



Determining Kinetic Coefficients of Domestic Wastewater Treatment Using Tripikon-S Septic Tank with Monod Formula: An Experiment Study

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Abstract: The research goal is to investigate the kinetic coefficients of Tripikon-S. The experiment was conducted on a Tripikon-S reactor scale bench laboratory. Domestic wastewater and anaerobic seed sludge were collected from the WWTP Taman Tun Dr. Ismail in Kuala Lumpur, Malaysia. The kinetic investigation was carried out by continuously pushing the wastewater at five different flow rates into the reactor with a peristaltic pump. The experiment samples of treating wastewater were collected from the reactor's inner and outlet lines to monitor chemical oxygen demand (C.O.D), pH, and temperature twice daily. The activated sludge samples inside the reactor were collected using the specific hose to measure the concentration of Volatile Suspended Solids (V.S.S) three times per week. Ammonia (NH₃-N), Orthophosphate (PO₄-P), Total Volatile Acids (T.V.A), and alkalinity levels were measured once a week. The Monod formula was used to determine the kinetic coefficients, resulting in the values of the maximum specific growth rate (μ_{max}) of 0.0021 d⁻¹, specific decay rate (K_d) of 0.001 d⁻¹, saturation constant (K_s) of 52.16 mg/L C.O.D., growth yield (Y) 0.062 $\frac{g\ V.S.S}{g\ C.O.D}$ and maximum substrate utilization rate (k) 0.034 $\frac{g\ C.O.D}{g\ V.S.S.d}$ with the treatment efficiency was 97% for COD elimination.

Keywords: Kinetic Coefficients, Domestic Wastewater, Tripikon-S, Monod Formula.

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1.1 Introduction

According to UN estimates, more than half of the global population will confront water scarcity by 2025. Improving water resource management and providing access to water and sanitation services (WASH) is vital for addressing various social and economic inequities. According to global cost-benefit studies, fulfilling water needs and basic sanitation and hygiene can produce good social and economic advantages relative to the costs necessary. Improving WASH services for vulnerable groups will change the balance of the cost-benefit analysis, considering changes in these individuals' social positions and dignity [1]. Wastewater created by household, industrial, and agricultural activities contains a complex mix of inorganic and organic contaminants that require adequate treatment technologies to decrease their negative environmental and human health impacts [2]. This problem will be exacerbated by the fact that some vulnerable groups do not have access to excellent and healthy sanitation, including people who live on the banks of rivers, which is related to domestic wastewater treatment. However, water

fouling can be suppressed with the proper wastewater treatment method, and wastewater can be used as a source of nutrients and recycled water. Therefore, wastewater treatment technology is vital to achieving a sustainable societal future [1]. Development in developing countries generally does not make enough efforts to reduce the factors that cause the decline in water quality compared to the emergence and development of waterborne diseases and make the appropriate strategies [3].

Pontianak Municipality is the capital city of West Kalimantan Province, which is riverside precisely on the equator line with an elevated place about 0.10-1.50 m of water sea level and has the potential to be developed as a water tourism destination. However, the existence of settlements along the riverbanks that generally do not have proper wastewater treatment makes the river a waste disposal site. Settlements along the banks of the river become the source of domestic wastewater pollution including sewage water that is strongly suspected to be the primary source of waterborne diseases. This condition is suspected to be the source of annual diarrhoea outbreaks in the city, which is high and



is suspected to be the leading cause of the decline in the river's water quality. Diarrheal diseases in children are more common in tropical countries than in developed countries, especially in urban areas with poor sanitation systems and high-density levels [4]. Waterborne disease can cause many deaths, especially for children, who are the most vulnerable group in society, if the proper treatment is not given. Efforts to ensure safe drinking water quality are a significant challenge for public health [5]. Pollution from home and non-domestic activities like settlements, industry, and water transportation endangers the sustainability and comfort of many riverbank cities. The characteristics and quality of safe drinking water sources are decreasing due to waste pollution sourced from surrounding activities [6]. Policies applied to cities located on the banks of rivers should be managed with sustainable and inclusive principles based on the facts of their location [7]. Waterborne diseases are the most severe problem in developing countries. Subsequently, the diseases are precipitated by inadequate sanitation and water supply [6], [8]. The incidence rate of waterborne diseases can be seen based on the number of hospitalized patients and the death rate for waterborne diseases [6]. Water contamination by pathogenic microorganisms found in wastewater is a severe, increasing threat to human health [5].

The conventional septic tank is considered inappropriate and unfeasible to implement due to the distance of approximately 3-4 meters between the river water level and the building's floor. Tripikon-S is one of the alternatives to domestic sewage treatment created by Prodjopangarso (Civil Engineering Laboratory at Gajah Mada University) to be implemented in such an environment, and it has shown encouraging results. This technological innovation is carried out to solve the issues of tide-related environmental situations, such as coastal areas, estuaries, rivers, and wetlands [9]. Developing countries like Indonesia rely mainly on on-site waste treatment, such as septic tanks or pit latrines [10]. Septic tank-based on-site systems are typically installed in every home or residence. [11].

Tripikon-S (Figure 1) is a vertical septic tank suitable for use in shallow water areas, riverbanks, and other similar environments. Its principal processes are anaerobic. Today's most often used home wastewater treatment technologies include aerobic and anaerobic biological processes and membrane bioreactors [12]. The basic concept of the design is to use three concentrically installed pipes: a small pipe as an inlet connected to the toilet, a medium pipe as a digester reactor, and a large pipe as a space for sewage overflow. The three pipes are arranged vertically and can be applied for alternative wastewater treatment from household and household industrial activities, requiring only a tiny area of land [9]. Tripikon-S adopting Hydraulic Retention Time (H.R.T) of conventional septic tanks for about 0.51 days and require desludging every six months to three years, causing inconveniences in the local community[13]. In Indonesia, sludge in septic tanks is frequently emptied by truck and sent to a home sludge handling facility known as the fecal sludge treatment plant (I.P.L.T.) [11], which is in Indonesia with frequency immediately after six months of use and no later than three years. However, this is not the case with Tripikon-S, where fecal sludge can be drained by the user by pumping river water or from outside the system into the drain pipe so that the sludge that collects at the bottom of the large pipe will move upwards to the Tripikon-S drain pipe.

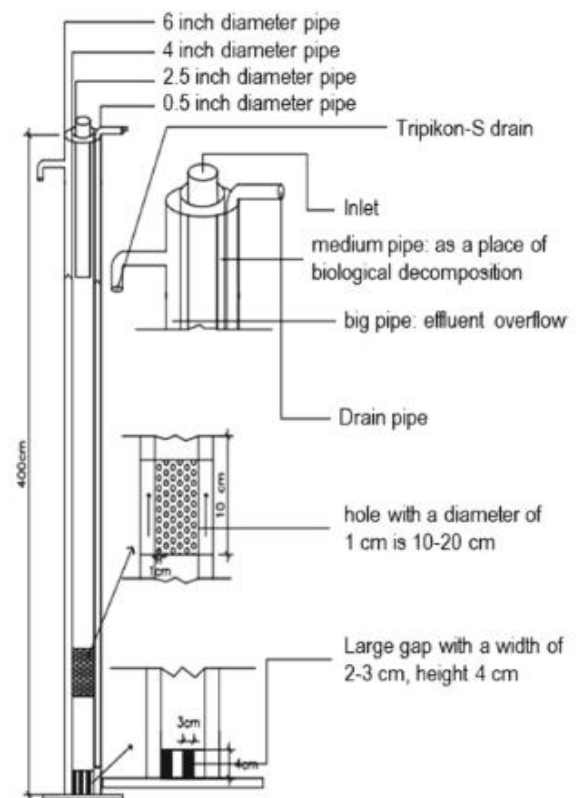


Figure 1. Design of Tripikon-S [9].

Realistic bioprocess models typically require kinetic rate data input. By conducting kinetic studies on a laboratory scale, identifying kinetic coefficients of domestic wastewater treatment using Tripikon-S will be possible. Kinetic coefficients are pretty beneficial for calculating the exact amount of the required septic tank. This experiment aims to determine the kinetic coefficients of home wastewater treatment utilizing Tripikon-S on a laboratory scale. The load of organic materials in a wastewater treatment reactor can affect the dynamics of microorganisms and the kinetics of anaerobic processes [14], including Tripikon-S.

1.2 Materials and Methods

1.2.1 Experimental Setup and Procedure

The continuous flow of domestic wastewater into the scale bench Tripikon-S reactor was conducted during the experiment (Figure 2). The scale bench Tripikon-S reactor used in the experiment consisted of two chambers in a symmetrical position. The main chamber measured 11 cm in diameter and 150 cm in height, with two perforations. The hole was located at the bottom side, sizing 1 x 1 cm, and the higher was 0.5 cm in diameter. The other chamber was around the main chamber, where the outlet tube was located. Most bio sludges lay in one-third of the main chamber volume, especially at the lowest part, and the small portion spilled over into the surrounding chamber. The raw residential wastewater was placed in a container connected to the peristaltic pump via a hose, which was linked to the inlet tube leading to the main chamber, and the outlet pipe was linked to another container for processed municipal wastewater. A tube connected the tops of both chambers to a gas flowmeter, and a rubber cap served as a biogas sample point. The experiment parameters were monitored daily using laboratory analyses.

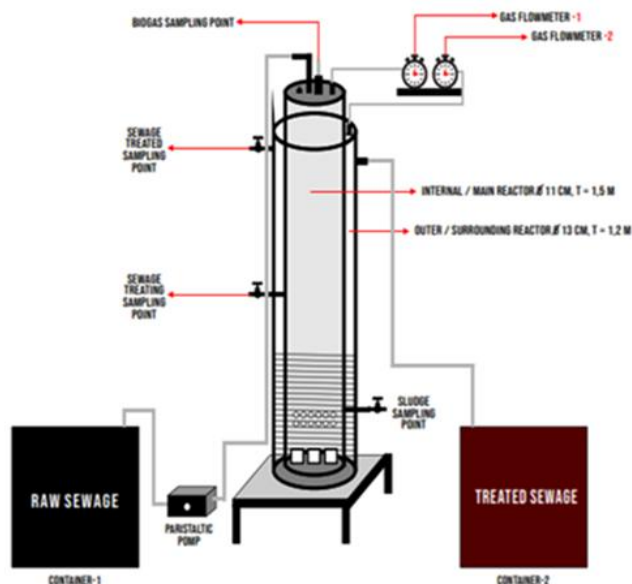


Figure 2. The setup of the Tripikon-S reactor during the kinetic study [15]

1.2.2 Acclimatization of Seed Sludge

The raw domestic wastewater used during the acclimatization and kinetic study in the experiment was the same as that taken from the Taman Tun Dr. Ismail WWTP, Kuala Lumpur, and the characteristics presented in Table 1. The amount of domestic wastewater needed for both stages of the experiment has been calculated in advance, and all the wastewater prepared is kept in a preservation chilling room at a temperature of $4^{\circ}\text{C} \pm 2^{\circ}\text{C}$. The samples were collected thrice weekly in the effluent channel for C.O.D. measurement.

Table 1. The features of raw residential effluent employed in the experiment.

No.	Parameter	Magnitude	Unit
1.	Biochemical Oxygen Demand (B.O.D)	115.55	mg/l
2.	C.O.D	222	mg/l
3.	Total Suspended Solids (TSS)	146	mg/l
4.	Total Kjeldahl Nitrogen (TKN)	12.04	mg/l
5.	Ammonia ($\text{NH}_3\text{-N}$)	18.76	mg/l
6.	Phosphate (as O-Phosphate/ PO_4^{3-})	13.3	mg/l
7.	Temperature	25	$^{\circ}\text{C}$
8.	pH	6.5	-

Source: [15].

The satisfactory anaerobic sludge used as seed sludge material for the experimental reactor was taken from a conventional septic tank in Kuala Lumpur under the supervision of Indah Water Consortium Sdn. Bhd. The initial color of the sludge

was brown, indicating low biomass concentration. The bio-sludge is cleaned using a plastic strainer to eliminate unwanted items and coarse particles. 10 Liters of bio-sludge are added to the reactor and left to settle on the bottom side for around seven days before being left till the condition stabilizes. The acclimation process took 15 days and involved installing a flow rate of 4.06 L/d of raw domestic wastewater. The wastewater was streamed until a relatively stable C.O.D. removal was achieved, and the reactor was ready to start kinetic studies. The acclimatization study by [16] obtained that after 15 days of continuous acclimatization process, a stable concentration of C.O.D is achieved.

The acclimatization process was essential for bacterial adaptation to the new environment, and stable reactor conditions were necessary before a kinetic study was conducted. Microorganisms need ample time to adjust to the new environmental conditions inside the bioreactor during the acclimatization stage [17]. Bacterial growth in the bioreactor does not occur throughout the acclimation procedure. Bacteria will continue to multiply, but some will die owing to adaptive mechanisms, decreasing vital resources, and the presence of harmful chemicals [18].

1.2.3 Kinetic Study

Kinetic studies offer valuable information about pollutant removal reaction mechanisms and processes in wastewater [19]. The research by [20] on a downstream system reactor that treats synthetic domestic wastewater increased the flow rate from 20.4 to 61.2 L.d^{-1} . The samples were withdrawn at the reactor's influent and effluent line three times a week for C.O.D. analysis and once weekly for measuring $\text{NH}_3\text{-N}$ and $\text{PO}_4\text{-P}$. The samples of sludge were withdrawn three times a week in the main reactor and the effluent line to determine volatile suspended solids (V.S.S.). The V.S.S. concentration represents the value of biomass concentration, while the attached biomass concentration might be assumed to be V.S.S. [21]. The samples are collected from the main chamber daily for temperature, pH, T.V.A., and alkalinity measurements. The Monod formula was applied to determine the kinetic coefficients. A study by [22] obtained experimental data validated through an established mathematical biokinetic model using one of the Monod models.

1.2.4 Analytical Methods

Grab sampling was implemented, and the values of C.O.D., V.S.S., $\text{NH}_3\text{-N}$, $\text{PO}_4\text{-P}$, pH, temperature, T.V.A., and alkalinity were measured using the Standard Methods for the Examination of Water and Wastewater (1976). Studies on the fundamentals of anaerobic digestion for domestic wastewater treatment are widely available which is the result of research or field observations, including the characteristics of raw materials such as nutrient concentration, particle size and presence of inhibitory materials as well as process parameters such as process configuration, pH, temperature, total solids and volatile compounds, N-total, NH_4 , C.O.D., carbon/nitrogen ratio, retention time, organic loading rate [23]. The V.S.S. concentration represents the value of the biomass concentration, while the attached biomass concentration might be assumed to be the V.S.S. value [21]. The samples were withdrawn at the reactor's influent and effluent line three times a week for C.O.D. analysis and once weekly for measuring $\text{NH}_3\text{-N}$ and $\text{PO}_4\text{-P}$. The samples of sludge were withdrawn three times a week in the main chamber and the effluent line to determine Volatile

Suspended Solids (V.S.S.). The samples were also collected from the main chamber daily to analyze temperature, pH, T.V.A., and alkalinity measurements.

1.2.4 Calculation Methods

An overview of the conditions of microorganisms and using substrates obtained in laboratory experiments is indispensable in scaling up a reactor or processing unit and vice versa. The experiment employed the Monod mode to characterize the growth rate of the mixed bacterial population and substrate usage in the Tripikon-S reactor. Sufficient data on kinetics need to be collected so that the microbiology can be adequately represented mathematically. Monod (1949) revealed the findings of an experiment that thoroughly examined the outcomes of a static reactor and related cell-specific growth rate (bacteria) to the concentration of organic substances as the functional limiter in tests. The Monod formula is one of the most widely used mathematical models in microbial growth research, with substantial theoretical and practical ramifications. The Monod formula establishes a link comparing the specific growth rate of bacteria seen in rapidly expanding biological wastewater treatment reactors where the concentration of electron donors is a limiting factor in cell growth [24]. Therefore, the Monod formula is used in this study. The microbial kinetics research of the downflow reactor system carried out by [20] obtained to be sufficiently by the Monod equation with a correlation coefficient of 0.9272.

1.2.4.1 Kinetic Modeling for Substrates

Substrates play a significant role in lowering substrate, nitrogen, and phosphorus concentrations. A laboratory scale experiment done by [21] regarding domestic wastewater treatment found a relationship between variations in organic loading. Evaporation, Nitrification, denitrification, ammonification, fixation, plant absorption, microbial decomposition, and ammonium adsorption are some nitrogen-removal mechanisms used in wastewater treatment technology [25].

The substrate balance in the reactor expressed $\frac{V \cdot dS_E}{dt} = Q_I \cdot S_I - \frac{\mu \cdot X_R \cdot V}{Y} - Q_E \cdot S_E \dots (1)$. On the steady state condition, the $\frac{V \cdot dS_E}{dt} = 0$, so the equation becomes $0 = (Q_I \cdot S_I) - (\frac{\mu \cdot X_R \cdot V}{Y}) - (Q_E \cdot S_E)$. Because of the steady state condition $Q_I = Q_E$, so $\frac{\mu \cdot X_R \cdot V}{Y} = Q(S_I - S_E)$ then, $\mu = \frac{Q \cdot Y(S_I - S_E)}{X_R \cdot V}$. Because of $\mu = \frac{1}{SRT} + K_d$, so the formula to find Y and K_d is $\frac{Q \cdot Y(S_I - S_E)}{X_R \cdot V} = \frac{1}{SRT} + K_d$ or $\frac{Q \cdot Y(S_I - S_E)}{X_R \cdot V} = \frac{1}{Y \cdot SRT} + \frac{K_d}{Y} \dots \dots \dots (2)$. With the linearizing plot of $\frac{Q \cdot Y(S_I - S_E)}{X_R \cdot V}$ versus $\frac{1}{SRT}$ yields the value of $\frac{1}{Y}$ and intercept $\frac{K_d}{Y}$.

1.2.4.2 Kinetic Modeling for Bacterial Balance

Hydrolysis is the first phase of the anaerobic processing process, in which enzymes mediate the early breakdown of organic materials by decomposing lipids, polysaccharides, and proteins are transformed into molecules with reduced molecular weight. The compounds serve as an appropriate carbon source for developing anaerobic microorganisms [23]. The bacterial balance in the reactor expresses $\frac{V \cdot X_R}{dt} = (Q_I \cdot X_I) + (\mu \cdot X_R \cdot V) - (W_E \cdot X_E - (K_d \cdot X_R \cdot V))$. because of steady-state conditions, the $\frac{V \cdot X_R}{dt} = 0$, with assuming the X_I is negligible or $= 0$

so $\mu = \frac{1}{SRT} + K_d$, while $\mu = \frac{\mu_{max}}{K_S + S_E}$ so the formula to find μ_{max} and K_S . Kinetic coefficients are

$\frac{1}{SRT} + K_d = \frac{\mu_{max}}{K_S + S_E}$, or $\frac{1 + (SRT \cdot K_d)}{SRT} = \frac{\mu_{max}}{K_S + S_E}$ with taking reciprocal the formula, resulting $\frac{SRT}{1 + (SRT \cdot K_d)} = \frac{K_S + S_E}{\mu_{max}}$, or in the form of a linear equation resulting $(\frac{SRT}{1 + (SRT \cdot K_d)}) = (\frac{1}{\mu_{max}}) + (\frac{K_S}{\mu_{max}} \cdot \frac{1}{S_E}) \dots \dots (3)$

with linearizing of $\frac{SRT}{1 + (SRT \cdot K_d)}$ versus $\frac{1}{S_E}$ will yield positive $\frac{K_S}{\mu_{max}}$ and intercept $\frac{1}{\mu_{max}}$.

1.3 Results and Discussion

1.3.1 The acclimatization process performance

The acclimatization process carried out the flow rate of 4.06 L/d of the raw domestic wastewater within 15 days. The wastewater is streamed after 15 days until the relatively stable C.O.D. removal is achieved in the 30-34 mg/L range. The slow discoloration of the biological sludge shows the color getting darker than before. During the acclimatization process, no bacteria grow within the bioreactor (the stationary phase), also known as the no growth phase. Despite this, bacteria continue to grow, with some even dying. This is due to the ongoing adaptation process, essential nutrient depletion, and toxic compounds [18]. The domestic wastewater process in Tripikon-S was anaerobic, so fully anaerobic bacteria were utilized. Wastewater treatment performance can be evaluated based on the process of treatment efficiency that can be achieved or the amount of reduction in pollutant concentration. However, these calculations cannot provide sufficient information about the dynamics of pollutant compound removal. Most laboratory or pilot-scale investigations under controlled conditions do not accurately reflect the operational realities of treatment plants. In 2019, Yulistyorini et al. conducted a review of 89 Anaerobic Baffled Reactor (ABR)-based facilities in Indonesia, and only about 14% produced acceptable results, with the ability to remove organic compounds B.O.D ranging from 25% to 98% and an average of 74% [26]. This experiment found that by applying flow rate variations, the removal efficiency of the Tripikon-S reactor ranged from 48-80%, which is quite close to the research produced by [27] found the highest deletion rate of around 85%.

Temperature is among the crucial parameters that affect the performance of wastewater treatment. Temperature is a critical parameter influencing the biochemical conversion pathway, reaction rate, and input energy. The temperature was pretty stable ($29 \pm 1^\circ\text{C}$), indicating that mesophilic bacteria were dominant in the reactor. The operating temperature of anaerobic reactors can vary. It most commonly takes place in mesophilic conditions due to the consequence of low operating costs. It is feasible to work under mesophilic settings, which is the most popular choice because of its low operating expenses [23]. Mesophilic conditions are the most adequate for treating mixed wastewater to obtain methane gas [14]. A publication by [16] states that anaerobic wastewater treatment reactors can be operated at temperatures well below 35°C , lowering the growth rate of bacteria while maintaining sufficient biomass.

As a result, it is critical that the process temperature remains consistent during the fermentation process and that no situations

allow for abrupt temperature swings. Relatively stable temperature during the experiment indicated substrate conversion, and its rate was steady [14]. Microbial communities can change at low temperatures where the diversity of alpha communities decreases in activity, but reactors can continue to work well [28].

1.3.2 Removal of organic and nutrient compounds

The C.O.D. test is the most effective and straightforward approach to determining the strength of organic molecules in household wastewater. The concentration of organic compound pollutants in wastewater treatment and aquatic monitoring is expressed as B.O.D and C.O.D. [29]. B.O.D and C.O.D. indicate the level of organic pollution in wastewater and waters where high levels of these pollutants can damage the health of humans,

animals, and plants, especially when released into the environment without appropriate treatment [19]. Table 2 shows the dynamics and efficiency of C.O.D. removal due to variations in organic load. Some wastewater treatment plants operate for C.O.D. treatment and nitrification in wastewater treatment tanks, which are used to estimate autotrophic or heterotrophic biomass parameters [30]. This study found that C.O.D. removal efficiency tends to increase with the increase of the H.R.T. Continuous process in wastewater treatment is a continuous or semi-continuous feeding system in which the hydraulic retention time (H.R.T.) is the average settlement time of organic compounds in the reactor. Depending on the technology used, the process stage can be single-phase or two-phase [23].

Table 2. The characteristics of organic and nutrient compounds removal

H.L.R., (L/d)	OLR, (mg.COD/ L.d)	HRT, (d)	Inf. C.O.D., (mg/L)	Eff. C.O.D., (mg/L)	C.O.D. Removal efficiency, (%)	Inf. P, (mg/L)	Eff. P, (mg/L)	Inf. NH ₃ , (mg/L)	Eff. NH ₃ -N (mg/L)
4.1	600	3.4	160	33	± 80	18.68	3.4	23.7	10.50
6.3	1230	2.2	195	43	± 78	18.68	5.6	23.7	12.60
9.5	1300	1.5	137	55	± 59	18.68	7.07	23.7	9.80
11.2	1400	1.2	130	65	± 50	18.68	6.3	23.7	11.20
12.1	1800	1	151	79	± 48	18.68	13.52	23.7	22.96

Source: [15]

Nitrogen and phosphorus are nutrients or biostimulants that are essential for microbial growth. The accumulation of nitrogen and phosphorus contaminants in untreated wastewater can lead to river eutrophication, which harms the aquatic environment and human life [31]. Water from wastewater treatment frequently contains specific nutrients such as nitrogen and phosphorus, which can harm the soil and increase N₂O emissions [32].

The nitrogen concentration in wastewater is one of the parameters to control the nutrient content in biological reactors. The experiment obtained fluctuations in wastewater nitrogen concentration as the organic loading rate increased. Microorganisms engaged in nitrogen conversion include ammonia-oxidizing bacteria, ammonia-oxidizing archaea, whole ammonia-oxidizing bacteria, nitrite-oxidizing bacteria, heterotrophic denitrifying bacteria, and anaerobic ammonia-oxidizing bacteria, which are typically the dominant ammonia oxidizers in domestic wastewater treatment systems [33].

Phosphorus plays a vital role in nutrient control inside the reactor. Domestic wastewater generally contains high phosphorus compounds, especially before producing synthetic detergents with inorganic phosphorus concentrations ranging from 0.5 to 1.0 mg/L. However, most inorganic phosphorus is derived from human faces due to protein breakdown and phosphate degradation in urine. The amount of phosphorus released depends on protein consumption. Phosphorus is also essential for reducing pollution from surface water sources, linked to the eutrophication of receiving water

bodies [34]. The experiment shows that effluent phosphorus increased with the organic loading rate (Table 2).

1.3.3 Control Parameter

The V.S.S. measurement is an obvious sign of biomass production and a helpful measure of reactor solids. V.S.S. is the most commonly used metric to track biomass development in biological wastewater treatment systems since it is easy to measure and takes little time to analyze. The concentration of organic solids is estimated using the weight loss during ignition, known as volatile suspended solids [35]. The experiment obtained that the concentration of V.S.S. in the reactor varied while the waste channel decreased with the increase of H.R.T. The increased H.R.T. leads to an increase in organic load due to the increased flow rate that feeds wastewater as the source of biomass substrate. The cell growth occurred concurrent with the oxidation of organic matter, so the amount of biomass and growth rate were proportional to the substrate consumption rate. A suitable balance of methane and acidogenic bacteria is required to operate optimally for anaerobic wastewater treatment units. Methane bacteria tend to be more sensitive to shifts in environmental conditions, such as pH, temperature, and food loads, than acidogenic bacteria. pH has a significant impact on volatile fatty acid metabolism and methanogenesis. As a result, a favorable pH level must be maintained. Throughout the experiment, the pH remained relatively steady in the range of 6.7 to 6.8. Naturally, without it, no effort is required to stabilize. The stability of pH could be achieved because alkalinity concentrations were sufficient to buffer the

decrease in pH, which impacts short-chain fatty acid production. These conditions present the biological processes during the kinetic study that persisted in a desired condition of the anaerobic process since most methanogens have pH optima near neutrality. Under the influence of increasing organic loads, the formation of volatile acids will be faster than those that can be digested by methane bacteria, whose growth rate is slow. Volatile acid analysis is almost always performed to control the process of anaerobic wastewater treatment reactors.

Along with the metabolic degradation of organic materials, anaerobic and facultative bacteria hydrolyze and simplify complicated molecules to lower molecular weights, such as short-chain fatty acids. Many literatures have reported that the waste stream, rich in Volatile Fatty Acids (V.F.A.), originates from anaerobic digestion or acidogenic fermentation from biologically degradable waste [36]. In the acidogenic phase, diatomic hydrogen (H_2) is formed as an intermediary chemical that helps to maintain electron balance. This phase also produces V.F.A. eaten by methanogenic bacteria in the final phase [37]. As a precursor of biogas, V.F.A. is produced in the fermentative phase in the steps of acidogenesis and acetogenesis [38]. Table 2 shows the average T.V.A. concentrations obtained on the kinetic study. The average concentration of T.V.A. during the kinetic study ranged from 16.40 to 18.77 mg/L, showing insignificant change with increased organic loading. This circumstance also shows that volatile acids do not accumulate beyond the neutralizing ability of natural buffers. During the experiment, the bacteria collaborated to degrade organic materials until the methane-producing bacteria transformed them into methane and carbon dioxide. This state also implies a sufficient population of methane-forming bacteria, and acidogenic bacteria's final products can be consumed at the same rate as when they were made, keeping the pH favourable for methane bacteria. It is possible to conclude that during the experiment, the anaerobic process achieved its optimal condition by achieving a satisfactory balance between methane and acidogenic bacteria.

Temperature is one of the significant aspects influencing the performance of wastewater treatment. Temperature is another crucial parameter influencing the biochemical conversion pathway, reaction rate, and input energy. Domestic wastewater treatment under temperature change demonstrates that increasing the temperature improves the overall process efficiency of the system [39]. In general, microbes and a consortium of bacteria that play a role in anaerobic reactors operate optimally at specific temperatures. So, paying attention to fermentation temperature conditions to maintain stability and prevent sudden temperature decreases or increases during the process is critical.

During the kinetic study, the temperature was relatively stable ($29 \pm 1^\circ\text{C}$), which showed that mesophilic bacteria were dominant in the reactor. According to [40], the optimal temperature is mesophilic ($25\text{--}45^\circ\text{C}$). The optimal temperature for anaerobic digestion is often in the mesophilic range ($28\text{--}35^\circ\text{C}$) and only a few below 30°C . Mesophilic conditions (temperature and inoculum) are optimal for processing waste mixtures to produce methane gas [14]. A study by [16] found that anaerobic wastewater treatment

reactors can be run at temperatures below 35°C , which reduces bacterial growth while keeping adequate biomass. Microbial communities can change at low temperatures where the diversity of alpha communities decreases in activity, but reactors can continue to work appropriately [28]. The relatively stable temperature during the experiment indicated substrate conversion, and its rate was steady [14].

The alkalinity concentration in wastewater is crucial for biological treatment because it affects the effectiveness of biological nitrification processes. In a wastewater treatment system, alkalinity evaluates the ability of wastewater to neutralize acids and is used to determine the buffer capacity of wastewater and sludge. In an anaerobic processing reactor, weak acid salts such as acetate, propionate, and hydrogen sulphide can be formed and contribute to alkalinity. Ammonia or hydroxide may contribute to the overall alkalinity of the water. During the kinetic investigation, the alkalinity ranged from 130 to 200 mg/L, considered a medium-strong concentration. The anaerobic process's alkalinity helps resist pH fluctuations produced by adding acids. The pH range during the kinetic study was relatively constant.

pH is essential in wastewater treatment because it influences process performance and efficiency. It is an essential component in chemical and biological wastewater treatment systems. pH and V.F.A. levels are critical for stabilizing the anaerobic digestive system and influencing hydrolytic acidification and methanogenic bacteria. Low pH or high V.F.A. concentrations indicate that the system is acid-inhibited. The ideal pH range for methanogenic bacteria is around 6.50 to 8.20, and their metabolic activity diminishes until they are blocked [41].

Organic Loading Rate (O.L.R) is a critical operational parameter in anaerobic digestion, governed by material properties and operating circumstances. O.L.R. refers to the daily chemical oxygen requirement (C.O.D.) or volatile suspended solids load (V.S.S.) provided into the reactor. Mesophilic single-stage digestion reactors typically have an O.L.R. of 1.0-1.7 kg V.S.S. m, or 1.72.9 kg C.O.D. $\text{m}^{-3} \text{days}^{-1.2}$ [42]. A study by [43] obtained the effect of continuously varying Hydraulic Loading Rate (H.L.R) and O.L.R. in field-scale reactors on T.S.S., C.O.D., and B.O.D. removal efficiency. Hydraulic loading and temperature reduced the efficiency of nitrogen and COD removal due to an increase in O.L.R., which slowed bacterial performance [44]. The experiment showed that the increase in O.L.R. tends to decrease efficiency.

However, substrate removal efficiency increased with the increase in H.R.T. Both O.L.R. and H.R.T. are the most commonly applied parameters in calculating the capacity of the anaerobic reactor. O.L.R. and H.L.R. are critical design parameters that affect the performance of wastewater treatment reactors. Hydraulic load and temperature inside the wastewater treatment reactor affect the efficiency of nitrogen and C.O.D. removal [44]. The effects of H.L.R. and O.L.R. variations and their combinations must be assessed to process C.O.D. Total [43]. Table 3 presents the characteristic of the control parameter.

Table 3. The characteristic of the control parameter

H.L.R., (L/d)	OLR, (mg.COD/L.d)	HRT, (d)	Alkalinity as CaCO ₃ (mg/L)	pH	Temp., °C	Inside V.S.S. (mg/L)	Eff. V.S.S. (mg/L)	TVA as Acetic Acid (mg/L)
4.1	600	3.4	159.3	6.7	30.0	32,038.38	2	17.79
6.3	1230	2.2	147.9	6.8	29.9	57,390	4	17.14
9.5	1300	1.5	143.6	6.7	30.0	69,188.6	4	16.40
11.2	1400	1.2	143.6	6.8	30.0	52,072.52	4.3	17.79
12.1	1800	1	157.1	6.7	30.0	55,409.21	4	18.77

Source: [15]

1.3.4 Kinetic Coefficients with Monod Model

The approach to scale-up describing the microbiology and substrate utilization in wastewater treatment systems is an essential aspect to consider. Sufficient data on kinetics need to be collected to be able to represent mathematically. Kinetic coefficients derived during the kinetic study of the reactor are presented in Table 4. The statistical analysis of the results using Equations (2) and (3) are shown graphically in Figures 3 and 4. Kinetic coefficients K_d and Y were derived from the experimental data by graphing values of $(Q.(S_I-S_E)/(X_R.V))$ versus $\frac{1}{SRT}$ (Figure 3), showing the straight line. Figure 3 shows that the value of K_d was 0.001 d^{-1} and Y was $0.062 \text{ kg V.S.S./kg C.O.D.}$. The value of K_d is then input into equation (3) to determine the value of K_s and μ_{max} were $52.16 \text{ mg/L C.O.D.}$ and 0.0021 d^{-1} respectively. K_s describes the concentration of the substrate where half of μ_{max} of the processing microorganism. Low K_s can be observed for microorganisms that acquire substrate quickly at low concentrations, while high values for ineffective microorganisms [45]. A study by [20] found that the kinetic coefficient K_d and Y were 0.0025 1/d and $0.1337 \text{ g VSS/g COD}$ respectively. Using values of Y and μ_{max} , the maximum substrate utilization rate (k) was defined $0.034 \text{ kg C.O.D./kg V.S.S.}$

Using K_d and μ_{max} , the minimum solid retention time (SRT_{min}) was defined ≈ 714 days. The Monod model's correlation coefficient was $\pm 0.8-0.94$. The values of the kinetic coefficients of the Tripikon-S reactor are presented in Table 4, which shows the values of interest.

Table 4. The kinetic coefficients of Tripikon-S

Kinetics Parameters	Values	Correlation coefficient
Y = Growth Yield (g VSS/g C.O.D.)	0.062	0,8
K_d = Specific Decay Rate (1/d)	0.001	0,8
μ_{max} = Maximum Specific Growth Rate (1/d)	0.002	0,94
K_s = Saturation Constant (mg/L) COD	52.16	0,94
k = Maximum Substrate Utilization Rate (g COD/g VSS d)	0.034	0,94

Source: [15]

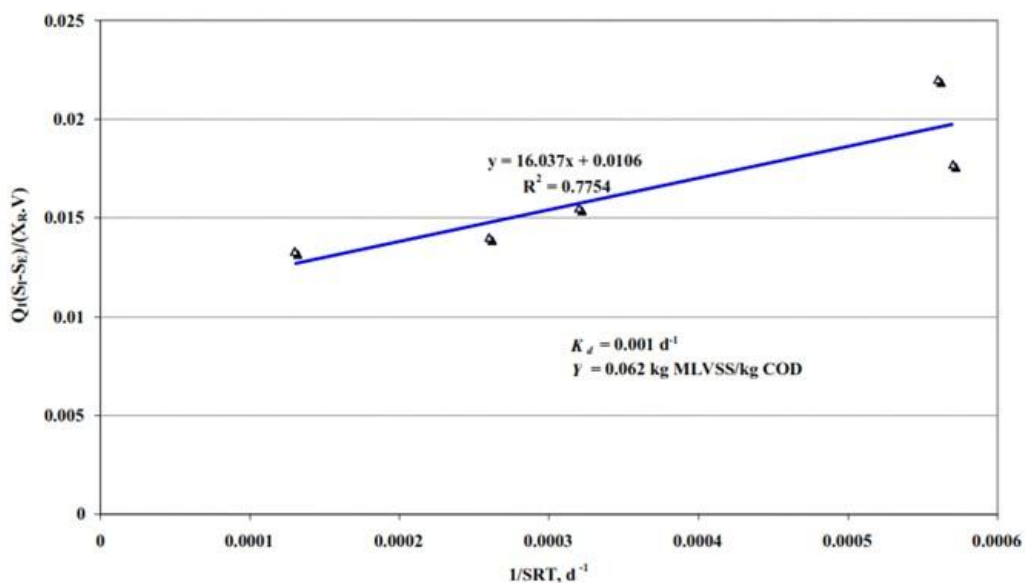


Figure 3. Plot of $\frac{Q.(S_I-S_E)}{X_R.V}$ versus $\frac{1}{SRT}$

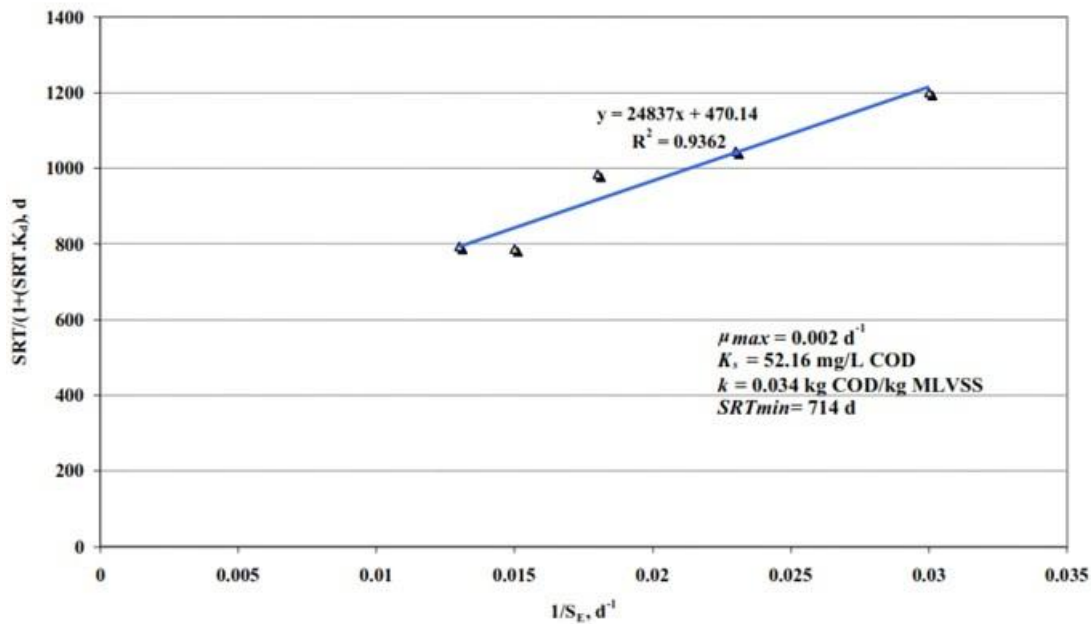


Figure 4. Plot of $\frac{SRT}{1+(SRT.K_d)}$ versus $\frac{1}{S_E}$

The Monod kinetics were generally adequate for modeling the Tripikon-S system's behavior. The Monod equation's mass balance quantitatively represents the link between microbial growth rate and substrate concentration. A thorough understanding of microbial growth and mortality dynamics in wastewater treatment reactors is required for efficient process control and manipulation[46]. Bacterial growth in a wastewater treatment reactor consists of four stages: lag, exponential, stationary, and death conditions, which can be determined using biomass concentration metrics [47]. When the environment is in favorable conditions for the growth of bacteria for their life, the bacteria that were initially dormant will be revived [17].

The kinetic coefficients can be used to assess the performance of Tripikon-S in large-scale applications. Kinetic coefficients can be used to assess the performance of wastewater treatment reactors in large-scale applications[20]. The use of Tripikon-S as a technology for domestic wastewater treatment or black water wastewater treatment, particularly in settlements, will be convenient and can be used as the primary and vital alternative to widely used technology choices, particularly for residential areas located on the banks of rivers, lakes, or other shallow waters, particularly in developing countries with little resources, little experience, and a shortage of skilled personnel. Tripikon-S is a practical solution to waste reduction because it is simple to install, requires little maintenance, and removes small volumes of fecal sludge.

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