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RESEARCH PAPER

Kinetic Characteristics and the Performance of Up-Flow Biological Aerated Filters (UBAF) for Iraqi Municipal Wastewater

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ABSTRACT

This study utilized kinetic models to study the treatment efficiencies of a laboratory-scale up-flow biological aerated filters reactor (UBAF). The treatment efficiency of a model reactor was studied using different operating conditions of the hydraulic retention times, organic loading rates, and kinetic parameters. As a result of the calculations, the second-order and modified Stover/Kincannon models are appropriate. The substrate removal rate constant $K_{2(S)}$ was 1.7 per day for the reactor, with a correlation coefficient of 0.9979. Utilizing the modified Stover/Kincannon model, the coefficient of the determined concentration was 0.9987; 0.9265; and 0.9685 for Chemical oxygen demand (COD); ammonium nitrogen (NH_4^+-N); and Total Nitrogen (TN), respectively. The calculation of the saturation value constants and maximum utilization rate for Chemical oxygen demand (COD); ammonium nitrogen (NH_4^+-N); and Total Nitrogen (TN) was performed using the modified Stover-Kincannon model were 178.57 and 201.80 for COD; 1.876 and 4.6 for NH4 $^+$-N; 3.823 and 6.644 for TN, respectively. It is possible to determine the kinetic parameter for removing COD, NH_4+-N, and TN from wastewater by using the modified Stover-Kincannon model.

Keywords: Domestic wastewater, Kinetic constant, second-order model, Removal efficiency, Kinetic modeling, Stover-Kincannon model

INTRODUCTION

A significant problem facing the world today is environmental pollution that needs to be deal with due to population growth, urbanization, climate change, and industrialization (K. R. Kalash & Albayati, 2021; Pramanik et al., 2012). Wastewater is considered one of the most significant waste streams that discharge a massive amount of polluted water into the environment(K. R. Kalash et al., 2019).

The conventional biological treatment process is reliable for removing nutrients and organic matters in wastewater. However, treatment capacity, efficiencies, stability, and space requirements are present(K. R. Kalash & Albayati, 2021). Many toxic compounds were discharged into the environs due to various industrial activities(Kadhom et al., 2019; K. Kalash et al., 2020). They can harmfully affect public health and the environment(Al-furaiji et al., 2021). In addition to lower operational costs, the biological treatment process should be compact and stable. At the same time, it reduces noise and odor and generates high performance (Pramanik et al., 2012). Therefore, emergent technologies for wastewater treatment have attracted significant attention worldwide (Nga et al., 2020; TA, 2015). For aerobic wastewater treatment, fixed-film biological processes are getting more and more attention (Raj & Murthy, 1999).

New types of wastewater treatment plants utilizing biofilm reactors are compact, capable

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of being installed for wastewater treatment with comparatively low impacts (Sperling, 2007).The two types of growth in bioreactors are suspended and attached growth. The attached growth occurs when microorganisms adhere to support materials to form biofilms. The suspended growth occurs when microorganisms are suspended in suspension (V. Lazarova; J. Manem, 1995). On the other hand, both types of treatment involved gram-positive, and gram-negative bacteria can form biofilms. Still, the most common forms are Heterotrophic bacteria, fungi, Enterococcus faecalis, holozoic protozoa, E. coli, rotifers, nematodes, worms, and insects (Chen et al., 2013; N.F.Gray, 1999). This type of reactor has many advantages: high removal efficiency and The organic loading rate is high, hydraulic retention time is short, and sludge retention time is long (Nga et al., 2020; Tandukar et al., 2007; Zhou et al., 2015).

The Biological aerated filters (BAF) system with an attached growth process can allow secondary treatment of municipal and industrial wastewater (Büyükkamaci & Filibeli, 2002; Zhou et al., 2015). BAF is comparatively easy to operate, compact, and has efficiencies greater than activated sludge systems, especially carbonaceous and ammonia removal (Ha & Ong, 2007; Salih et al., 2020). The term BAF refers to combining the activity of the air with the filtration action of bacteria. The basic concept of the BAF is the same as the operation of a conventional bio-filter running in a submerged type.

Traditionally, It is a submerged sewage treatment reactor that utilizes a deep filtration system to combine toxic biological treatment and biomass separation to eliminate pollutants in the sewage (Abyar et al., 2017; Hua et al., 2017; Jianlong et al., 2000). As a result of the medium, the reactor can act as a deeply submerged biofilter that can effectively handle suspended solids of all kinds (Hassani et al., 2014).

Mathematical modeling has many benefits, including designing specific unit operations, optimizing and controlling wastewater treatment processes, and helping in understand the underlying biological and transportation mechanisms causing problems. Numerous mathematical models have been developed for biological processes, such as the model of Monod, the First and Second-Order kinetic, and the Stover/Kincannon. The literature provides numerous examples of such models (Büyükkamaci & Filibeli, 2002).

The reactor in this study was studied using various mathematical models, including the Monod model, the first-order kinetic model, the second-order kinetic model, and the modified Stover/Kincannon model. The result is that hybrid reactors can be designed using these models. According to calculations, the models that used second-order and modified Stover/Kincannon is the most applicable designating the system in this paper.

MATERIALS AND METHODS

This study involved the development of a model laboratory reactor. The reactor's design consists of the media held in the upper part of the reactor. The reactor is made from PVC, a cylindrical shape with a height of about 1.80 meters and an inner diameter of 0.30 meters, with a volume of 30 L. The up-flow mode is selected with the aeration introduced at the bottom of the reactor. The reactor was occupied with 40% plastic polyethylene carriers with a density of 170 kg/m^3 and was used as a filter for biofilm growth and attachment. With cylindrical tubes with a height of about 0.8 cm and an internal diameter of 1cm, it has a cross-support specific surface area of 1,028 m^{2}m^{-1}. In this study, the reactor involves contact between solid and liquid in a single piece of equipment. Focusing on the airlift pump inside the reactor secures the oxygen needed for the decomposition process and ensures an adequate effluent flow through the biofilter. The airlift bioreactors offer well mixing than bubble column reactors. The airlift bioreactors provide a configuration of a better degree of stability to liquid flow associated with bubble columns. Therefore, higher gas flow rates can be used without incurring operating problems like spray formation. A simple blower supplies the air necessary for the operation. The typical air employed is injected into the central riser of the Bioreactor; this makes the desired flow and recirculation within the reactor. Lastly, the air moves sludge around the plant, a design feature that eliminates mechanical pumps wherever possible. Figure (١) shows a schematic diagram of the reactor model. First, experiments were conducted with a hydraulic retention time (HRT) of 0.833, 0.416, and 0.277 days. The BAF reactor was operated for about 30 days at a natural HRT of 0.833 day until steady-state removals of COD, NH_4^+-N, and TN at values of 86-95%, 42-66%, and 51-73%, respectively, before the operating condition were varied. The flow rates used were 25, 50, and 75 mL/min, as shown in Table 1. The airflow rate was at 8 L/min, keeping a 6.5- 7 mg/L of (DO) dissolved oxygen concentration in the reactor.

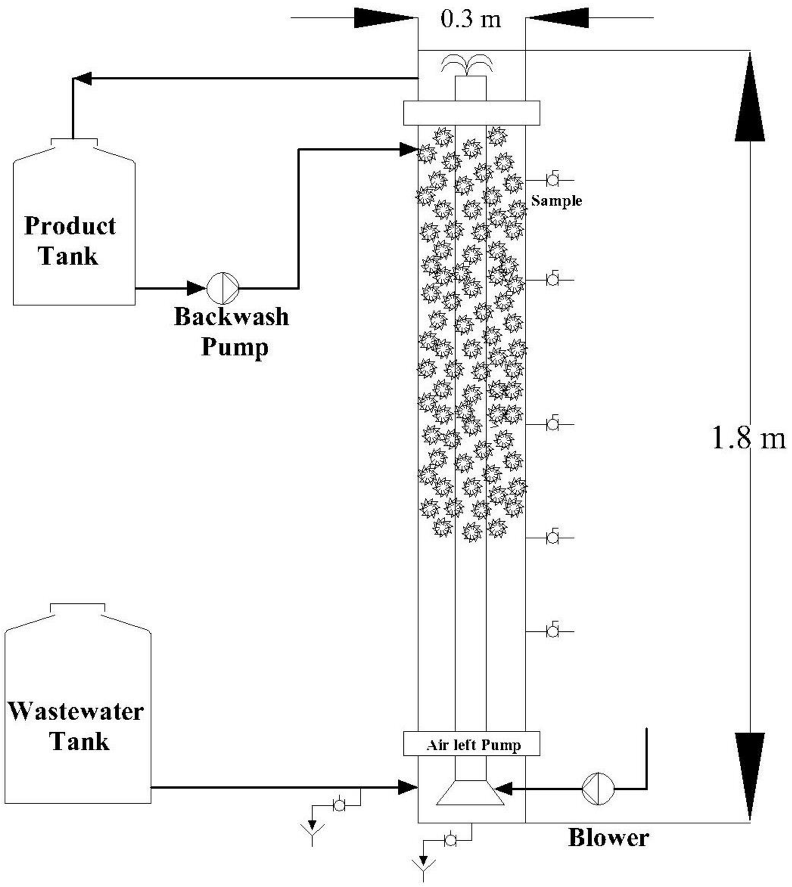

Fig 1. diagrammatic representation of the reactor model UBAF system.

The influent wastewater characteristics to the reactor were as follows: the biological oxygen demand BOD_5 ranged from 250 to 300 mg/L; the Chemical oxygen demand (COD) contented reached from 500 to 600 mg/L, and the mean total nitrogen (TN) concentration was reached from 39.4- 46.2 mg/L; ammonia nitrogen (NH_4-N) concentration was reached from 32.8-37.9; the pH value was 6.9–7.8. The water temperature was around 27 ^oC. According to Standard Methods, the COD, TN, and NH_4-N were measured using a (UV-vis) spectrophotometer (DR-3600, Germany).

Seed sludge in this study is activated sludge from a wastewater treatment facility's secondary settling basin from the formation of biofilms in the Bioreactor. With seed sludge diluted with water, 3,000 mg/L of mixed liquor suspended solids (MLSS) were obtained. MLSS was pumped and recycled continuously over the reactor to form biofilms on the media. Biofilms were consistent within the material during this step, and the effluent quality was stable.

Kinetic modeling is an essential means of investigation for reactor performance prediction. The modified Stover-Kincannon model is one of the most commonly used methods for identifying kinetic constants in stationary systems. It was used to design a model to simulate the continuous treatment of wastewater from dairy using trickling filters (Raj & Murthy, 1999), anaerobic hybrid reactor (Büyükkamaci & Filibeli, 2002), and treatment of municipal sewage by submerged biofilters(González-Martínez et al., 2000). Stover-Kincannon's kinetic model was used in this study to analyze COD removal in an Up-flow aerobic reactor.

At steady state, the substance removal rate in Stover–Kincannon based on the organic loading rate, models are considered as in formulas of Eq. (1) And Eq. (2) (Kapdan, 2005; Nga et al., 2020):

$$\frac{ds}{dt} = \frac{Q}{V}(S_i - S_e) \tag{1}$$

$$\frac{ds}{dt} = \frac{U_{max}\left({}^{QS_i}/_{V}\right)}{K_B + \left({}^{QS_i}/_{V}\right)} \tag{2}$$

Where

ds/dt = removal rate of the substrate (g / L. day).

KB = Constant of saturation (g / L. day).

V = Active volume of the reactor (L).

U_{max} = Constant maximum rate of utilization (g / L. day).

Q = volumetric flow rate (L / day).

In addition to two equations (1), (2), Eq (3) must be amended to reflect the inversion of removal rate of the substrate as a result of in-linearization. The last two Eq. are written as follows:

$$\frac{ds}{dt} = \frac{V}{Q(S_i - S_e)} = \frac{K_B}{U_{max}} * \frac{V}{QS_i} + \frac{1}{U_{max}} \tag{3}$$

The linear relationship is inverse between the total loading rate V/ (QSi) and V/Q(Si-Se). The slope and the intercept of this straight line are K_B/U_{max} and $1/U_{max}$.

When influent substrate concentration and organic loading rate are given, Using Eq. (4), we can calculate the effluent substrate concentration after obtaining the kinetic constants K_B and U_{max}.

$$S_e = S_i - \frac{U_{max} S_i}{K_B + \left({QS_i}/{V} \right)} \tag{4}$$

Furthermost, reactions in wastewater treatment and the thought of their kinetics are significant. The rate of reaction r is the term used to denote a chemical or species constituent (Debik & Coskun, 2009; N.F.Gray, 1999).

The first-order reaction has a reaction rate directly proportional to the reagent concentration.

The variation of substrate concentration rate can be demonstrated as:

$$\frac{-ds}{dt} = \frac{QS_i}{V} - \frac{QS_e}{v} - K_1 S_e \tag{5}$$

Subsequently, the (– ds /d t) is insignificant under pseudo-steady-state, so the Eq. (5) can be revised as:

$$\frac{S_i}{S_e} - 1 = K_1\ HRT \tag{6}$$

Where: S_e effluent concentrations and S_i influent concentrations (mg/L); k_1(S) represent the substrate removal rate constant.

The second-order reaction has a reaction rate proportional to the square of the reagent concentration(N.F.Gray, 1999). The second-order model is the most commonly used to define the kinetic constants in wastewater systems(Grau et al., 1975). The second-order model was established for wastewater treatment systems and contained parameters measured on a routine basis(Debik & Coskun, 2009).

As shown below, this model has the following equation (Büyükkamaci & Filibeli, 2002)(Doh & Chudoba, 1975):

$$\frac{-ds}{dt}\ K_{2(s)} x \left(\frac{S_e}{S_i} \right)^2 \tag{7}$$

As a result of linearizing and integrating Eq. (7), will be obtained:

$$\frac{S_i \theta}{(S_i - S_e)} = \theta + \frac{S_i}{K_{2(s)} x_o} \tag{8}$$

For the right part, the second term can be considered A constant, Eq(8) will be obtained,

$$\frac{S_i \theta}{(S_i - S_e)} = A + B\theta \tag{9}$$

The given constant: -

A = Si/ (K2($_S$) Xo).

B = larger than unity.

It is suggested that (S_i/S_e)/S_i represents substrate removal efficiency (E). As a result, you can write Eq. (9) in the following way:

$$\frac{\theta}{E} = A + B\theta \tag{10}$$

Where: -

S_e effluent concentrations and S_i influent concentrations (mg/L); X is the biomass concentration (mg VSS/L), and $k_{2(S)}$ represents the constant of substrate removal rate.

The model of Monod determines the substrate utilization rate (U) based on Se effluent, in which substrate consumption is proportionate to cell growth(Abyar et al., 2017). The formulation is given below:

$$r_{su} = \frac{KS_e}{K_s + S_e} X \tag{11}$$

where r_{su} is substrate utilization rate (g / L. day), X and S_e refer to the biomass concentration (g/L) and effluent substrate concentration (g/L), respectively.

Eq. (11) linked the r_{su} with U = r_{su}/X and simplified it as Eq. (12):

$$\frac{1}{U} = \frac{K_s}{K}\frac{1}{S_e} + \frac{1}{K} \tag{12}$$

Where: U is the specific substrate utilization rate.

RESULTS AND DISCUSSION

Table 1. Lists the results of several experiments conducted during the investigation.

Table 1: The results of experiments under-investigated operational conditions

Run	S_0 mg/L	S_e mg/L	D_o mg/L	Q ml/m	HRT day	VLR kg/m^3/d	OLD kg/d	NH_{4i} mg/L	NH_{4e} mg/L	TN i mg/L	TNe mg/L
1	534	49	7	25	0.833	0.404	0.64	34.6	20	42.2	17.8
2	544	53	7	25	0.833	0.409	0.65	35.2	19.7	43.0	15.81
3	515	70	7	25	0.833	0.370	0.61	37	22.7	45.1	20.28
4	600	55	6.5	25	0.833	0.454	0.72	35	20.9	42.7	18.7
5	522	66	6.5	50	0.416	0.76	1.25	33	16.7	40.23	14.9
6	588	60	6.5	50	0.416	0.88	1.41	32.3	21.7	39.48	19.42
7	555	54	6.5	50	0.416	0.835	1.33	33	21.7	40.2	19.4
8	515	52	6.5	50	0.416	0.771	1.23	33	21.5	40.2	19.2
9	533	60	6.5	75	0.277	1.182	1.91	32.8	21.7	40.0	19.4
10	500	53	6.5	75	0.277	1.117	1.8	34.5	17.7	42.0	15.8
11	540	58	6.5	75	0.277	1.205	1.94	36.2	17.9	44.1	15.15
12	532	49	6.5	75	0.277	1.207	1.91	37.9	17.45	46.26	15.57

A performance assessment of the system was based on the efficacy in removing COD, NH_4, and TN. As illustrated in Figure 2, when the BAF was put into service for 0-10 days, the COD, NH3-N, and TN removal efficiency fluctuated significantly.

During the operation time, the COD effluent concentrations reached 32.5 to 81.5 mg/L; this resulted in average removal efficiency of 86.4%; it has an average concentration of 52.26 mg/L. At this stage, the mean effluent NH_4-N concentrations ranged from 16.6 to 22.9 mg/L with an average value of 16.2 mg/L, and the average removal efficiency was 33.8 %. While the mean effluent TN concentrations ranged from 12.66 to 20.2 mg/L with an average value of 12.9 mg/L, and the average removal efficiency was 50.7 %. Although the change in COD load in the effluent, the efficacy in removing COD, TN, and NH3-N could still be maintained at 86-95%, 42-66%, and 51-73%, respectively. These confirmed a particular aptitude for the BAF to repel COD shock load in the wastewater.

In earlier studies, several authors have studied and operated bioreactors for wastewater treatment and reported their actual results. sequencing batch reactor had used to treat wastewater from the sugar industry with a moving-bed biofilm and achieved the BOD5 and COD removal efficiencies of 85% and 79%, respectively (Faridnasr et al., 2016). Taylor et al. (2007) operated an aerated biological filter (BAFs) on a pilot plant scale for domestic wastewater and achieved average COD removal efficiency of 83%. Higuera-Rivera & González-Martínez (2017) tested the kinetic parameters for simultaneously removing organic matter and ammonia nitrogen from residual synthetic wastewater using a biological aerated filter (BAFs). They achieved 87% removal efficiency of NH^{4+}-N beside 86% removal of COD. When an organic loading of 5.7 kg /m^3day COD was applied, the up-flow aerated filters could be removed around 88% of BOD_5, 75% of COD, and 82% of SS (Ahmed et al., 2006). According to these authors, COD removal was less efficient than the current study. It is shown that experimental results were affected by the operational conditions, different reactor structures, and wastewater types.

During this study, nitrogen was removed from the wastewater at a level of 50.7%, which is not very high. It can be explained as follows during nitrification, nitrogen in the influent changes from only a small amount in the reactor; other parts of nitrogen become biomass for bacteria during the assimilation process.

Based on the operating conditions and reactor structure, this study the primary mechanisms for removing organic matter and nitrogen may be considered an aerobic conversion. Organic materials of various forms have been assimilated and catabolized. Consequently, all wastewater compounds were transformed to biomass and CO_2; a portion of the untreated wastewater has remained in the effluent. Through the nitrification process, NH^{4+}-N is converted into NO_2 and then NO_3. The pH value was constant between 7.0 and 7.3, and this pH level is appropriate for the growth of microorganisms in the Bioreactor.

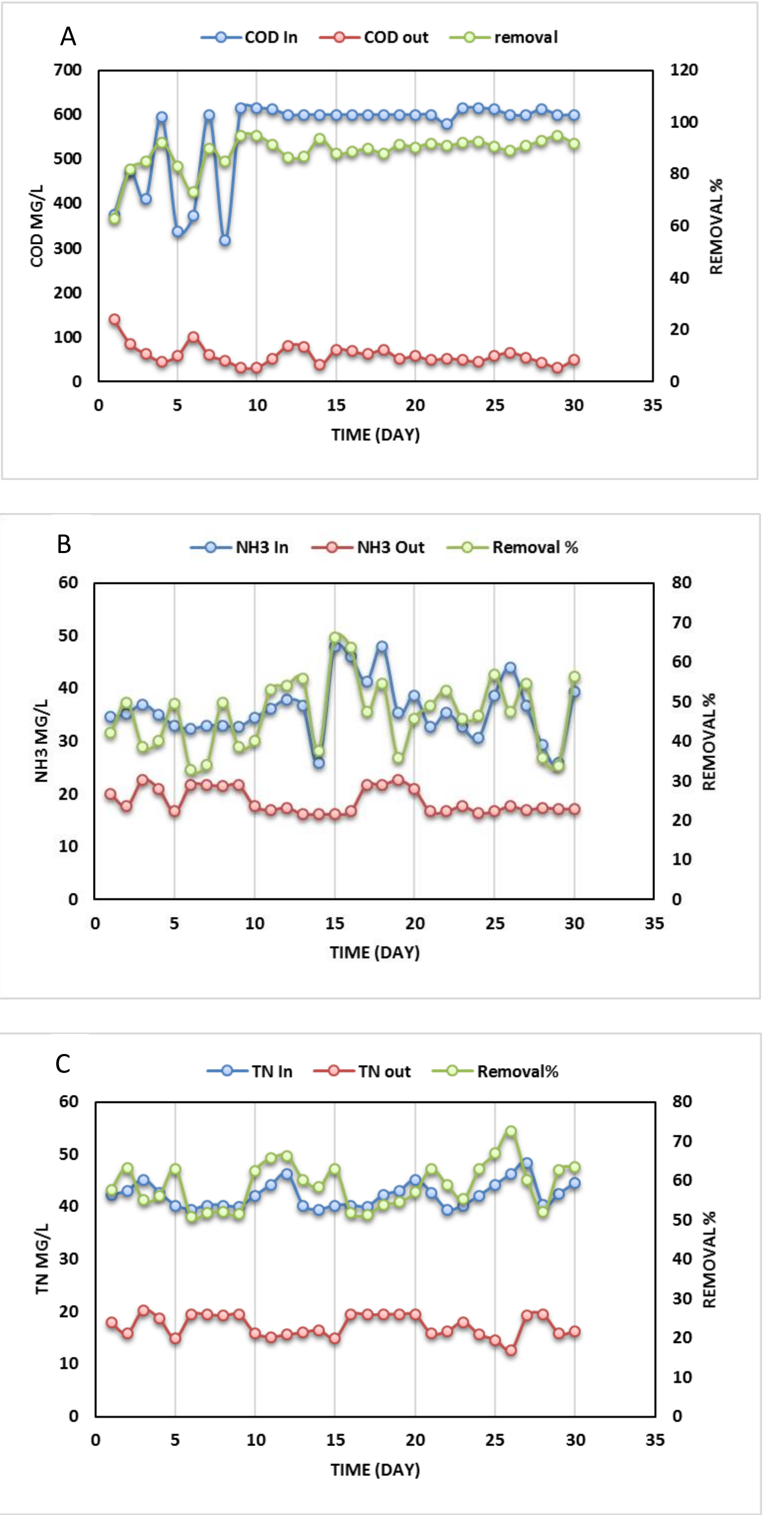

Fig 2. Efficacy in removing (A) COD, (B) TN, and (C) NH4-N in the reactor.

According to Figure 3, the organic load increases substrate utilization; these two parameters have a linear relationship. Thus, Compared to conventional activated sludge reactors, Bioreactor reactors had a removal capacity approximately two times higher(Tchobanoglous, G., Burton, F. L. and Stensel, 2003).

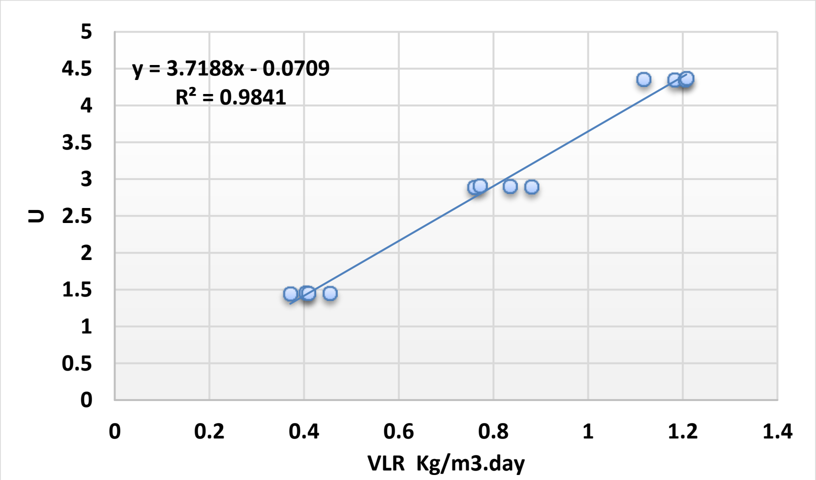

Fig 3. Relationship between volumetric load rate (VLR) and substrate utilization rate (U).

A further comparison between organic loading (OLD) and volumetric loading (VLR) is shown in Figure 4. There is a linear relationship between organic loading (OLD) and volumetric loading (VLR); the outcome for this result is under the suggestion made by Jianlong et al. (2000).

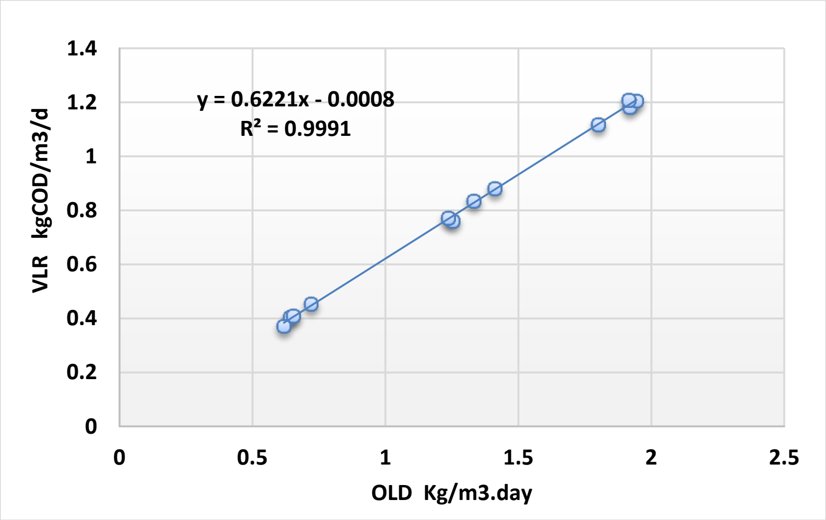

Fig 4. Correlation between volumetric substrate removal rate and organic load.

In Figure 5, the linear correlation plotted between V/QS_i and $V/[Q(S_i - S_e)]$ for COD outline resulting from the model's equation. According to their correlation coefficient ($R^2=0.9987$), the experimental and estimate data are in good agreement. Consequently, to describe the elimination performance of the COD, the modified Stover-Kincannon model may be considered in the present study. We calculated KB and U_{max} to be 178.57 (g /L day) and 201.80 (g /L day), respectively.

The formulas below Eq. (13) demonstrate the COD rate expression.

$$\frac{Q(S_i - S_e)}{V} = \frac{178.57\left(\frac{QS_i}{V}\right)}{201.80 + \left(\frac{QS_i}{V}\right)} \quad (13)$$

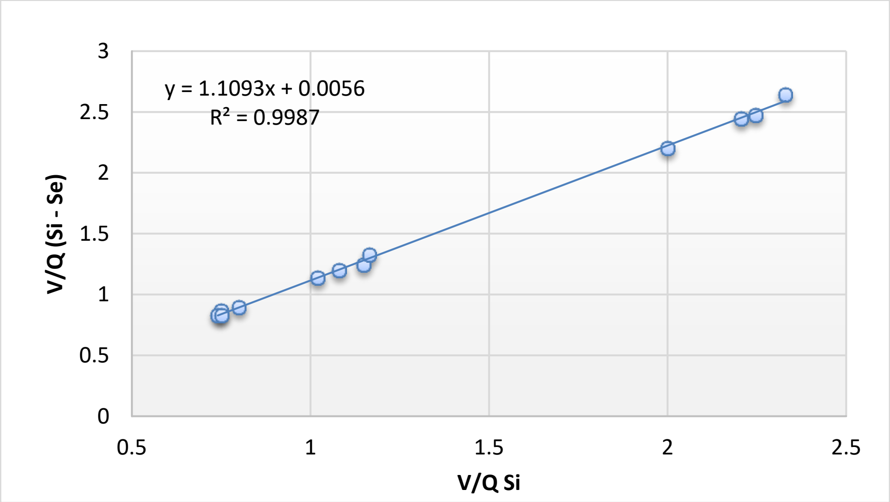

Fig 5. The plot of modified Stover-Kincannon model for COD removal.

By reforming, the Eq. (13) estimated concentration of COD in the effluent is determined by Eq. (13-1).

$$S_e = S_i - \frac{178.57S_i}{201.80 + \left(\frac{QS_i}{V}\right)} \quad (13-1)$$

Studies have shown the effectiveness of the Stover-Kincannon model in removing COD.

Nga et al. (2020) was working with a hanging sponge bioreactor and had obtained a maximum utilization rate K_B =75.034 (g /L day) and saturation value U_{max} =56.818 (g /L day) with a coefficient of determination (R^2) of 0.9943. On a UASB, Abyar et al. (2017)achieved a correlation coefficient (R2) of 0.9917 and kinetic constants of U_{max} = 24.75 (g /L day)and K_B = 25.997 (g /L day).

Hassani et al. (2014) study the kinetic modeling of COD removal using (MBBR) for wastewater treatment; Results indicated that the model of Stover–Kincannon and the experimental data agreed (R^2 = 0.9919), U_{max} and K_B were calculated as 13.14 (g COD /L day) and 13.62 (g COD /L day), respectively. Dyestuff and COD from synthetic wastewater were studied by Kapdan (2005); Results indicated the Stover-Kincannon model had a good fit with experimental data and that K_B and U_{max} were respectively 17.8 (g COD /L day), 19.5 (g COD /L day). Different kinetic constants between researchers indicate that reactor arrangement and operating conditions significantly impact kinetic coefficients.

The ammonium removal model is also shown in Figure 6 when applied to ammonium removal. A plot of V/ [Q (Si-Se)] against V/(QSi) yields 1/U_{max} as the intercept point, and the slope represents U_{max} / KB.

Based on the intercept and slope in Figure 6, we calculated constant kinetic U_{max} and K_B

values of 1.867 (g /L day) and 4.6 (g /L day), respectively, with R^2 of 0.9265, Stover-Kincannon's modified model is approved for application. As compared to (Yang et al., 2015) study, the values of the saturation constant (K_B) and maximum utilization rate (U_{max}) in this study are more significant. Anaerobic bacteria were used to investigate the oxidation of synthetic wastewater containing $NH4^+$ by Abbas et al. (2015); they achieved U_{max} = 22.29 (g /L day) and KB = 27.253 (g /L day)with a correlation coefficient of 0.9810 Based on the Stover-Kincannon model. Therefore, we have the following rate expression for the removal of NH4+-N from Eq. (14)

$$\frac{Q(S_i - S_e)}{V} = \frac{1.876\left({}^{QS_i}/_{V}\right)}{4.602 + \left({}^{QS_i}/_{V}\right)} \tag{14}$$

By reforming, the Eq. (14) estimated concentration of COD in the effluent is determined by Eq. (14-1).

$$S_e = S_i - \frac{1.876\, S_i}{4.602 + \left({}^{QS_i}/_{V}\right)} \tag{14 - 1}$$

A few publications have used the Stover–Kincannon model to investigate NH4 $^+$-N removal in bioreactors. Nga et al. (2020) was operated a bioreactor and had obtained a coefficient of determination (R^2) of 0.9810. The saturation value KB and maximum utilization rate U_{max} constant are obtained as 2.96 (g /L day) and 4.713 (g /L day), respectively.

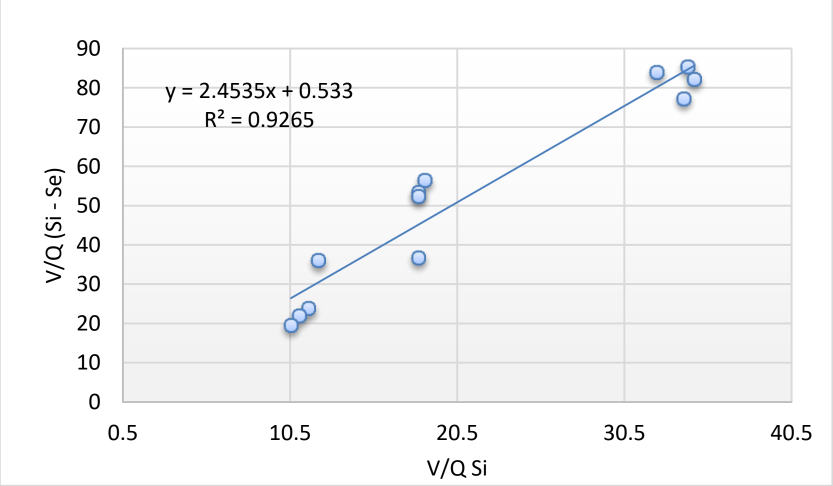

Fig 6. Modified Stover-Kincannon model for NH_4^+ removal in a bio-reactor.

As shown in Figure 7, TN loading V/ (QTN_i) is plotted against TN removal rate V/ [Q (TN_i - TN_e)]. Based on slope and intercept with a coefficient of determination (R2 = 0.9685), TN removal kinetic constants were established as U_{max} = 3.83 (g /L day) and K_B = 6.644 (g /L day). Accordingly, the expression for the rate of TN will follow the formula given below:

$$\frac{Q(TN_i - TN_e)}{V} = \frac{1.876\left({}^{QTN_i}\!/_V\right)}{4.602 + \left({}^{QTN_i}\!/_V\right)} \tag{15}$$

effluent TN concentration can be expected by Eq. (15-1).

$$TN_e = TN_i - \frac{1.876\,TN_i}{4.602 + \left({}^{QTN_i}\!/_V\right)} \tag{15 - 1}$$

The nitrogen removal by using the UASB reactor was exhibited using the modified Stover-Kincannon model (Ni et al., 2012). As a result, the constants K_B and U_{max} are calculated as 12.1 (g /L day) and 11.4 (g /L day), respectively, with R^2 of 0.9990. For an anammox hybrid reactor, Tomar & Gupta (2016) calculated U_{max} and K_B as 46.043 (g /L day) and 47.072 (g /L day), respectively.

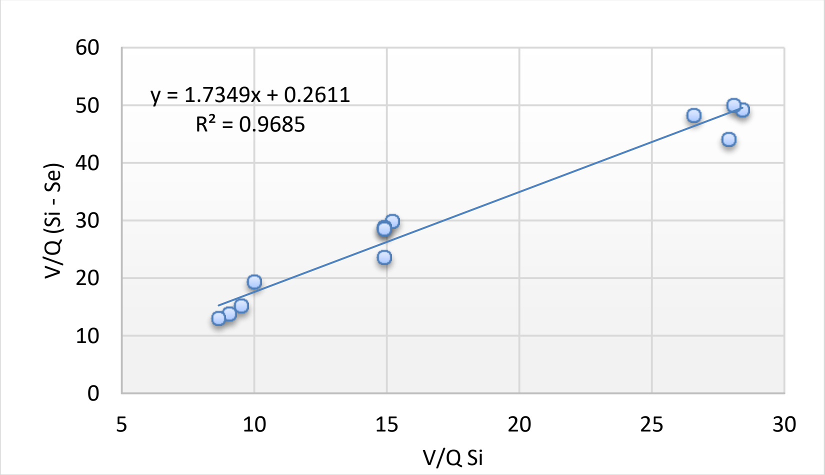

Fig 7. Modified Stover-Kincannon model for TN removal in the bio-reactor.

The experimental data of the bioreactor were applied in the first-order substrate removal kinetics to determine the rate of change in COD concentrations, as shown in Figure 8. The model constant (K_1) was obtained by plotting ($S_i - S_e$)/HRT versus (S_i) as 1.59 per day for COD removal rates with the R^2 of 0.425. The value of K_1 was substituted into Eq. (16) as follows:

$$\frac{S_i}{S_e} - 1 = 1.59\,HRT \tag{16}$$

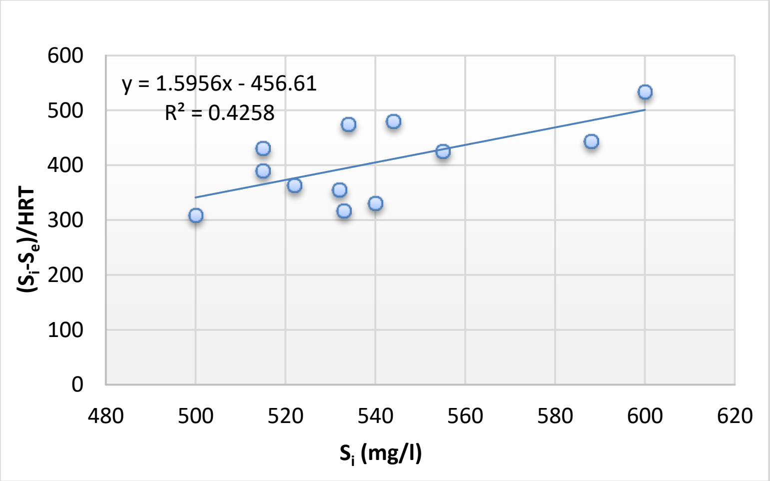

Fig 8. Modeling the region of a fixed bed using First-order kinetics.

As obtainable earlier, this model could not be acceptable to the experimental data (R^2 = 0.425).

The Monod model was used to estimate biomass concentration in the unpacked zone from maximum specific substrate utilization rates (k). The second-order kinetic model is defined in Table 2, and the values (A) and (B) of the fixed bed section have been determined using Figure 9. The importance of (A) and (B) was selected as 1.1161 and 0.0007, respectively, with R^2 of 0.9979. Table 2 summarizes the second-order rate constants ($k_{2(S)}$), which were estimated from (A) values. In the reactor's effluent substrate concentration is calculated using this formula given below:

$$S_e = S_i * (1 - \frac{HRT}{1.1161 + 0.0007HRT}) \tag{17}$$

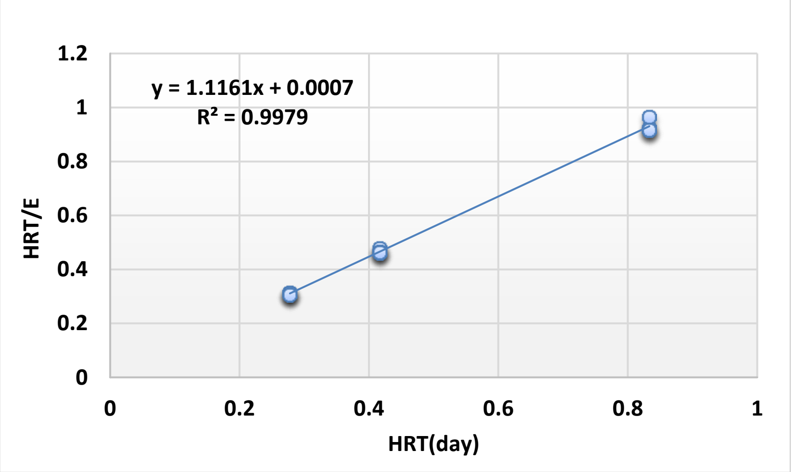

Fig 9. Modeling the region of a fixed bed using second-order kinetics.

Table 2. Kinetic data for the Monod and Second-Order Kinetic Model

Run	S_i mg/L	S_e mg/L	D_o mg/L	Removal (E) %	Q ml/min	X mg/L	HRT day	HRT/E	$K_{2(s)}$ / day
1	534	49	7	90.8	25	277.14	0.833	0.917	1.679
2	544	53	7	90.2	25	281.57	0.833	0.923	1.683
3	515	70	7	86.40	25	256.54	0.833	0.964	1.749
4	600	55	6.5	90.83	25	312.79	0.833	0.917	1.671
5	522	66	6.5	87.35	50	262.62	0.416	0.476	1.732
6	588	60	6.5	89.79	50	303.56	0.416	0.464	1.688
7	555	54	6.5	90.27	50	287.429	0.416	0.461	1.687
8	515	52	6.5	89.90	50	265.411	0.416	0.463	1.691
9	533	60	6.5	88.74	75	271.943	0.277	0.313	1.708
10	500	53	6.5	89.4	75	256.346	0.277	0.310	1.700
11	540	58	6.5	89.25	75	276.9346	0.277	0.311	1.699
12	532	49	6.5	90.78	75	276.5030	0.277	0.305	1.677

CONCLUSIONS

During the continuous operation of the reactor, different loading rates of COD, NH4+, and TN were used to treat wastewater. The reactor utilizes a single piece of equipment for the treatment of sewage. This design feature secures the oxygen required for the decomposition process. A simple air pump is used to supply the air needed for the operation. The reactor achieved an efficiency of 86.4% for COD removal and 33.8 %, 50.7 % for $NH4^+$ and TN 50.7%. The kinetic analysis for the removal of chemical oxygen demand (COD), ammonium ($NH4^+$-N), and Total Nitrogen (TN) was carried out. The results indicated that the reactor's maximum utilization rate (U_{max}) and saturation constant value (K_B) were computed, and it was 178.57 and 201.80 for COD; 1.876 and 4.6 for NH4 $^+$-N; 3.823 and 6.644 for TN, respectively. Several kinetic models are applicable for BAF reactor modeling, including the second-order kinetic, Monod, Sundstrom, Contois, Barthakur, Grau model, Stover_/Kincannon model's, etc. In this study, we can conduct that the Stover/Kincannon and second-order models yielded higher correlation coefficients, 99.87 for COD removal and 92.65, 96.85 for NH4+ and TN, respectively. The BAF reactors could be designed using these models. The overall reactor was modeled with a second-order kinetic model. The removal rate constant ($k_{2(S)}$) was 1.7 per day. The kinetic studies conducted in laboratory-scale reactors can estimate treatment efficiency in different conditions. They can also be used to formulate treatment plans for different reactor designs. Various mathematical models need to be applied to precisely define the BAF reactor.

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CONFLICT OF INTEREST

The authors declare that there is not any conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/ or falsification, double publication and/or submission, and redundancy has been completely observed by the authors.

LIFE SCIENCE REPORTING

No life science threat was practiced in this research.

REFERENCES

Abbas, G., Wang, L., Li, W., Zhang, M. and Zheng, P. (2015). Kinetics of nitrogen removal in pilot-scale internal-loop airlift bio-particle reactor for simultaneous partial nitrification and anaerobic ammonia oxidation. *Ecological Engineering*, *74*, 356–363.

Abyar, H., Younesi, H., Bahramifar, N., Zinatizadeh, A. A. and Amini, M. (2017). Kinetic evaluation and process analysis of COD and nitrogen removal in UAASB bioreactor. *Journal of the Taiwan Institute of Chemical Engineers*, *78*, 272–281.

Ahmed, Z., Lim, B.-R., Cho, J. and Ahn, K.-H. (2006). Effects of the internal recycling rate on biological nutrient removal and microbial community structure in a sequential anoxic/anaerobic membrane bioreactor. *Bioprocess and Biosystems Engineering*, *30*(1), 61–69.

Al-furaiji, M. H., Kalash, K. R., Kadhom, M. A. and Alsalhy, Q. F. (2021). *Evaluation of polyethersulfone microfiltration membranes embedded with MCM-41 and SBA-15 particles for turbidity removal*. *215*, 26764.

Büyükkamaci, N. and Filibeli, A. (2002). Determination of kinetic constants of an anaerobic hybrid reactor. *Process Biochemistry*, *38*(1), 73–79.

Chen, M., Yu, Q. and Sun, H. (2013). Novel Strategies for the Prevention and Treatment of Biofilm Related Infections. *International Journal of Molecular Sciences*, *14*(9), 18488–18501.

Debik, E. and Coskun, T. (2009). Use of the Static Granular Bed Reactor (SGBR) with anaerobic sludge to treat poultry slaughterhouse wastewater and kinetic modeling. *Bioresource Technology*, *100*(11), 2777–2782.

Doh, M. and Chudoba, J. (1975). *Kinetics of multi component substrate removal by activated sludge*. *Water Research, 9, 637–642..*

Faridnasr, M., Ghanbari, B. and Sassani, A. (2016). Optimization of the moving-bed biofilm sequencing batch reactor (MBSBR) to control aeration time by kinetic computational modeling: Simulated sugar-industry wastewater treatment. *Bioresource Technology*, *208*, 149–160.

González-Martínez, S., Lippert-Heredia, E., Hernández-Esparza, M. and Doria-Serrano, C. (2000). Reactor kinetics for submerged aerobic biofilms. *Bioprocess Engineering*, *23*(1), 57–61.

Grau, P., Dohányos, M. and Chudoba, J. (1975). Kinetics of multicomponent substrate removal by activated sludge. *Water Research*, *9*(7), 637–642.

Ha, J. H. and Ong, S. K. (2007). *Nitrification and denitrification in partially aerated biological aerated filter (BAF) with dual size sand media*. 9–17.

Hassani, A. H., Borghei, S. M., Samadyar, H. and Ghanbari, B. (2014). Utilization of moving bed biofilm reactor for industrial wastewater treatment containing ethylene glycol: kinetic and performance study. *Environmental Technology*, *35*(4), 499–507.

Higuera-Rivera, A. I. and González-Martínez, S. (2017). Determination of kinetic parameters in a biological aerated filter (BAF) for wastewater treatment. *Lecture Notes in Civil Engineering*, *4*, 668–673.

Hua, B., Xiong, H., Kadhom, M., Wang, L., Zhu, G., Yang, J., Cunningham, G. and Deng, B. (2017). Physico-Chemical Processes. *Water Environment Research*, *89*(10), 974–1028.

Jianlong, W., Hanchang, S. and Yi, Q. (2000). Wastewater treatment in a hybrid biological reactor

(HBR): effect of organic loading rates. *Process Biochemistry*, *36*(4), 297–303.

Kadhom, M., Albayati, N., Salih, S., Al-Furaiji, M., Bayati, M. and Deng, B. (2019). Role of Cellulose Micro and Nano Crystals in Thin Film and Support Layer of Nanocomposite Membranes for Brackish Water Desalination. *Membranes*, *9*(8), 101.

Kalash, K., Kadhom, M. and Al-Furaiji, M. (2020). Thin film nanocomposite membranes filled with MCM-41 and SBA-15 nanoparticles for brackish water desalination via reverse osmosis. *Environmental Technology and Innovation*, *20*, 101101.

Kalash, K. R. and Albayati, T. M. (2021). Remediation of oil refinery wastewater implementing functionalized mesoporous materials mcm-41 in batch and continuous adsorption process. *Desalination and Water Treatment, 220*, 130–141.

Kalash, K. R., Kadhom, M. A. and Al-Furaiji, M. H. (2019). Short-Cut Nitrification of Iraqi Municipal Wastewater for Nitrogen Removal in a Single Reactor. *IOP Conference Series: Materials Science and Engineering*, *518*(2).

Kapdan, I. K. (2005). Kinetic analysis of dyestuff and COD removal from synthetic wastewater in an anaerobic packed column reactor. *Process Biochemistry*, *40*(7), 2545–2550.

Gray. N.F. (1999). *Water Technology*. New York,Toronto :Wiley.

Nga, D. T., Hiep, N. T. and Hung, N. T. Q. (2020). Kinetic modeling of organic and nitrogen removal from domestic wastewater in a down-flow hanging sponge bioreactor. *Environmental Engineering Research, 25*(2), 243–250.

Ni, S.-Q., Sung, S., Yue, Q.-Y. and Gao, B.-Y. (2012). Substrate removal evaluation of granular anammox process in a pilot-scale upflow anaerobic sludge blanket reactor. *Ecological Engineering, 38*(1), 30–36.

Pramanik, B. K., Fatihah, S., Shahrom, Z. and Ahmed, E. (2012). Biological aerated filters (BAFs) for carbon and nitrogen removal: A review. *Journal of Engineering Science and Technology*, *7*(4), 428–446.

Raj, S. A. and Murthy, D. V. S. (1999). Comparison of the trickling filter models for the treatment of synthetic dairy wastewater. *Bioprocess Engineering, 21*(1), 51–55.

Salih, S. S., Mohammed, H. N., Abdullah, G. H., Kadhom, M. and Ghosh, T. K. (2020). Simultaneous Removal of Cu(II), Cd(II), and Industrial Dye onto a Composite Chitosan Biosorbent. *Journal of Polymers and the Environment*, *28*(1), 354–365.

Sperling, M. Von. (2007). *Activated Sludge and Aerobic Biofilm Reactors*. IWA Publishing LONDON.

TA, S. (2015). Mercury sorption by silica/carbon nanotubes and silica/activated carbon: A comparison study. *Aqua*, *64*, 892–903.

Tandukar, M., Ohashi, A. and Harada, H. (2007). *Performance comparison of a pilot-scale UASB and DHS system and activated sludge process for the treatment of municipal wastewater*. *41*, 2697–2705.

Taylor, P., Belgiorno, V., Feo, G. De, & Napoli, R. M. A. (2007). *Combined Carbonaceous Removal and Nitrification with Biological Aerated Filters*. *December 2014*, 37–41.

Tchobanoglous, G., Burton, F. L. and Stensel, H. D. (2003). *Wastewater Engineering: Treatment and Reuse* (4th editio). Mc Graw-Hill, New York.

Tomar, S. and Gupta, S. K. (2016). Investigating the role of co-substrate–substrate ratio and filter media on the performance of anammox hybrid reactor treating nitrogen rich wastewater. *Journal of Bioscience and Bioengineering*, *121*(3), 310–316.

V. Lazarova; J. Manem. (1995). *Biofilm characterization and activity analysis in water and wastewater treatment*. *29*(10), 2227–2245.

Yang, G., Feng, L., Wang, S., Zhou, J., Guo, C., Xia, T., Sun, W., Jiang, Y., Sun, X., Cao, L., Xu, X. and Zhu, L. (2015). Potential risk and control strategy of biofilm pretreatment process treating raw water. *Bioresource Technology*, *198*, 456–463.

Zhou, Z., Shen, X., Jiang, L., Wu, Z., Wang, Z., Ren, W. and Hu, D. (2015). Modeling of multimode anaerobic / anoxic / aerobic wastewater treatment process at low temperature for process optimization. *CHEMICAL ENGINEERING JOURNAL*, *281*, 644–650.