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Schematic design of particular reactor with the aim of aerobic bacteria decomposition

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Abstract
The wastewater reuse is one of the solutions of sustainable water resources and needs the additional treatment and standardization based on the type of consumption according to the vast range of its environmental pollutants. Nowadays, the biological processes are utilized to treat the industrial wastewater containing the organic materials and it is proved that this method is also effective in the treatment of domestic wastewater. The device is designed and constructed in order to study the effect of various parameters on the performance of reactor. The diluted molasses is used as the feed, and also the additional sludge from the domestic treatment of activated sludge is utilized as the seed sludge. First, the reactor is operated with primary organic load, and then the organic load is gradually increased to reach the better efficiency and stable conditions. The sludge escape was enhanced at the beginning of start up by increasing the organic load, and the use of acne on the surface of chambers reduced the sludge escape and maintained the sludge in the first chamber and increased the output. The increase organic load led to the first granule particles in the 35th day in two first chambers. The size of granules in the first chamber was smaller than the other chambers. The decreased hydraulic retention time (HRT) in constant organic load not only did not lead to the change in suspended solid output, but also the efficiency was increased.

Keywords: Reactor design, bacteria decomposition, aerobic, anaerobic, design parameters.

Introduction
The anaerobic technology to treat the industrial wastewater leads to the development of reactors wherein the speed of organic material decomposition is increased due to the concentration and retention time of sludge [5]. The Anaerobic baffled reactor (ABR) is a new type of anaerobic systems and has two-phase operation. The creation of optimal conditions for microorganisms in each phase and the increased efficiency are among the properties of two-phase systems [13]. The position of blades in the direction of flow in this reactor changes its direction towards up and down and reduces the sludge escape[3]. Due to the multi-part building of reactor, it separates the acid and methane-production phase [9]. However, because of methane production in all chambers, the full separation of phases seems impossible. The first chamber of this reactor can operate as the protection against the toxic substances and thus reduces the effect of these materials in the next chambers. Therefore, the methane-production bacteria, which are susceptible to a large extent, continue to act easily in the next chamber, thereby it leads to the stability of reactor [14].
The reduction of hydraulic retention time (HRT) or increased organic load in these reactors due to the increased amount of gas production leads to the accumulation of fatty acid, drop in pH, and reduced efficiency and this is due to the faster speed of acid-production reaction than methane production [6]. The ratio of BOD_5/COD is a key parameter in biological treatment of wastewater. This ratio can be increased and the appropriate conditions of biological removal and better process performance provided at the next stages of treatment by this reactor for treatment of wastewater with low BOD_5/COD due to the hydrolysis and acid reactions [16]. Despite the fact that the reactor does not require the granular sludge for optimal performance (5), various reports have presented its production in this reactor. The sludge of this reactor has the non-granular form in the primary chambers due to the activity of acid-production bacteria, and granular in the next chambers due to the more activities of methane-production bacteria [1]. The investigation of technical problems in the manufacture and operation of treatment plants by anaerobic method indicates that this type of reactor will be a good choice due to the simplicity in structure and its function, but unfortunately there is no enough experience neither in the research nor the industrial local scales, and there are the some points, which need further research, despite the conducted measures.

Anaerobic treatment process
The aerobic treatment process can be mainly classified into two groups of suspended and attached growth processes which are designed and operated as follows:
- The upward and downward packed bed reactors
- The expanded bed reactor
- The fluidized bed reactor

i. Suspended growth processes
These processes are usually designed and operated as follows:
- Anaerobic reactors with complete mixing
- Anaerobic contact reactor
- Sludge bed reactor with upward flow

Moreover, other models and reforms of anaerobic processes such as the following cases are now applied specifically for treatment of sludge in industrial wastewater:
- Sequencing batch reactor (SBR)
- Anaerobic lagoons
- Membrane smoothers

In practice, the aerobic treatment is done after the anaerobic treatment of wastewater. It has been proven that the strong industrial wastewater treatment by aerobic method is more economical than the aerobic treatment processes. However, the quality of treated wastewater is usually lower in aerobic processes because it has the higher concentration of suspended solids. Furthermore, the anaerobic processes are not suitable for treatment of seasonal flows.

ii. Kinetics of anaerobic digestion

The kinetics of reaction should be known in each process, and the process of anaerobic digestion is also not an exception. For instance, we should know the sludge retention time in digestion machines in order to achieve an effective anaerobic decomposition. The inflow volume and the retention time are both the adequate information to estimate the size of machine and measuring the output speed of materials. The new cells (microorganisms) are also synthesized or produced during the immobilization of organic materials of wastewater. These new produced cells have essentially the organic nature, and thus increase the BOD load in the system both in the form of live and dead cells through contributing in organic part of wastewater. Therefore, different types of microorganisms are utilized to remove organic materials from wastewater during the biological treatment on the one hand, and also the organic solids are added to wastewater in the form of new cells (which are also called the additional microorganisms or extra sludge) during the treatment. Therefore, such these circumstances require maintaining the perfect balanceof biological mass in the wastewater during the treatment. This is usually done by controlling the growth of new cells in the biological system. It is essential to have clear understanding of kinetics of anaerobic digestion for effective control of growth and proper balance of bio-mass in the system.

- Microbial growth rate
- The consumption rate of substrate (organic material or feed)
- Limiting substrate or nutrient which affect the cell growth
- The autophagy decomposition or the death rate of microorganisms in the system

The equation constants, which are obtained from the kinetic equations of high speed ratios, are called the kinetic coefficients or the growth constants. The microorganisms play the complex roles in cultivation of mixture in wastewater treatment because their metabolic activities, the growth rate and substrate absorption are correlated in the body and help each other. Therefore, it is essential to know the microorganisms, which are usually in the wastewater, the types of their metabolism and influence of environmental factors such as the temperature, pH, mixture, necessary nutrients, the partial elements, oxygen, etc on their growth rate as well as their destruction speeds in order to maintain the proper balance og mixture cultivation in biological treatment.

- Specific growth rate (μ)

The rate of increased bio-mass $\frac{dx}{dt}$, is directly proportional to the concentration of bio- mass in the reactor, X, in wastewater treatment system for cultivating the mixture of microorganisms existed in most of the wastewaters, and it is called the proportion factor of specific growth speed constant. The kinetic equation is presented below for such this speed as follows:

$$R_g = \frac{dx}{dt} = \mu X \qquad (1)$$

$$\mu = \frac{dx/dt}{X} \qquad (2)$$

R_g=Growth rate of biomass
μ = Specific growth speed of biomass
$\frac{dx}{dt}$ = Rate of change in biomass
X = Concentration of biomass in reactor

- Loading coefficient

The new cell mass, which is produced for the unit of substrate consumed or removed by microorganisms in system, is now called the cell loading. The kinetic equation for such this coefficient is presented as follows:

$$Y = \frac{\text{Bacterial growth rate}}{\text{Consumption rate of substrate}} = \frac{R_g}{R_{su}} \qquad (3)$$

Y= Cell loading coefficient
$\frac{dx}{dt}$ = Rate of change in biomass
X_t= Biomass concentration at time t
X_0=Biomass concentration at time t
S_0=Input substrate concentration at time t
S□ =Output substrate concentration after time t

The Y value depends on the nature of substrate, the type of microbial species in the system and the temperature. When Y is measured along the top of growth curve (or at the end of period for removing the substrate), the loading is called real. The active biomass in reactor is the sum of all live organisms and is usually expressed in terms of Mixed Liquor Volatile Suspended Solids (MLVSS). However, all MLVSS include the decomposable volatile suspended solids as well as the non-decomposable volatile suspended solids.

- Constant of substrate maximum consumption rate, K

Since most of the experiments have shown that Y is almost constant for pure cultivations and the heterogeneous populations of many wastewater treatment systems, the maximum specific growth rate (μ_{max}) and the cell loading (Y) are considered constant with confidence. Therefore, the $\frac{\mu_{max}}{Y}$ ratio, which is called the constant of maximum substrate consumption rate, is considered fixed. The equation for such this constant is asl follows:

$$K = \frac{\mu_{max}}{Y} (d^{-1}) \qquad (4)$$

K= Constant of maximum substrate consumption rate, $time^{-1}$

μ_{max}= Maximum specific speed of bio-mass growth

- **Half-speed constant, K_s**

The specific speed of growth in microorganisms has the close correlation with the substrate consumption rate, and the pure growth is seen even when the microorganisms are in the hunger conditions in the system. The half speed constant, refers to the limiting concentration of substrate or nutrient in one second maximum growth rate of biomass.

$$\mu = \mu_{max} \frac{S}{K_s + S} \quad (5)$$

μ = Specific speed of bio-mass growth, $time^{-1}$

μ_{max}= Maximum specific speed of biomass growth, $time^{-1}$

S = Limiting concentration of solution substrate or nutrient (7)growth (usually mg/l)

Ks= Constant half-speed or concentration of substrate in one second of maximum specific speed of substrate consumption, mg/l

- **The autophagy destruction coefficient, K_d**

When the substrate concentration, (feed), S, in the wastewater becomes minimal, the microorganisms metabolize their protoplasm (self-digestion), and the concentration of biomass is reduced in the reactor or system due to the death of some cells. This phenomenon is called the autophagy bio-mass destruction. The speed of this biomass destruction is proportional to the remaining biomass concentration. The constant of proportionality, which is the coefficient of biomass destruction is measured as follows:

$$R_d = -K_d X \quad (6)$$

Rd= Speed of autophagy destruction for biomass

Kd= Coefficient of autophagy inhibition

X = Concentration of biomass

The biological processes are usually designed using 5 above-mentioned synthetic biological constants. However, the conditions, under which these constants are determined in design calculations, should be taken into account while including these constants. To design the biological processes, which are applied in specific wastewater treatment, it would be better to determine the kinetic constants in the laboratory.

iii. Main equations of kinetic constant

$$R_g = \frac{dX}{dt} = \mu X \quad (8)$$

$$\mu = \mu_{max} \frac{S}{K_s + S} \quad (9)$$

$$R_g = \mu_{max} \frac{S}{K_s + S} X \quad (10)$$

$$R_g = \frac{\mu_{max} S X}{K_s + S} \quad (11)$$

$$R_d = -k_d X \quad (12)$$

$$R_{d(net)} = \mu_{max} \frac{S}{K_s + S} X - k_d X = Y \frac{K \times S}{K_s + S} - k_d X \quad (13)$$

$$R_{su} = -\mu_{max} \frac{XS}{Y(K_s + S)} \quad (14)$$

$$K = \frac{\mu_{max}}{Y} \quad (15)$$

$$R_{su} = \frac{K \times S}{K_s + S} \quad (16)$$

Designing the system and design considerations

The additional sludge of treatment plant located in the West Tehran reactor is used for germination reactor. The dilution with water is initially done for preparing the sludge, and then an amount of molasses is discontinuously added for adaption of bacteria to new environment. This period lasts about 3 months. Before transferring this sludge to inside the reactor, we should separate the coarse and waste materials, thus the prepared sludge is passed through a sieve with pores of a millimeter. The amount of suspended solids (SS) is determined equal to 59g/l and the value of its VSS equal to 35g/l. The raw molasses produced in sugar plant is utilized to produce the COD. The dilution of raw molasses is done in 1000-L reservoir for production of feed with different CODs. To control the pH and alkalinity of soda and sodium bicarbonate and the control of COD:N:P ratio according to 350:5:1, the phosphate fertilizer and urea are utilized as the source of nitrogen and phosphorus, and also the micronutrients are applied such as zinc, cobalt, nickel, iron, molybdenum and copper. The main factors, which should be considered in designing the anaerobic wastewater treatment, are as follows:

- Type and quality of wastewater: Despite the fact that the anaerobic treatment of domestic wastewater with low power has been more common, it is more suitable for treatment of industrial wastewater. The wastewater with low COD or BOD does not usually produce enough methane gas in order to be used economically as an energy source.
- Optimal efficiency: The treatment for wastewater treatment with high intensity of pollution with optimum efficiency for more removal of organic materials and wastewater production with low concentration of suspended solids will be achieved when a purification system includes the anaerobic treatment and then the aerobic treatment.
- The changes in the flow and concentration of organic materials: The fluctuations in the wastewater flow and changes of their organic material concentration can disrupt the balance between the methane production and formation of acid and affect the function of system.
- Temperature and Ph conditions: The system is usually at the range of mesophilic temperatures from $25^{\circ}C$ and $30^{\circ}C$ and has the neutral pH range. The reduced pH may prevent the Methane production or affect it.
- Nutrients and partial elements: The optimal concentrations of essential nutrients such as nitrogen,

phosphorus, sulfur, etc should be within the ratio of 50: 5: 10 (Mg/l 50: 5: 10 = N: P: S) and partial elements such as iron, copper, nickel, zinc, etc in the wastewater.

- The toxic compounds: The concentration of toxic compounds, which prevent the growth of necessary microorganisms, should be less than or within the specified limits. The concentration of these elements is determined by investigating the proper treatability and analysis in the laboratory.
- Methane gas production: If the system is designed for methane gas production for using as the source of energy, the amount of methane production is important for converting each BOD or COD unit or each unit of decomposed VSS. 3501 Methane is usually produced from the fixation of each 1 kgCOD in STP.

The volume of reactor is voluntarily considered equal to 5 liters for designing a semi-industrial reactor in batch mode, and then the calculations are done on it. The reactor dimensions can be designed according to the current standard for tank reactors.
The partial mass balance for benzene around the reactor:

$$(-r_A)V = \frac{dN_A}{dt} \quad (17)$$

By integrating and simplifying the equation above, for reaction time inside the reactor, we will have:

$$t_R = \frac{1}{k}\ln\frac{1}{1-x} \quad (18)$$

i. Designed system

The active volume of this reactor is equal to 600 liters and its dimensions of 122 cm long, 45 cm wide and 120 cm high. The sampling sites include one in a distance of 8 cm from the floor and the other on the surface of wastewater for each chamber. The produced gases are gathered at the top of reactor and can be transferred into the outside by a pipe. The overall scheme of this pilot is shown in Figure 1.
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A converter device of electric element is applied for adjusting the temperature of wastewater input to a reactor. The control of input flow temperature is done by a thermostat with precision of 1 °C.

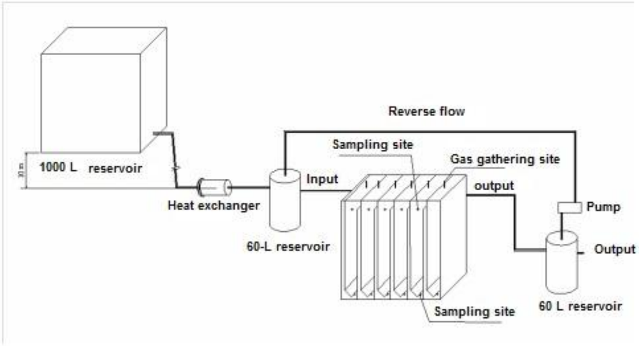

Fig.1. Pilot elements and flow path

Reducing the effective hydraulic retention time in constant organic load

We retain the input organic load and the upward speed of liquid is increase and the hydraulic retention time reduced to 15 hours by retaining the acnes in chamber. In this case, the efficiency of removing the COD is obtained about 86% to 92% and the efficiency of BOD removal in the reactor about 95%. These results also indicate that about 55 percent of input COD is removed in the first chamber at a retention time of 2.5 hours. According to the Figure 4, the reduced hydraulic retention time of COD removal efficiency is partially reduced in the first chamber, but the overall efficiency increased and this indicates that the remaining COD is removed in the next chambers. According to the Figure 2, the efficiency is increased in the last chambers and this can be due to the increase in the fluid velocity.

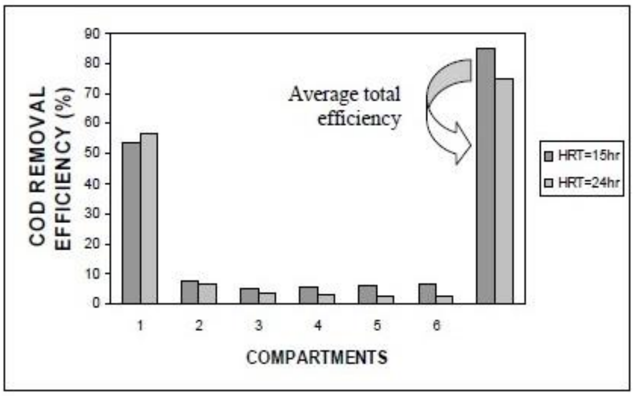

Figure 2. The COD removal efficiency in chambers at various retention times

Lower gases are produced in the last chambers compared to the first chamber and the integration of gas substrate is lower and the channelization of flow is more than the first chamber. Therefore, the flow channelization is reduced by enhancing the speed. According to the figure 3, the amount of output suspended materials is increased at the beginning of retention time change at (h15 = HTR (Kg COD/m3.d5) and then its amount is gradually reduced by 130 mg/l during the operation time of reactor. By increasing the speed of liquid, the sludge with the velocity of less than the growing speed of fluid, becomes volatile and the amount of output suspended solids increased.

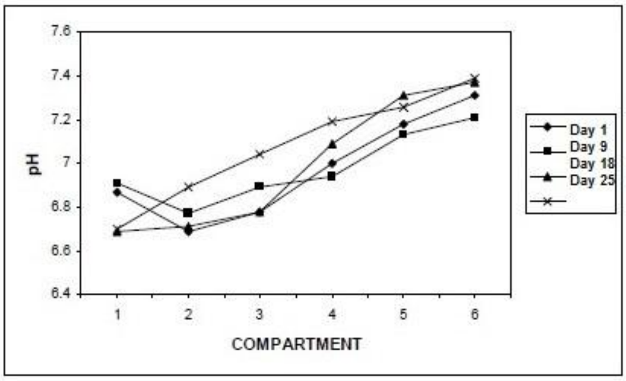

Figure 3. Comparison of suspended output solids

According to Figure 4, the pH in the first chamber is higher than the second chamber in the first days of upward fluid velocity variation. This data indicates that a part of acid production reaction is done in the second chamber. The reduced retention time decrease the contact time between the sludge and input wastewater and the amount of acid production decreased in the first chamber and the remaining acid produced in the second chamber. Furthermore, the increased speed of liquid will lead to the escaped biomass from the first chamber towards the second chamber. The pH is reduced in the first chamber and gradually increased in the next chamber after reaching the steady state of system, thus the phase separation is completely done. Furthermore, the multi-part design of reactor creates a neutral zone between the acid and methane production phases, and thus the methane producers will not be exposed to the low pH during the organic shock.

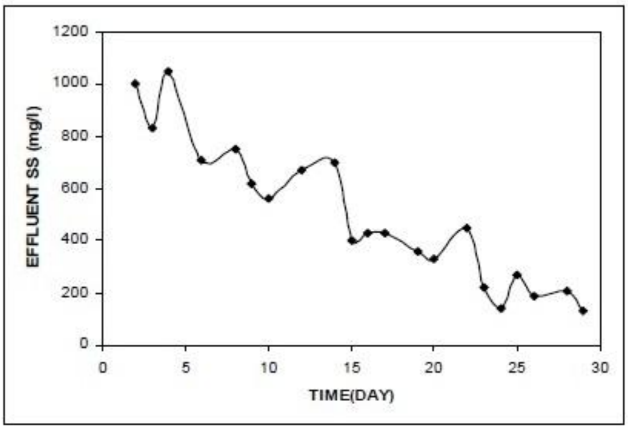

Figure 4. pH display in output of different chambers

Summary and conclusion

A mixture of populations of microorganisms, which naturally exist in the wastewater, can use the decomposable dissolved and colloidal organic materials as their foods for growth and reproduction. Therefore, the wastewater is generally treated by more biomass for removal of colloidal and dissolved solids from the initial treatment wastewater. This wastewater treatment is called the secondary treatment and since it usually uses the biological process, it is called the biological wastewater treatment.

The biological wastewater aims at integrating and separating the colloidal non-settling material and stabilizing the organic materials. The main objective of urban wastewater is to reduce the organic materials and the nutrients such as nitrogen and phosphorus in most of the cases. In anaerobic digestion, the substrate involved in anaerobic microorganisms is converted into alcohol and acid, and finally as mentioned to methane and carbon dioxide. In addition to removal of microbes without the presence of oxygen in anaerobic treatment, methane gas is produced which is an important part of treatment.

The short retention time will intentionally lead to the sludge escape. In this case, the application of acne is effective for maintaining and retaining the sludge in the chambers and increased efficiency particularly in the first chamber. The increased rate of liquid in constant organic load due to the escape of sludge from the first chamber reduces the efficiency of removal in the first chamber, but leads to the increase in overall efficiency. The reactor at constant hydraulic retention time is sustainable than the gradual changes in organic load.

The efficiency of first chamber is increase by enhancing the organic load. The reduced hydraulic retention time due to the low acid-production activity in the first chamber and its increase in the second chamber lead to pH in the first chamber compared to the second chamber and the pH is gradually increased from the first to the last chamber after reaching a steady state. Any shock to the reactor affects the sludge of first chamber and this chamber acts as a protective for sludge of the next chamber particularly the methane producers.

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