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A Comparative Study of the Activated Sludge Process and Trickling Filter to Identify the System Requiring the Least Area of Land

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Abstract
The rising cost of land across the globe has led to economic problems. One of the challenges brought by the high land price is constructing wastewater treatment systems with a small footprint. This paper compares the design of two domestic wastewater treatment systems, the activated sludge process (ASP) and trickling filter (TF), to determine which design requires the least area of land. The conventional activated sludge process design used the ASP equation, and the TF design used Rankin's method. The results showed that both systems have good removal efficiency. The ASP has a surface area of 3864 m^2, and the surface area for the TF is 5000 m^2. Therefore, the ASP is the better alternative when constructing a wastewater treatment system on a small land area.

Keywords: Activated Sludge, Trickling Filter, Wastewater Treatment Plants, Biological Oxygen Demand.

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دراسة مقارنة بين نظام الحمأة المنشطة ومرشحات التنقيط لمعرفة أي الأنظمة يتطلب مساحة أرض أقل

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الملخص

أدى ارتفاع تكلفة الأراضي في جميع أنحاء العالم إلى مشاكل اقتصادية. أحد التحديات الناجمة عن ارتفاع تكاليف الأراضي هو بناء أنظمة معالجة مياه الصرف الصحي ذات مساحة صغيرة. هذا البحث يقارن بين تصميم نوعان من أنظمة المعالجة، نظام الحمأة المنشطة (ASP) ونطام مرشحات التنقيط (TF) لإيجاد أي النظامين يتطلب أقل مساحة. تم استخدام المعادلات الخاصة ل ASP وذلك لتصميم نظام الحمأة النشطة واستخدم طريقة رانكين لتصميم نظام TF. أظهرت النتائج أن كلا النظامين لهما كفاءة إزالة جيدة. اما بخصوص المساحة لكل منهم فقد بلغت المساحة السطحية المشغولة بنظام (ASP) 3864 m^2 ومساحة (TF) 5000 m^2. بناءً على ذلك يمكن القول إن نظام الحمأة المنشطة ASP هو أفضل خيار عندما يتطلب الأمر بناء محطة معالجة مياه صرف صحي على مساحة صغيرة من الأرض.

الكلمات المفتاحية: الحمأة المنشطة، مرشحات التنقيط محطات معالجة مياه الصرف الصحي، متطلب الأكسجين الحيوي.

1. Introduction

Domestic wastewater, also known as municipal wastewater, sanitary wastewater or sewage, is the used water discharged from the residential, commercial and institutional zone of cities, towns or communities and collected through the sewerage system. Occasionally, small industries discharge partially treated liquid wastes into sanitary sewers, which mix with domestic wastewater. Generally, domestic wastewater contains organic and inorganic

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solids and microorganisms, primarily bacteria. The wastewater composition depends on the source of its generation, where domestic wastewater is generally 99.9% water and 0.1% solids (Kou et al., 2022; Karia et al ., 2023). Microorganisms reduce or remove the solids component of wastewater. The primary wastewater treatment methods are the suspended growth process (for example, activated sludge process, aerated lagoon, oxidation pond, and aerobic and anaerobic digester) and attached growth process (for example, trickling filter, rotating biological contactors, bio towers and up-flow filter). These wastewater treatment plants remove floating materials and inorganic and organic solids from domestic wastewater (Karia and Christian, 2016)

People need water of the best quality for their daily lives, and because of this, water quality has been receiving global attention. Treated water is essential to ensure safe consumption by humans and other living things. There is also an urgent need to construct better and more compact wastewater treatment systems. The cost and availability of land and the implementation of secondary treatment standards have given rise to the demands for wastewater treatment plants with small footprints that produce effluent with high standards while fulfilling the requirement for waste minimization. The increase in the wastewater flow and organic loading due to the population increase led to the need for large sewage treatment plant (STP) for treating organic wastewater pollutants, which has given rise to economic problems (Shahot et al., 2021)

The suspended growth process is primarily an aerobic activated sludge process, which maintains a high microorganism population (biomass) by recycling solid from a secondary clarifier. Even though this process ensures similar biological metabolism in removing carbon and other substances in biofilm attached growth and suspended growth systems, there are some distinct advantages and disadvantages to using a biofilm system. The fundamental difference is in assembling the biomass, substrate and oxygen. In the suspended growth system, the effluent from the settling tank and activated sludge are combined in a reactor container through aeration to introduce oxygen and allow contact between the substrate and the microorganisms. The liquid flows to a settling tank, which removes the microorganisms and discharges the

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effluent (Li, 2019). In the biofilm or fixed film (attached growth) process, microbial growth occurs on the surface of stones or plastic media. The higher surface area of the biofilms allows the wastewater to pass over the media and increases the amount of the substrate adsorbed from the influent. As the film builds up, it provides a diverse habitat for transforming the wastewater constituents, such as the carbon and nitrogen components. The aerobic, anoxic and anaerobic mechanisms may occur in individual biofilms, and the limiting substrate is altered by the biofilm thickness. This process shows the complexity of modelling fixed-film processes (Shahot, 2017; Aziz and Sazan, 2015; Shahot and Ahmed, 2012; Shukla and Ahammad, 2022). Conducted a study to compare the performance of a conventional activated sludge process (ASP) with a modified trickling filter (MTF) for urban sewage treatment. The MTF (2 h hydraulic retention time HRT with effluent recycling) and ASP (8 h hydraulic retention time (HRT) showed >60 % removal efficiency for COD, NH_3-N and PO_4^{3-}-P. The MTF showed better performance than the ASP in denitrification, where 5 mg/L of NO_3^--N was detected in the effluent of MTF.

This study compares the activated sludge process with the trickling filter to design an STP for a city with 50 MLD (million letter per day) to determine which system uses less land area given the high price of land in the present day.

2. Material and Methods

2.1 Activated Sludge Process

The activated sludge process is a type of biological wastewater treatment process for treating sewage or industrial wastewaters using aeration and a biological floc composed of bacteria and protozoa. It is one of several biological wastewater treatment alternatives in secondary treatment, which deals with the removal of biodegradable organic matter and suspended solids (Metcalf and Eddy et al., 2014). Figure 1 shows the schematic diagram of an activated sludge process.

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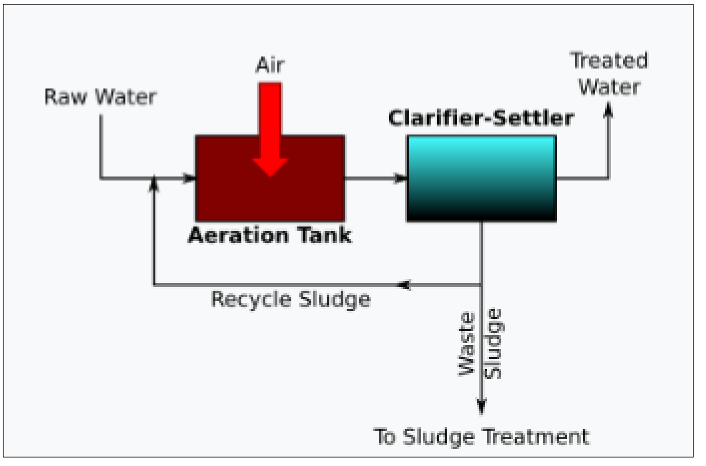

Fig 1. Schematic Diagram of an Activated Sludge Process

2.1.1 Design Criteria

- Side water depth, SWD $= 3 - 4.5\ m$
- L: B $= 2:1\ up\ to\ 6:1$
- B: D $= 15:1$
- HRT$= 4 - 12\ hrs$
- SRT $= 10 - 15\ days$
- MLSS $= X = 1000 - 3000\, mg/L$
- Volumetric loading $= 300 - 600\ kg\ BOD_5/1000\ m^3.d$
- Volume of the tank

$$V = \frac{\theta_c Y Q (S_0 - S_e)}{X[1 + K_d \theta_c]}$$

Where $Y = 0.6\ \ and\ \ K_d = 0.06$ are constants

2.2 Trickling Filter

A trickling filter is a type of wastewater treatment system. It consists of a fixed bed of some material, such as rocks, coke, gravel, slag, polyurethane foam, sphagnum peat moss, ceramic, or plastic media, over which sewage or other wastewater flows downward and causes a layer of microbial slime (biofilm) to grow, covering the bed of media (Karia and Christian, 2016) . Figure 2 shows trickling filter

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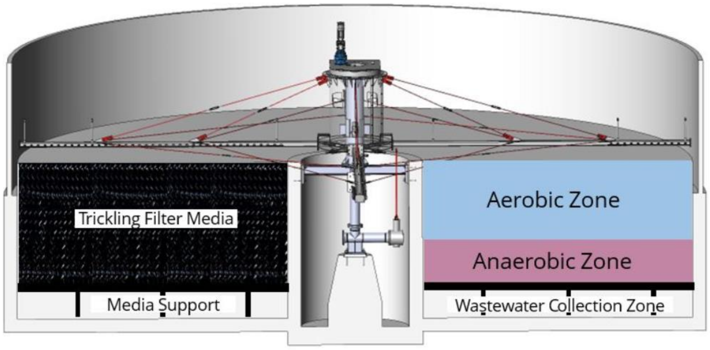

Fig 2. Trickling Filter

2.2.1 Design Criteria

The following sets of equations were developed for the performance of high rate filters.

- For a single-stage high rate TF system, the equations are as follows:

$$S_e = \frac{S_i}{3 + 2R_1}$$

And

$$E_1 = \frac{1+R_1}{1.5+R_1}$$

Where:
S_i = concentration of settled influent Biological Oxygen Demand (BOD) to filter, mg/L
S_e = concentration of settled filter effluent BOD, mg/L
R_1 = recirculation ratio
E_1 = efficiency of filter expressed in fractions

3. Results and Discussions

The city has to compare the surface area of two STPs with an average flow of 50 MLD and 200 mg/L influent BOD_5, 30 mg/L desired effluent, 200 mg/L suspended solid influent and 20 mg/L effluent.

3.1 Activated Sludge Process

Compute Soluble Effluent BOD_5

BOD_5 in the effluent due to microorganisms (biological suspended solid) S_{ss}

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$$\therefore\ S_{ss} = 0.80 \times 20 \times \frac{1.42}{1.47} = 15.46\frac{mg}{L}$$

$$\therefore\ soluble\ effluent\ BOD_5\quad S_{sol} = 30 - 15.46 = 14.54\ mg/L$$

Compute the volume & the surface area of the tank
Assuming $\theta_c = SRT = 10\ days\ and\ X\ in\ the\ tank = 2000\ mg/L$
Applied in equation 1, therefore, the volume equal to $= 17387\ m^3$
As we need smallest surface area,
Thus assuming SWD= $4.5\ m$

Compute the dimension of the tank
Provided 2 units

$$\therefore\ Area\ of\ one\ unit = 3864/2 = 1932\ m^2$$

Assuming L: B $= 6:1$
So, the width $B = 18\ m\ \&\ the\ length\ L = 108\ m$
(Acceptable as$< 150\ m$)

Therefore, Reaction tank size = 108 (L)× 18 (W) × 4.5 (D)

$$\therefore\ The\ Surface\ Area\ of\ the\ Tank\ \ A = 17387/4.5 = 3864\ m^2$$

Design Checks

1. **FOR HRT**

$$HRT = \frac{V}{Q} = \frac{17387\ m^3}{50000\ m^3/d} = 0.347\ day = 8.34\ hrs$$

$(acceptable\ as\ between\ the\ ranges\ (4 - 12\ hre)$

2. **FOR VOLUMETRIC LOADING**

$$\text{Volumetric Loading} = \frac{(200-14.54)\times 50\ MLD}{17387} = 0.533 kg/m^3.d = 533.32\ kg/1000\ m^3.d$$

Acceptable as between the range (300−600) $kg/1000\ m^3.d$

3.2 Trickling Filter

Now, as the maximum treatment efficiency of a single TF is normally not more than 85%. Therefore, we would adopt a one-stage (high rate) TF system.

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Compute the total BOD load applied to the filter
BOD load applied is

$$S_i \times Q = 200\ (\mathrm{mg/L}) \times 50\ \mathrm{MLD} = 10000\ \mathrm{kg/d}$$

Determine recirculation ratio

$$E_1 = \frac{1 + R_1}{1.5 + R_1}$$

$$\therefore\ \frac{200 - 30}{200} \times 100 = \frac{1 + R}{1.5 + R}$$

$$\therefore R = 1.83 \approx 2$$

Compute the volume of the filter, V
Assuming organic loading rate as 1kg BOD/m³.d

$$V = \frac{BOD_5\ applied\ per\ day\ (kg/d}{organic\ loading\ (kg/m^3\,.\,d)}$$

$$V = \frac{10000\ (kg/d)}{1\ (kg/m^3\,.\,d)} = 10000\ m^3$$

Compute the surface area then the diameter of the filter (d)

$$A_s = \frac{V}{h} = \frac{10000}{2} = 5000\ m^2$$

$$\therefore d = 79.78\ m \approx 80\ m$$

Design Checks

1. **Check for Hydraulic Surface Loading with Recirculation**

$$\text{Hydraulic Loading} = \frac{(Q + Q \times R)(m^3/d)}{A_s\ (\mathrm{m^2})}$$

$$= \frac{(50000 + 50000 \times 2)(m^3/d)}{5000(\mathrm{m^2})} = 30\ m^3/m^2.d$$

(Accepted as less than permissible limit 0f 40 $m^3/m^2.d$) (Karia and Christian, 2016)

Based on the results, both treatment systems are appropriate for a high flow rate of 50 MLD. Both treatment systems showed good

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design checks; for example, the hydraulic loading of the trickling filter is 30 $m^3/m^2.d$, which is between the 10-40 $m^3/m^2.d$ required by the design criteria. The hydraulic retention time and volumetric loading for the activated sludge process are 8.32 hours and 533 kg/m^3/d. Both parameters are within the permissible value of 4-12 hours for HRT and 300-600 kg/m^3/d for volumetric loading. The BOD_{in} is 200 mg/L, and the BOD_{out} is 30 mg/L. Thus, both systems have a removal efficiency of 85%, and since the efficiency did not exceed 85%, this will adopt a one-stage (high rate) TF system instead of the two-stage requirement stated in the design criteria. AS has a surface area of 3864 m^2, and TF has 5000 m^2, which saves 1136 m^2 or almost 23 % of the land area when using the activated sludge system. The footprint (horizontal dimension) of the activated sludge process system is small compared to the trickling filter system, which minimizes the required land area. Figure 3 illustrates the footprint or land area required by the activated sludge system vs the trickling filter system. Based on the results, adopting the ASP can reduce the land area and buffer by about 23%. Therefore, ASP offers more advantages in terms of space. Many researchers (Sadri, and Mesghali,2023; Shahot et al., 2014;Liu et al., 2022; Shukla, and Ahammad, 2023) reported that AS and TF typically have an efficiency of over 80 %. Therefore, using a small land area does not pose any issue as long as the efficiency is higher than 80%.

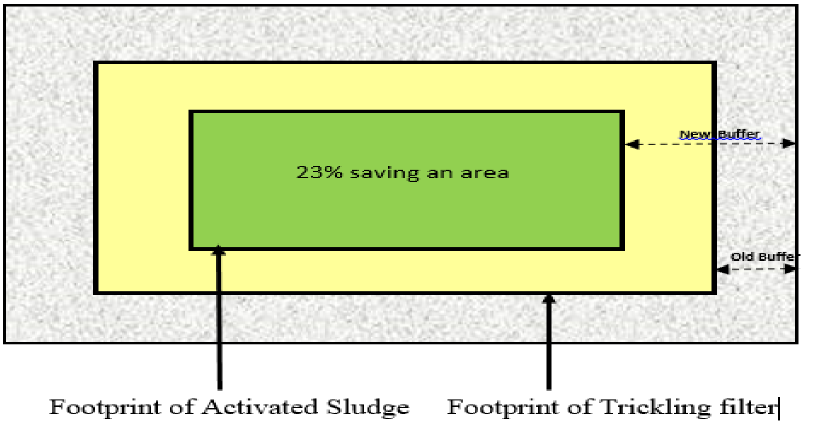

Fig 3: Activated Sludge Footprint and Trickling Filter Footprint

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4. Conclusions

This study compared the designs of two systems, activated sludge and trickling filter, to determine which system requires less land area. The calculations showed that the activated sludge process requires 3864 m^2 land area, and the trickling filter requires 5000 m^2, which means that the ASP uses 1136 m^2 or about 23% less land area. This finding has significant implications for the actual treatment plants since ASP is the more viable system when there is a requirement for a smaller land area and compact wastewater treatment system without compromising efficiency.

There are some future recommendations that could be considered when small land area is needed such as studying the area of rotating biological contactor (RBC) and moving bed bioreactor (MBR) and finding which better alternative when constructing a wastewater treatment system on a small land area.

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