IOP Conference Series: Earth and Environmental Science

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The 5th International Seminar on Science and Technology (5th ISST 2025) 30/10/2025 - 30/10/2025 Pamulang, Indonesia

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Preface

Climate Resilience and Sustainable Resource Management

Smart Technologies for Sustainable and Healthy Living

Circular Economy and Sustainable Innovation

Water, Energy, and Food Nexus for Resilient Societies

Preface

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Dear distinguished guests, colleagues, presenters, and participants,

It is my great honor and pleasure to welcome you to the 5th International Seminar of Science and Technology (ISST 2025), organized by the Faculty of Science and Technology, Universitas Terbuka. As the Chairwoman of this seminar, I am delighted to witness the continued enthusiasm and commitment of the academic and professional communities in supporting this international scientific forum.

This year, ISST proudly carries the theme "Advancing Science and Technology for a Sustainable and Resilient Future." This theme reflects our collective responsibility not only to advance scientific and technological innovation, but also to ensure that such advancements contribute to sustainability, resilience, and long-term societal well-being in the face of global challenges.

We are honored to welcome our distinguished keynote and plenary speakers, respected leaders, scholars, researchers, practitioners, and students from various institutions and countries. Your presence today demonstrates the strong spirit of collaboration and knowledge sharing that lies at the heart of ISST.

The 5th ISST is conducted in a hybrid format, enabling both on-site participation at Universitas Terbuka and virtual attendance through online platforms. This approach allows broader participation and reflects our commitment to inclusive and accessible academic engagement.

Aligned with our main theme, this seminar serves as a strategic platform for discussing cutting-edge research, innovative ideas, and practical solutions in science and technology that support sustainable development and resilience across sectors. Through keynote sessions, plenary discussions, and parallel scientific presentations, we hope this seminar will foster meaningful dialogue, interdisciplinary collaboration, and future research partnerships. Selected papers presented at this seminar will also be published in the *IOP Conference Series: Earth and Environmental Science*, providing an opportunity for participants to disseminate their research to a wider international audience.

I would like to express my sincere gratitude to Universitas Terbuka, particularly the Rector and the university leadership, for their continuous support. This conference was funded through the EQUITY WCU (Enhancing Quality Education for International University Recognition – World Class University) program. We gratefully acknowledge this support in making the event possible.

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To all presenters and participants, I encourage you to actively engage in discussions, exchange insights, and take full advantage of this academic forum. May ISST 2025 inspire new perspectives, innovative collaborations, and impactful contributions toward a sustainable and resilient future.

Finally, I wish all of you a productive seminar, insightful discussions, and good health throughout the event.

Thank you very much.

Chairwoman of ISST 2025
Vita Elysia, S.T., M.Sc., Ph.D.

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31. Dr. Ir. Edi Rusdiyanto, M.Si. Universitas Terbuka - Indonesia

Peer Review Statement

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Peer Review Statement

All papers published in this volume have been reviewed through processes administered by the Editors. Reviews were conducted by expert referees to the professional and scientific standards expected of a proceedings journal published by IOP Publishing.

- **Type of peer review:** Double Anonymous
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- **Number of submissions sent for review:** 30
- **Number of submissions accepted:** 10
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- **Average number of reviews per paper:** 1.07
- **Total number of reviewers involved:** 13
- **Contact person for queries:**
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Performance Evaluation and Kinetic Modeling of Modified Moving Bed Biofilm Reactor (MBBR) for Domestic Wastewater Treatment

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Performance Evaluation and Kinetic Modeling of Modified Moving Bed Biofilm Reactor (MBBR) for Domestic Wastewater Treatment

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Abstract. In an effort to mitigate the contamination of the river in DKI Jakarta, this study implemented a modified MBBR using K3 Kaldnes medium to treat domestic effluent. The kinetic model and the MBBR unit were compared in terms of the treatment of residential effluent at hydraulic retention times (HRT) of 0.75, 2, 3, and 4. Initial wastewater characterisation, reactor setup, seeding, acclimatization, and reactor operation were all part of the study procedure. The highest performance was achieved at 4 hours of HRT, with 83.78% COD removal efficiency, 78.89% BOD removal efficiency, and 83.92% TSS removal efficiency. The residence wastewater quality standards were fulfilled at 0.75 hours for COD and BOD at the outflow, however Ministerial Regulation No.68/2016 on the Environment and Forests was not met for TSS. Based on the following parameters: 65.56 mg/L COD (K_s $coefficient$), d13.25 day^{-1} (μ_{max} coefficient), 0.39 mgMLVSS/mgCOD (Y coefficient), and 0.05 day^{-1} (K_e coefficient), the Monod model provides the most comprehensive explanation for the MBBR process for COD removal. These findings show that MBBR is biologically very effective and kinetically well-suited for COD removal under the operating conditions.

1. Introduction

A Pollution Index (IP) research by DLH Provinsi DKI Jakarta (2023) found that DKI Jakarta waterways are contaminated [1]. Public health is seriously threatened by this extreme amount of water pollution, especially as it makes waterborne illnesses like diarrhea more common in the populations who live nearby. Overall, 165,966 persons in DKI Jakarta had diarrheal illnesses, with 40,418 of those instances occurring in West Jakarta [2]. In 2022, Indonesia's sanitation rate was 80.92%, with securely managed sanitation making up 10.16%, according to the Bappenas report (2023). Indonesia aimed for 90% appropriate sanitation and 15% safe sanitation by 2024. Thus, DKI Jakarta wastewater issues must be addressed. By delivering clean, safe, and adequate sanitation, this effort will support SDG 6.

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Activated sludge, lagoons, and the moving bed biofilm reactor (MBBR) may remove pollutants from wastewater. The MBBR wastewater treatment system breaks down organic pollutants aerobically and anaerobically using microbes [3]. Microbial development has four phases: adaptation (lag), exponential, stationary, and death [4]. The solid load forms a biofilm on biocarrier medium because microorganisms thrive there [5]. Previous research found that adding 40% of Kaldnes 1 (K1) medium with an 8-hour hydraulic retention time (HRT) decreased the COD, BOD, and TSS of tempeh industrial wastewater by 87.89%, 86.91%, and 85.63%, respectively [6]. Therefore, this study used Kaldnes 3 (K3) media. K3 medium exceeds K1 with its 500 m^2/m^3 specific surface area and 19 baffles [7]. K3 media's surface area and baffles allow thicker biofilm development and more microorganism growth [8].

Parameter analysis was performed utilizing 0.75, 2, 3, and 4 hour HRT variations in this research. Kinetic calculations also predicted treatment system performance, optimized operations, and assessed design outcomes [9]. Monod and Contois kinetics were used in this investigation. Shorter HRT fluctuations may be used to increase STP processing capacity, and the outcomes of the kinetic calculations should provide practical predictions that may be used on a field scale.

This study examine how well the Moving Bed Biofilm Reactor (MBBR) can remove of COD, BOD, and TSS from household wastewater using the Kaldnes 3 (K3) medium with different HRT and quality standards from Regulation No. 68 of 2016 which is in charge of forests and the environment.

2. Methodology

2.1 Biofilm Reactor Moving Bed Preparation

For aerobic treatment, aerators are used in the upflow MBBR reactor. The rectangular reactor is 40 cm long, 25 cm broad, and 28 cm high. Figure 1 shows an MBBR reactor modification with fluidized medium and an effluent separator 5 cm from the effluent. K3 media occupies about 40% of the reactor capacity. Pumps feed wastewater straight into the K3-media-containing MBBR reactor, which runs continously. The reactor operated with HRT variations of 4, 3, 2, and 0.75 hours at SPALDT Sentra Primer Barat, Kembangan, West Jakarta, while the Environmental Laboratory, Universitas Trisakti, Jakarta, tested the MBBR reactor's parameters.

2.2 Acclimatization and Seeding

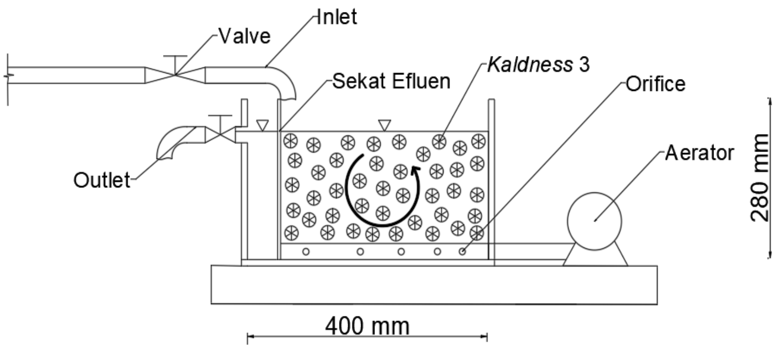

Figure 1. Moving Bed Biofilm Reactor Schematic

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Reactor functioning involves seeding and acclimatization. The Tangerang Tanah Tinggi WWTP aeration basin unit supplied the biomass sample for seeding. To acclimatize, seeding continued until MLVSS biomass content reached 4000 mg/L [4,10]. The glucose substrate was regularly replaced with pure wastewater to continue acclimatisation. At 75:25, 50:50, 25:75, and 0:100, glucose was combined with clean wastewater for acclimatization. Acclimatization phase shift occurs when MBBR reached steady-state.

2.3 Kinetics Model

Wastewater treatment specialists can anticipate system performance, adjust operating parameters, and assess design outcomes using substrate kinetics [9]. Monod and Contois kinetic models were examined in this work. Table 1 lists mathematical formulas for substrate kinetics.

Table 1. Different removal kinetics mathematical expressions

Kinetic Model	Equation	References
Monod	$\mu = \mu_{max}\left(\frac{S}{K_s + S}\right)$	[11]
	$\frac{(S_o - S_e)}{X_1\theta_i} = \frac{k_e}{Y} + \frac{1}{Y}.\frac{1}{\theta_c}$	
	$\frac{\theta_i}{1 + k_e\theta_i}S_e = \frac{K_s}{\mu_{max}} + \frac{1}{\mu_{max}}S_e$	
Contois	$\mu = \mu_{max}\left(\frac{S}{K_s X_i + S}\right)$	[12]
	$\frac{\theta_c}{1 + \theta_c k_e} = \frac{K_s X_i}{\mu_{max} S_e} + \frac{1}{\mu_{max}}$	

3. Results and Discussion

3.1 Domestic Wastewater

For this study, several criteria were used to determine the quality of the treated household wastewater. These criteria include BOD, COD, TSS, O&G, ammonia, N-total, pH. In accordance with Ministerial Regulation No. 68 of 2016, the concentrations of COD, BOD, and TSS were higher than what is recommended in the Domestic Wastewater Quality Standards. 144.71 mg/L of influent COD exceeded the quality limit of 100 mg/L. BOD and TSS exceeded standards. Therefore, a residential wastewater treatment procedure, such as a Moving Bed Biofilm Reactor (MBBR), is needed to fulfill criteria and not contaminate the environment. According to effluent requirements, BOD, COD, and TSS must be eliminated by 80%, 93%, and 94%. Table 2 shows raw household wastewater parameters and effluent standards.

Table 2. Comparison between effluent and untreated household wastewater

Parameter	Unit	Results	Effluent Standards*	% Removal needed
Phosphate	mg/L	15.60	–	75%
Ammonia	mg/L	0.53	10	20%
Oil & Grease	mg/L	1.45	5	61%
TSS	mg/L	136.24	30	94%
COD	mg/L	144.71	100	93%
N-Total	mg/L	17.42	–	98%
BOD	mg/L	52.07	30	80%
pH	-	7.33	6 – 9	satisfy quality requirements

* The cleanliness criteria for home waste are established by regulation 68 from the Ministry of Forestry and the Environment in 2016.

3.2 Seeding & Acclimatisation

The process of seeding began with 806 mg/L of Mixed Liquor Volatile Suspended Solid (MLVSS). There was a steady range of 3269–4799 mg/L for MLVSS from day 40 to day 51. This study recorded 4799 mg/L MLVSS concentration after 51 days of seeding. The increase of MLVSS indicates the growth of heterotrophic bacteria that use organic matter as a substrate.

Acclimatisation was carried out after the MLVSS concentration reached 4799 mg/L. Four steps with varied ratios comprised this technique. The stepwise increase in substate concentration is important because wastewater may contain complex compound and microorganism require time to adapt their metabolic pathways and enzyme system. The steps were adjusted until COD removal reached a stable level (±5%). As the biofilm structure developed, microbial activity and substrate utilization became more efficient, thereby improved COD removal. MLVSS concentration reached 4282 mg/L and COD elimination 83.33% after 38 days. When the fourth acclimation stage achieved steady state with an 81.25-83.33% COD elimination range on days 36 and 38, the reactor could operate continuously.

Subtrate addition induced COD concentration fluctuations during acclimatisation, allowing microorganisms to adapt to wastewater. Biofilm production during acclimatisation might also impact wastewater organic matter decomposition. Active microbes in effluent, temperature, pH, DO, and nutrient availability may also affect COD elimination [13].

3.3 MBBR Reactor Performance

3.3.1 COD Removal and Hydraulic Retention Time

The laboratory study found that after 4 hours of HRT, influent COD concentration averaged 134.86 ± 143.10 mg/L, with effluent COD of 21.56 ± 19.98 mg/L (Figure 2). The standard deviation-refined total COD concentration dataset. Kinetic analysis only used standard deviation-filtered data. Days 1–3, 5, and 8–19 showed lag, exponential, and stationary phase of microbial growth

(Figure 2). The initial HRT variation showed COD removal effectiveness vary from 70% to 92.11%, peaking on day 15 (Figure 2). The system stabilized on day 12, 72 detention cycles.

The amount of COD in the input water was 129.34 ± 124.53 mg/L after 3 hours of HRT. The amount of COD in the output was 27.82 ± 27.07 mg/L on average (Figure 2). Days 22–24, 30–31, and 31–33 were the microbial lag, exponential, and stationary phases (Figure 2). From 66.67% to 88%, COD elimination effectiveness peaked on day 30. With 80 detention cycles, one obtained steady conditions on day 30 which is the tenth operating day in a HRT of three hours.

Input COD levels were 135.36 ± 146.64 mg/L after 2 hours of HRT, and output COD were 36.85 ± 29.33 mg/L (Figure 2). Phases 36–40, 43, and 45–47 were lag, exponential, and stationary (Figure 2). The rate at which COD was removed hit 83.33% on day 45. The hydraulic retention time for the 9th operating day, Day 43, was 2 hours. After 108 detention cycles, the system reached steady state.

Within 0.75 hours of HRT, the COD levels in the input were 122.73 ± 119.57 mg/L and those in the output were 41.51 ± 46.25 mg/L (Figure 2). Daily 50–51, 52, and 53–54 saw microbial lag, exponential, and stationary phases (Figure 2). COD elimination efficiency peaked at 83.33% on day 52 after decreasing from 56.00%. After 160 detention cycles, steady state was reached on day 53, the fifth day of operation, with a hydraulic holding time of 0.75 hours of water. Lower hydraulic retention period reduces COD removal efficiency. COD elimination peaked after 4 hours of hydraulic retention, indicating that longer detention durations improve wastewater-microorganism interaction and organic matter decomposition [14]. The COD of the sewage met the Indonesian domestic wastewater standard set by Rule 68/2016 of the Ministry of Forests and the Environment within 0.75 hours when the system was working at its best.

3.3.2 BOD Removal and Hydraulic Retention Time

An average removal effectiveness of 78.89% was found in influent BOD concentrations of 44 to 52 mg/L during 4 hours HRT (Figure 3). Top BOD removal was 81.82%, decreasing 44 mg/L to 8 mg/L. Fluidisation and sedimentation break down organic materials into new microbial cells, lowering effluent BOD [15]. Days 1, 12, and 5–12 showed lag, exponential, and stationary phase microbial growth. The system was stable at 60 detention cycles on day 10.

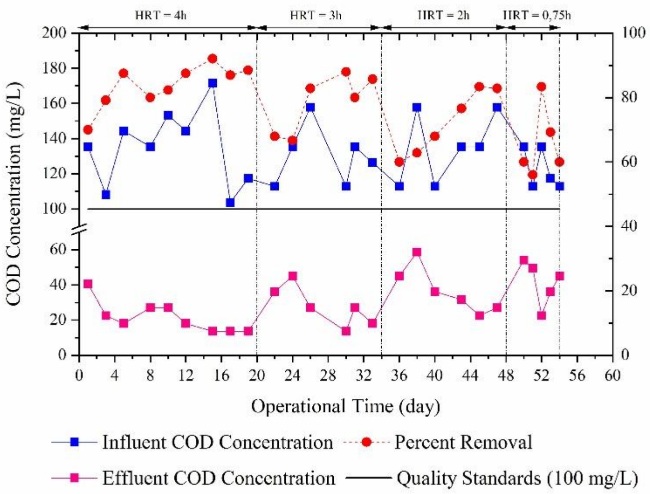


Figure 2. Variations in HRT affect MBBR COD parameter removal

Influent BOD concentrations varied from 42 to 52 mg/L after three hours of HRT, with an average removal efficacy of 75.05%. BOD was 10–14 mg/L effluent. On days 24, 30, and 26–33, microbial lag, exponential, and stationary phases occurred. On day 31, the eleventh operational day, a stable state was reached after 88 detention cycles and a 3-hour hydraulic retention period.

Influent BOD concentrations varied from 44 to 52 mg/L after 2 hours of HRT, with an average removal effectiveness of 70.53%. Figure 5 shows that the effluent was 12–16 mg/L. On days 38, 45, and 45–47, microbial lag, exponential, and stationary phases were observed. Day 43, the ninth operational day, produced 108 steady-state detention cycles at a 2-hour hydraulic retention period.

The final concentrations of the effluents were 18 mg/L, the average removal efficiency was 63.13% and the values of the BOD were 46-52mg/L (Figure 3). Days 52, 52, and 52–54 were the microbial lag, exponential, and stationary phases. The deviation that followed after 128 cycles of detention came to a stable point on day 38 which is the fourth day of operation and HRT was 0.75 hours.

BOD removal averaged 78.89% over 4 hours of HRT (Figure 3). Flow rate changes and decreased microorganism-organic substrate contact time reduce removal efficacy for shorter hydraulic retention periods [16]. However, BOD removal effectiveness did not drop significantly over hydraulic retention duration fluctuations, possibly owing to reactor oxygen supply ensuring successful microbial decomposition [17]. There was a 0.75-hour HRT, which in accordance with the requirement Regulation 68/2016 of the Indonesia Ministry of Environmental and Forestry stated that it is necessary for the sewage to meet standards for domestic wastewater quality.

3.3.3 Impacts Hydraulic Retention Time on the Removal of TSS

Following 4 hours of HRT, the lab observed an average influent TSS concentration of 141.78 ± 128.29 mg/L and an effluent TSS of 21.67 ± 16.43 mg/L (Figure 4). Kinetic analysis TSS concentration dataset refined by standard deviation. Day 15 removed TSS the most, from 195 to 16 mg/L. Days 1–3, 5, and 8–15 were microbial lag, exponential, and stationary phase (Figure 4). Day 10 indicates 60 detention cycles and stable state.

About 137.0 ± 120.2 mg/L of TSS was in the influent, and about 23.5 ± 18.75 mg/L was in the output (Figure 4). Elimination of TSS was 69.52% to 89.59%. The microbe lag, exponential, and stable stages occurs every day from days 22 to 24, 26 to 33, and 26 to 33. On day 30, the 10th day of operation at 3-hour HRT, the state became steady after 80 detention cycles.

The inflow (TSS) concentration was 100.8 ± 104.4 mg/L and the outflow (TSS) concentration was 28.5 ± 18.75 mg/L as mentioned at HRT of two hours, which means that the removal efficiency was 60.82 and 81.90 percent. Two types of phases—microbial lag and exponential—took place on days 36–38, 45, and 43–47. A HRT of two hours on the ninth day of running brought about stability on Day 43.

Figure 4 shows that during a 0.75-hour HRT, the influent had a TSS concentration of 113.4 + 116.5 mg/L, whereas the effluent had a concentration of 38.0 + 36.25 mg/L. A TSR between 55.45 and 72.09% does not meet the requirements of regulation No. 68 of 2016 from Indonesia's Ministry of Environment and Forestry. On days 50–51, 52, and 53–54, microbial lag, exponential, and stationary phases occurred (Figure 4). A total of 128 steady-state operating day five (Day 52) detention cycles was observed when starting with a HRT of 0.75 hours.

Operating optimally, TSS removal efficiency was highest after 4 hours of HRT. At 2 hours of

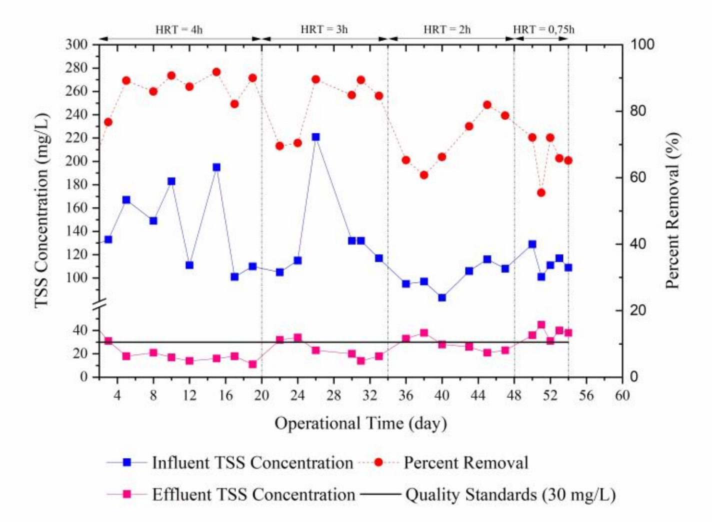


Figure 3. MBBR's TSS parameter removal based on HRT fluctuations

HRT, when effluent quality reached the legal level, the optimal condition—the fastest time to create compliant effluent—occurred.

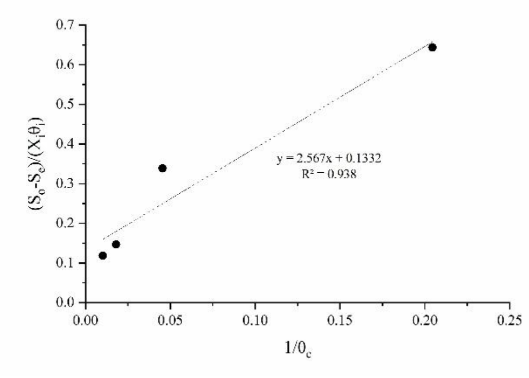
The adherence of suspended particles to the Kaldnes K3 medium, where biofilm development takes place, is responsible for the drop in effluent TSS content. Microbial cells attached to the medium progressively separate and spread into the bulk liquid, demonstrating dynamic behavior in biofilms. Increased TSS in the effluent is a result of biofilm solids detaching, which raises the removal efficiency overall. The decrease in TSS removal effectiveness after 0.75 hours of HRT was probably due by biofilm sloughing.

3.4 Kinetics Analysis Parameters

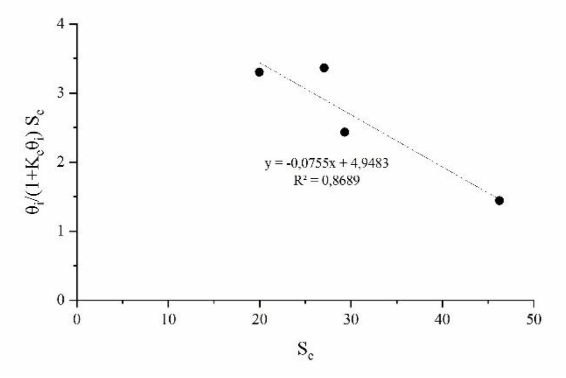
Kinetic analysis predicts biological reactors' wastewater pollutant removal performance.

3.4.1 Microorganism Growth Monod Kinetics

The yield coefficient (Y) of the COD removal was 0.39mg MLVSS/mg COD (Figure 5a). This measurement fulfilled the criterion 0.3025–0.77 mg MLVSS/mg COD [18,19]. A high Y value shows that microbes can convert a lot of organic materials [20]. A higher Y value might boost microorganism growth rate (μ_{max}).



(a)



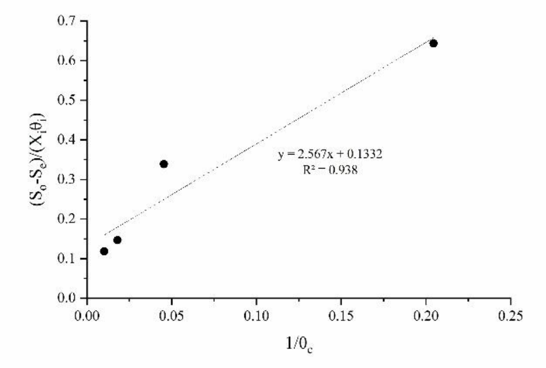
(b)

Figure 4. On COD, monod kinetics for calculating (a) K_e and Y and (b) μ_{max} and K_s

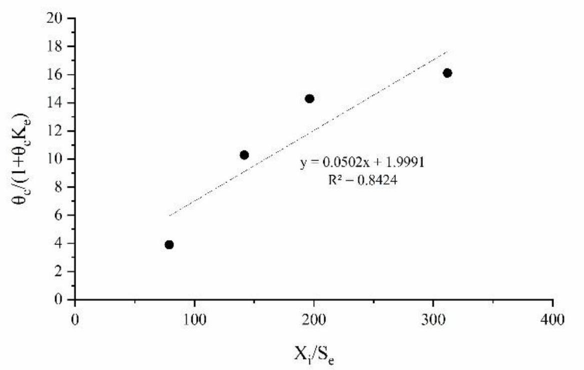
The analysis found μ_{max} of 13.25 days-1 for COD removal (Figure b). The μ_{max} value for COD removal in activated sludge reactors surpasses the 2-10 day^{-1} range compared to publications [10]. Previous research found a μ_{max} value of 13.44 days^{-1} for hybrid MBBR treatment of industrial waste [21]. A low K_e suggests bacteria can live and degrade substrate more efficiently [22]. A kinetic rate constant K_e of of 0.05 day-1 was reported as the result of the inquiry. This value was within the usual range of 0.03 to 0.07 day^{-1} (Figure 5a) and fulfilled the criteria set forth in the literature [23]. Those organisms with a lower substrate affinity constant K_s have a greater propensity to take up the substrate, so that the utilisation efficacy at lower than optimal concentrations is increased. The value of COD removal rate constant K_s was estimated to be 65.54 mg/L COD as shown in Figure b.

3.4.2 Growth of the Microorganisms in the Contois Kinetics Model

The yield coefficient (Y) and microbe death coefficient (K_e) are found using methods similar to those used by Monod kinetics. In Monod kinetics, the values of K_e and Y are the same compared to Contois. This shows that both the medium and the quantity of microbes affect the rate of growth. When Contois kinetics were used, COD was eliminated with an endpoint of K_s equals 0.01 mmol/L COD/mg MLVSS and μ_{max} equals 0.27 day^{-1} (Figure b). When compared to Monod kinetics, the values of K_s were 65.56 mg/600mg MLVSS and μ_{max} were 13.25/day^{-1}. The differences in the Monod and the Contois kinetics are seen and it can be explained by the different methodologies adopted.



(a)



(b)

Figure 5. Using Contois kinetics, determine K_e and Y (a) and μ_{max} and K_s (b) on COD

That which differentiates between the parameters obtained from the two kinetic models indicates that the microbial growth in the reactor was influenced not only by substrate concentration but also by biomass density. In the Monod Kinetics model, microbial growth is assumed to depend solely on substrate concentration, while the effect of biomass concentration is not explicitly considered. In contrast, the Contois Kinetics model incorporates the ratio between substrate concentration and microbial biomass, making it more suitable for systems with high biomass concentrations such as biofilm reactors. The relatively lower $K_S$value obtained from the Contois model suggests a higher apparent substrate affinity under biomass-dependent conditions, while the lower μ_max value reflects growth limitations caused by microbial competition and diffusion resistance within the biofilm. Conversely, the higher μ_max predicted by the Monod model may overestimate the intrinsic microbial growth potential because it does not account for biomass-related limitations. These differences indicate that Contois kinetics may better represent substrate utilization behavior in systems with dense microbial populations, where interactions between substrate availability and biomass concentration significantly influence the overall biodegradation rate.

4. Conclusion

With COD removal efficiency of 83.78%, BOD 78.89%, and TSS 83.92%, 4 hours HRT has best performance. The COD and BOD standards stipulated by the Republic of Indonesia's Rule 68/2016 of the Ministry of Forests and the Environment, have been met for all HRT varieties. At 0.75 hours, the system failed the TSS quality criterion. Furthermore, the Monod model best described biological elimination. With an R^2 value of 0.938, we can say that the yield coefficient (Y) of the Monod kinetic framework is 0.39 MGMLVSS/day COD, K_e is 0.05 day-1 for the decay constant, μ_{max} is 13.25 day^{-1} for the maximum specific growth rate, and K_s is 65.56 MGMLVSS/day COD L for the half-saturation constant. Moving Bed Biofilm Reactor (MBBR) systems using the K3 medium have been found to be effective in the treatment of domestic wastewater. This paper explains how the treatment using MBBR works and gives the kinetic data that can be used for designing scale-up plant and making it run well.

Acknowledgement

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