste water. As a result of the treatment, biomass is generated [1]. The oxygen demand is normally high and the process required sufficient aeration and agitation for the effective oxygen transfer. Such a process is known as the activated sludge system [1, 2]. However, the performance of the activated sludge process is limited by the availability of oxygen and, therefore, it is important to consider the treatment efficiency which is dependent(s) on the availability of oxygen and the concentration of biomass as mixed liquor suspended solids. The activated sludge process is a suspended growth process where part of the generated biomass is completely mixed with the fresh wastewater [3].

Aeration of domestic wastewater may easily form floc; fine suspended and colloidal mater of the sewage forms aggregated biosolids known as floccules. If floc is allowed to settle and then added to the fresh sewage along with the vigorous aeration, the flocculation occurs in a shorter time than the usual process. The general rule applied to activated sludge processes are that the ratio of the influent degradable matter expressed as COD: N: P should be 100: 5: 1 [2, 3].

The present investigation is focused on the performance of the activated sludge system for a domestic wastewater treatment. Based on the growth model, kinetic constants were obtained using the experimental data for the removal of organic pollutants.

THEORY: MICROBIAL GROWTH AND SLUDGE PRODUCTION

The sludge production is a major characteristic of the activated sludge process. The consumption of the substrate resulted in the growth of new biomass. The rate of the substrate utilization is described by the following equation:

$$-r_S = \frac{Q(S_0 - S)}{V} = \frac{S_0 - S}{\tau} \tag{1}$$

where Q is the flow rate, V is the working volume of the aerated vessel, $S_0 - S$ represents the consumed substrate for the duration of hydraulic retention time (τ). If Monod rate model is applied for the propagation of microorganisms, then substitution of the rate equation into equation 1 gives the following equation:

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$$\frac{kS}{K_s + S} = \frac{S_0 - S}{\tau} \quad (2)$$

where K_S is Monod constant and k is the rate constant. The treatment efficiency (E) is defined on the basis of the biodegradable substrate or the substrate removal. That is normally BOD removal or soluble COD removal [4].

$$E = \frac{S_0 - S}{S_0} \quad (3)$$

Now the dynamic model is used, as the biomass balance is considered. As a result, the biomass is known as volatile suspended solids (VSS), that is, the biomass originated from the utilized substrate (mg/l).

The activated sludge process parameters such as reaction kinetics, food to microorganism ratio (F/M), sludge retention time (θ_C), COD removal and the process performance were examined. The CSTR type of the bioreactor with a settling basin was selected for this research work. The data obtained were fitted by the kinetic models described in this paper and the kinetic coefficients were also determined. The F/M ratio was defined by the following equation:

$$\frac{F}{M} = \frac{S_0}{(\tau)(X)} \quad (4)$$

where, S_O is the influent substrate concentration (mg/l), τ is the hydraulic retention time (day) and X is the biomass concentration (mg/l). The specific rate of the substrate utilization (U) is defined as the product of F/M and the treatment efficiency (E). The relation present U is obtained by substituting equation 3 into equation 4 for the F/M and the yield resulted as:

$$U = \left(\frac{F}{M}\right)E = \frac{S_0 - S}{(\tau)(X)} \quad (5)$$

The specific rate of utilization can be measured by the substrate utilization per unit mass of organisms U = – r_s/X. The rate of the substrate utilization is defined by Monod equation [5, 6]:

$$-r_s = \frac{\mu_m XS}{Y(K_s + S)} \quad (6)$$

In equation 6, the term μ_m/Y is often replaced by a constant k, defined as the maximum specific substrate utilization rate, and then equation 5 is simplified for the rate model:

$$U = \frac{kS}{K_s + S} \quad (7)$$

The mean cell residence time in the activated sludge system (θ_C) is measured (by) as stated in the following equation:

$$\frac{1}{\theta_C} = YU - k_d \quad (8)$$

The yield and endogenous decay coefficients were determined by equation 8. This equation is applied either in the recycle or the non–recycle case [1, 3, 7]. In the next section, the experimental data are presented to define the yield factor and the decay coefficient.

Dorste [1] has studied the foam formation and a poorly settling sludge, which are two of the most major problems associated with the activated sludge process. A sludge that show poor settling characteristics is referred to as a bulking sludge. Filamentous microorganisms are usually responsible for a bulked sludge. Large surface area to volume ratios for these microorganisms retards their settling velocities. The causes and combative measures for filamentous bulking have been discussed in the literature [2, 8, 9]. Fungi are the most familiar filamentous microorganisms. The vegetative structure of the most fungi is composed of filaments, which actually contain a number of nuclei. Fungi are not commonly significant in a wastewater treatment [8–10]. Nitrogenous bacteria are among the most frequently reported filamentous organisms in surveys of the bulking sludge [2, 10]. Utilization of a wide variety of carbon as nitrogen sources and the achievement of the maximum growth rate at a low substrate concentration (low of half–velocity constant) support the potential for this organism to compete effectively in the activated sludge systems characterized by low or variable nutrient concentrations [11,12]. *Nocardia* filaments are concentrated in the foam compared to the mixed liquor. Foam removal is a logical and beneficial control measure of these and other species that cause foaming [13–15].

It is well understood that a great number of municipal treatment plants are not operating efficiently [12, 13]. The fluctuation in the effluent quality may exist, which may be considered as one of the major environmental pollution sources [16, 17]. The purpose of the present study was to demonstrate how effectively a well monitored activated sludge system can be operated. Also, a suitable kinetic model was proposed which predicts the municipal wastewater treatment at Ghaemshar plant. The rate constants and the decay coefficient were determined.

MATERIALS AND METHODS

The fresh wastewater with a fixed composition was collected from an influent equalization tank of the domestic treatment plant, Ghaemshar, Iran. The wastewater was collected in 20 liter(s) polyethylene containers and stored at 4°C until being used. The wastewater was characterized and the typical composition is summarized in Table 1. One liter of sludge as the seed solution was taken from the aeration tank (a domestic wastewater treatment plant, Ghaemshar, Iran).

Table 1. Characteristic of the domestic wastewater used in this study

Components	Concentration
COD	420
BOD	240
$N-NH_3$	17
$N-NO_2$	6
$N-NO_3$	11
$P-PO_4$	55
SS	202
VSS	112
p H	7.4

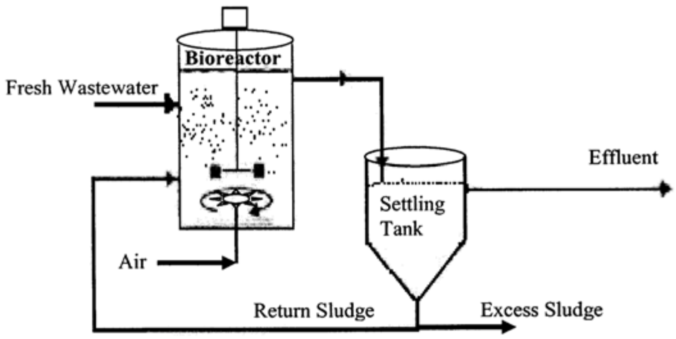

Figure 1. Continuous Operating Activated Sludge Process for Domestic Wastewater Treatment

The schematic diagram of the experimental setup is shown in Fig 1. To demonstrate the use of the activated sludge process in a domestic wastewater treatment plant, a bench–scale aeration tank was built for the bench–scale experimental model. The aeration tank was made from plexi–glass in the form of a rectangular with 30 liter working volume. The air was supplied via an air pump (Aquarium Air Pump 8500, 6W, 220V/ 50 Hz). A porous ceramic gas sparger was used. Initially, a batch culture was propagated by introducing the recycle sludge from the treatment plant and then the dense sludge was transferred to the aerated tank with the fresh wastewater. In addition, some nutrients such as nitrogen and carbon (5ml of whey and 1g of glucose) were supplied in the inoculum flask to accelerate the biomass production. The retained sludge enhanced the steady state operation of the activated sludge system. The fresh wastewater was introduced into the aeration tank and then the effluent was settled in a settling basin. A portion of the settled sludge was recycled into the aeration tank to enhance the treatment efficiency. The excess sludge was removed from the settling tank. The reactor was operated at room temperature, approximately 25°C. The wastewater working volume without aeration was 30 liters. Air bubbles were introduced from the bottom of the tank through the gas sparger, the biomass and the maintaining wastewater were sufficiently aerated.

The experiments were designed to collect data based on the returned sludge ratio, the biomass generation and the removal of organic compounds from the wastewater. The fresh wastewater was introduced to the aeration vessel. Clear effluent from the settled sludge was separated in a settling tank, the sludge was partially recycled and the excess sludge was disposed.

The samples were collected based on a daily sampling for the routine analysis. The following parameters were analyzed according to the standard method [4]: COD, BOD, $N-NH_3$, NO_2, NO_3, PO_4, SS, VSS and pH. The pH was monitored by pH meter model 320 from WTW (Germany). For COD, a colorimetric method with the closed reflux method was developed. Spectrophotometer (Cecil 1000, Cecil Instrument, Cambridge, England) at 600nm was used to measure the absorbance of COD samples. The dissolved oxygen concentration in the wastewater was monitored by a DO probe. The DO meter was supplied by WTW DO Cell OX 325, electro DO probe, Germany. Turbidity was also measured by a turbidity meter model Turbo 350 IR, WTW (Germany). BOD and all other routine tests were also followed by Standard Methods [4].

RESULTS AND DISCUSSION

The aerobic process was employed in order to reduce the organic pollutants of the wastewater. The biological process was implemented to accelerate the biodegradation and oxidation of organic compounds in the wastewater. Microorganisms were grown on the wastewater. Daily samples were taken at a starting point right after introducing the inoculum. The bacteria propagation, the ratio of the retuned sludge and the hydraulic retention time were monitored. Several important process parameters were studied. The kinetic coefficients, COD removal and growth factors were the major parameters, which may have influenced and enhanced the biological treatment. The best recycle ratio for the return sludge was 40%, which was resulted in a process efficiency of about 93%.

Figure 2 presents the kinetic model similar to Monod rate model for the double reciprocating rate and the substrate that is based on a double reciprocated form of equation 7 for the linearized model. The experimental data were well fitted with the proposed equation. The value obtained for the correlation coefficient (R^2) was 0.984. The rate constant (k) was 1.71 d^{-1} and Monod constant K_S was 85.5 mg/l. The large value of K_S shows that either the biomass grown on the wastewater has a low affinity for the substrate or that the rate expression can be simplified and may lead to the first order [6]. Another reason related to the process which is operated in the substrate limited conditions, the decay of biomass through starvation, death and auto oxidation becomes significant. This phenomenon is collectively known as the endogenous decay which is proposed by the first–order rate expression [1, 2, and 16].

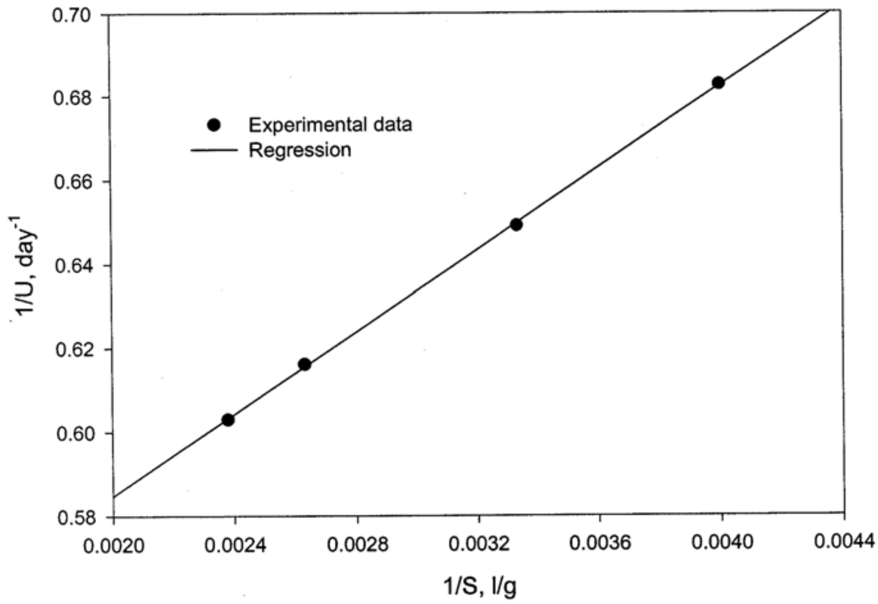

Figure 2. Kinetic model for a double reciprocating utilization rate and a leaving substrate

The successful wastewater treatment is shown in Figure 3. The data illustrate(s) the COD removal and COD with respect to the sludge detention time. About 90% of COD removal was achieved effluent at the sludge retention time longer than 6 days. The effluent COD dropped to about 20 mg/l with the sludge aged 8 days. According to justification made by Arsivala [18], for the Middle East region and the humid climate similar to the North of Iran, the process efficiency of more than 90% was considered to be a very efficient process.

Figure 4 shows the plotted data based on the equation (8), indicating the relationship between the sludge age and the utilization of the organic matter in the wastewater. The kinetic data (a biomass yield and decay coefficients) are defined in the modeled data. The value for the correlation coefficient (R^2) fitted with the model was 0.992. Based on the experimental data plotted, the decay coefficient (k_d) and the biomass yield (Y) were computed to be 0.06 d^{-1} and 0.52, respectively.

CONCLUSION

The activated sludge system was used to identify the influential parameter for the effective treatment. The sludge age was defined as one of the critical parameters in the RAS process. The kinetic model for the substrate

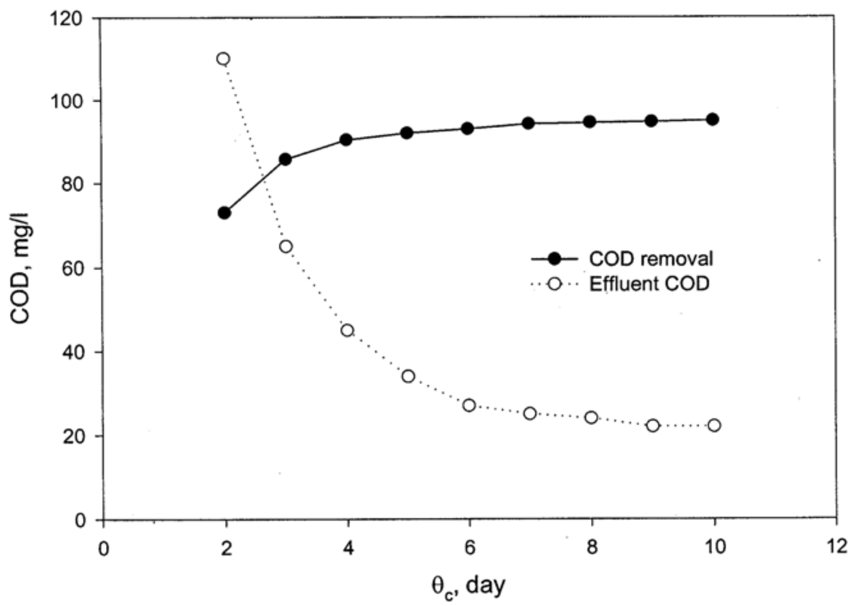

Figure 3. COD removal and the effluent COD with respect to the sludge retention time

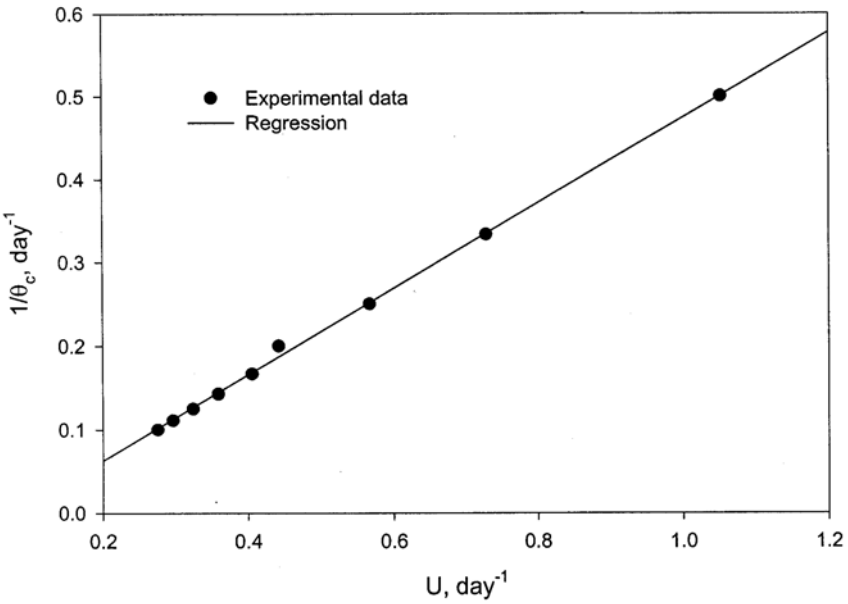

Figure 4. Sludge age relation with the utilization of the organic matter in the wastewater

utilization was introduced and the Monod type rate model was evaluated. The experimental data and the model were quite consistent. The substrate utilization rate constant (K_S) and rate constant (k) were defined as 85.5 mg/l and 1.71 d^{-1}, respectively. A 90% COD removal was obtained with the 8–day–old sludge. More than 52% yield of the organic loading was obtained. Also, the endogenous decay coefficient of 0.06 d^{-1} was obtained.

NOMENCLATURE

$-r_s$ – rate of substrate utilization, mg/l.d
Q – flow rate, l/d
V – working volume of the aerated vessel, l
S_0 – initial substrate, mg /l
S – final substrate, mg/l
τ – hydraulic retention time, d
k – rate constant, d^{-1}
K_S – Monod constant, mg/l
E – treatment efficiency, %
X – biomass concentration, mg/l
$\frac{F}{M}$ – food to microbe ratio, dimensionless
μ_m – maximum specific growth rate, d^{-1}
Y – biomass yield, dimensionless
U – substrate utilization rate, d^{-1}
θ_C – mean cell residence time, d
k_d – endogenous decay coefficient, d^{-1}

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