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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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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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.

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Moving Bed Biofilm Reactor (MBBR) System on Kaldnes Media for Removing Ammonia and Phosphate in Domestic Wastewater

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Moving Bed Biofilm Reactor (MBBR) System on Kaldnes Media for Removing Ammonia and Phosphate in Domestic Wastewater

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Abstract. Domestic wastewater is a significant contributor to water pollution in Jakarta. Successful waste treatment using the Moving Bed Biofilm Reactor (MBBR) technology should solve this problem. N-total and phosphate removability kinetics are measured in K3 Kaldnes medium to assess MBBR performance. This research was conducted on a laboratory scale, with variations in Hydraulic Retention Time (HRT) of 4, 3, 2, and 0.75 hours, using 40% media filling. The study findings revealed that variation in HRT gave the highest removal, which was 4 hours, and this gave 89.86% removal of phosphate concentration and 86.40 removal of ammonia concentration. The Stover-Kincannon equation has the best phosphate parameter kinetics, with R^2 of 0.9992 and maximum rate kinetics of 14.45mg/L.day and 12.46 mg/day. The ammonia parameters, such as the outlet concentrations, were within the Government Regulation No. 22/2021 quality requirements of the class III river water, and phosphate was below the stipulated quality requirements. The phosphate parameter, however, complies with the quality benchmarks at the U.S. Environmental Protection Agency (2009). Overall, the reactor displays good nutrient removal kinetics, but further development is required to attain full compliance with national phosphate regulations.

1. Introduction

The issue of sanitation, particularly open defecation, is a serious concern because it affects the pollution of water sources and the spread of diseases, such as diarrhoea. Data shows that diarrhea is still a leading cause of death in Indonesia, which is 14.5% in the 2020 Indonesian Health profile [1]. Water pollution in big cities, such as Jakarta, is not only caused by industrial activities, but also by domestic activities that continue to increase with population growth. Wastewater from domestic activities contributes 60% of pollution in water bodies [2,3]. Domestic waste, which consists of feces (blackwater) and greywater, is a major contributor to water body pollution.

The availability of clean water is so essential for human life that it is one of the main goals in sustainable development (SDGs). Indonesia has shown progress in improving access to proper sanitation, reaching 80.92% by 2022. DKI Jakarta is even higher, reaching 92.79%. However, access to safe sanitation is still a challenge, with the national figure only reaching 10.16% by 2022. The Indonesian government has set ambitious targets to achieve 100% access to improved sanitation and 30% safe sanitation by 2030 [4].

To overcome this problem, a biological stage of domestic wastewater treatment is necessary, which involves the use of microorganisms to break down organic compounds and reduce nitrogen levels in domestic wastewater. Due to its architecture, Moving Bed Biofilm Reactor (MBBR) uses biofilm, a fluidised growth mechanism [5]. Its advantages include a compact design that allows for more efficient use of space, reduced sludge production, and no issues with sludge bubbling [6,7].

There is a wastewater treatment plant (WWTP) in West Jakarta, known as SPALD-T Sentra Primer Barat, which specifically treats wastewater from the South Kembangan and Meruya areas. In the processing process, SPALD-T uses MBBR technology with K3 Kaldness media and an HRT of 8 hours. In the study, the removal of ammonia from secondary wastewater was achieved using an MBBR with three types of media: K3 Kaldnes (500 m^2/m^3), K5 Kaldnes (800 m^2/m^3), and M (1200 m^2/m^3), with a 30% media filling rate [8]. Each medium was able to remove ammonia by 87.3%, 71.8%, and 47.2%, respectively. In comparison, another study focusing on processing of tempeh industry wastewater with MBBR using K1 Kaldnes media, as much as 0%, 20% and 40%, and in HRT of 0, 2, 4, 6, and 8 hours, ammonia removal by 87.98% and phosphate removal by 82.93% were achieved at the optimum media variation of 40% [9].

Some versions of the K3 Kaldnes media and HRT that are shorter than the SPALD-T Sentra Primer Barat are used to remove phosphate and ammonia-filled household wastewater for 4, 3, and 0.75 hours. This study also discuss about 2nd Order and Stover-Kincannon dynamics. The study used Government Regulation 22/2021 of Indonesia on Environmental Protection and Management and Ministry of Environment and Forestry Regulation 68/2016 on Domestic Wastewater Quality Standards. This research evaluates MBBR performance with K3 Kaldnes media and the kinetics of the removal of the parameters.

2. Methodology

2.1 Seeding and Acclimatisation

The process was done to increase the microorganism population by the addition of activated sludge in batches through the use of domestic wastewater in the Tanah Tinggi WWTP aeration basin. It was seeded by the provision of nutrients in the form of glucose (C6H12O6), done in a batch system, and over 51 days. The seeding was done until the appropriate level of the MLVSS was taken to around 4000 mg/L, as required by the MLVSS standard of the reactor that varies between 4000 and 10000 mg/L [10,11]. After obtaining the determined biomass concentration, the acclimatisation stage can be continued. This process aims to establish a stable culture of microorganisms that can adapt to domestic wastewater. This process is carried out by adding domestic wastewater with different concentrations. The acclimatisation process is carried out over 38 days, until a biofilm forms on K3 Kaldnes media. The development of microorganisms can be observed from the increasing value of MLVSS and COD efficiency, which reaches a stable condition with a difference in efficiency of ±5 % compared to the previous cycle.

2.2 Continous Process

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The experiment was done within a duration of 54 days. It was performed by continuously changing the HRT, which had a running process. The HRT in the MBBR process is 4 hours, 3 hours, 2 hours, and 0.75 hours. Discharge rates are 4.5, 6, 9, and 18 L/h. At this stage, domestic wastewater flowed from the equalisation basin at the West Sentra Primer SPALD-T using a pump into the MBBR reactor, which had been filled with K3 Kaldnes media, ranging from 0% to 40%, with a predetermined variation in discharge and HRT. When the reactor is stable, flow rate and HRT are changed.

2.3 Parameters Analysis

The data results obtained from sample testing are analysed for the parameters phosphate and ammonia. The Ministry of Environment and Forestry Reg. No. 68 of 2016, the national water waste requirements under PP F.o. water No. 22 of 2021, and the EPA quality standards from 2009 were used to compare this test.

2.4 Kinetics Study

MBBR, 2nd-Order, and StoverKincannon kinetics are used to treat household wastewater. The kinetic models make it possible to predict the quality of operation of the entire treatment system, to optimise the operating conditions, as well as measure the results of the design with reference to the biological model applied. Table 1 shows the kinetic formula.

3. Results and Discussion

3.1 Domestic Wastewater Characteristics Preliminary Analysis

Preliminary analysis included N-total, phosphate, ammonia and oil and grease, which are the main parameters in the study. Sampling points were determined to be taken at the barscreen inlet and equalisation outlet of the SPALD-T Sentra Primer Barat. Table 2 demonstrates the initial state of the domestic wastewater, which will be the target of the research.

Table 1. Mathematical solutions of the diverse kinds of removal kinetics

Kinetic Model	Equation	Equation Number	References
Second-Order	$\frac{S_o \times HRT}{S_o - S_e} = HRT$	(2.1)	[12]
Stover–Kincannon	$\frac{V}{Q(S_0 - S_e)} = \frac{K_s V}{\mu_{max} Q S_0} + \frac{1}{\mu_{max}}$	(2.2)	[13]

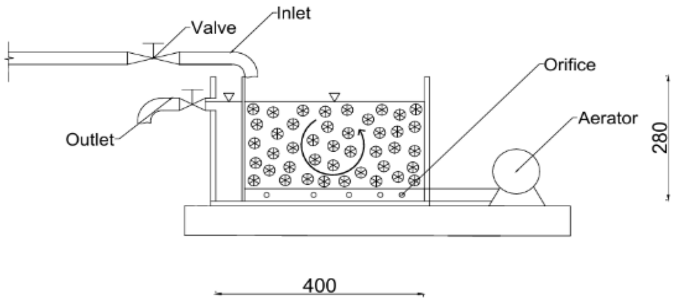


Figure 1. Schematic of MBBR reactor

As indicated in Table 2, the household wastewater quality test before treatment demonstrates that ammonia, oil, and grease are below the effluent limitations stipulated by Environment and Forestry Regulation 68/2016. In class III river water, which is used to raise fresh fish, animal livestock, water to irrigate crops, and other purposes, it was compared to national water quality standards for ammonia, N-total, phosphate, oil and grease, and the 2009 U.S. Environmental Protection Agency for N-total and phosphate concentration.

Table 2. Results of preliminary analysis of domestic wastewater characteristics

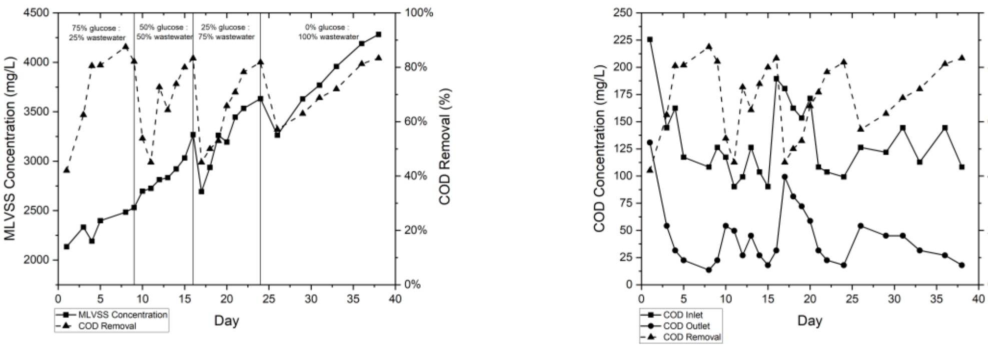
No	Parameters	Unit	Results	Quality Standards		
				Regulation of the Ministry of Environment and Forestry No. 68/2016	Government regulation No. 22/2021 in class III in river water	USEPA (2009)
1	Ammonia	mg/L	0,38 – 0,59	10	0,5	-
2	N-Total	mg/L	11,1 – 16,9	-	25	6
3	Phosphate	mg/L	11,3 – 16,6	-	1	3
4	Oil and Grease	mg/L	0,58 – 0,93	5	1	-

3.2 Seeding and Acclimatisation

In this study, seeding was performed by multiplying microorganisms in a 30-litre container, specifically a bucket. During the seeding process, glucose and new wastewater were added to provide food or nutrients for the microorganisms. The extent of growth in microorganisms was expressed by an increase in MLVSS concentration between 806.3 mg/L and 4799.3mg/L. During days 1 to 8, there were increments in the MLVSS concentration. This result was not particularly significant because the added microorganisms were still adjusting to the reactor conditions to grow and attach to the surface of the media, forming biofilms. On day 10, 5 L of new sludge and 9.14 grams of glucose were added because the concentration had decreased to 1528 mg/L. After adding nutrients, there was an increase in MLVSS until day 22, which amounted to 2025 mg/L.

It was observed that, on the 24th day, the MLVSS concentration decreased again to 1317.5 mg/L. Afterwards, 5 L of fresh sludge was introduced, and the MLVSS kept rising on the following day up to 3114.9 mg/L on the 38th day. This was the case because the new sludge added was of a high number of active microorganisms. When added to the reactor, the total amount of microbial biomass in the system increases significantly. As it was further observed, the next day, another steep rise in MLVSS took place until the desirable MLVSS concentration of 4799.3mg/L was achieved.

After the growth of microorganisms has met the requirements with a minimum total microorganism of 4799.3 mg/L, the process of adaptation the microorganisms in the reactor can be carried out. Acclimatisation was carried out with the longest HRT of 4 hours for 38 days. The concentration of MLVSS reached at the seeding stage decreased drastically to 2134.9 mg/L due to changes in environmental conditions during the transition to the acclimatisation process. Therefore, the multiplying process was repeated until a sufficient amount of MLVSS was achieved. The growth in the number of microorganisms and the COD removal efficiency that occurred during acclimatisation can be seen in Figure 2. The COD concentration removal graph shows that at the beginning of the adaptation stage, with 25% addition of pure wastewater and 75% clean water with glucose mixture, the COD removal efficiency only reached 42% and fluctuated on the following day due to the adapted of microorganisms to the wastewater used from the West Primary Centre SPALD-T. At the beginning of the acclimatisation process, the population of microorganisms capable of degrading COD was still small. However, on days 8 and 9, the condition stabilised, with efficiency reaching 82.14-87.50%. At the addition of 75% pure wastewater, the initial COD removal efficiency decreased to 45%, before it increased to 81.82% by day 24, reaching a stable condition. Until the use of 100% pure wastewater with initial adaptation, the COD removal efficiency reached 57.14%. At 108.28 mg/L input and 18.05 mg/L output, it reached 83.33% under steady circumstances.



(a) **(b)**

Figure 2. Microorganism growth and COD removal efficiency in the acclimatisation process

The concentration of MLVSS varied in the acclimatisation stage in this study. In the filling stage, 0% glucose and 100% wastewater had the maximum concentration of 4282 mg/L and 83.33 COD removal efficiency on day 38. Assuming a removal difference of ±5%, efficiency is stable and may continue to the main process.

3.3 HRT Impact on Parameters

3.3.1 HRT Impact on Phosphate Removal

The test results of phosphate levels before treatment obtained concentrations ranging from 10.12 - 16.71 mg/L. Figure 3 displays test analysis at 4, 3, 2, and 0.75 hours of HRT.

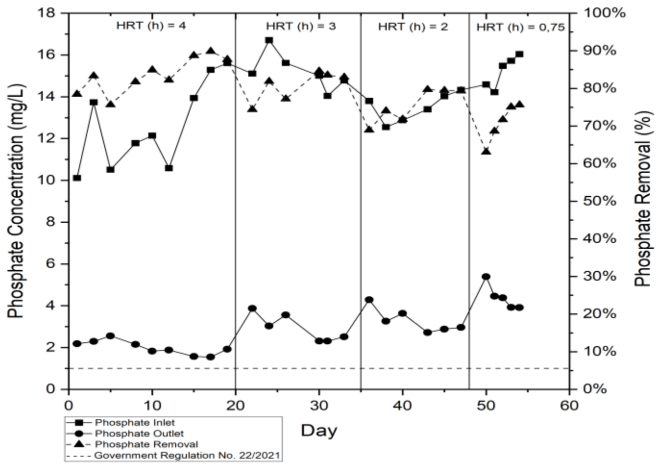


Figure 3. Graph of Phosphate removal to HRT

The SPALD-T Sentra Primer Barat had an average phosphate consentration of 12.63 mg/L when it came in and 1.99 mg/L when it left after MBBR reactor and K3 Kaldnes medium treatment. It took an average of 4 hours to remove 83.63 percent of the phosphate. The MBBR at HRT 4 hours can process phosphate at a rate of 0.06 kg $PO4/m^3$/day, while the media in the MBBR reactor has an ability of 0.002 kg $PO4/m^2$/day. During the initial operation of the reactor with a 4-hour HRT, there was a variation in the efficiency of phosphate removal on the initial day to 12 days before a stable level could be achieved at 90 times HRT, with an efficiency variation of about 5 percent on the final 3 data points. As such, the operation could be continued with a 3-hour HRT. If the outlet phosphate concentration is compared to the U.S. Environmental Protection Agency 2009 quality standard of 3 mg/L, the 4-hour HRT fulfilled the predetermined quality standard. In the meantime, the phosphate outlet concentration of HRT 4 hours is compared to the requirements of Government Regulation No. 22/2021, which is 1 mg/L of class III in river water, which also does not comply.

At 3 hours HRT, the average input concentration was 15.21mg/L and the output concentration was 2.93mg/L, with 80.77% phosphate elimination. A 3-hour MBBR can process 0.10 kg $PO4/m^3$/day of phosphate, whereas the medium can process 0.004 kilogram $PO4/m^2$/day. At the beginning of the operation of the reactor, it fluctuates because microorganisms need time to adapt, rendering them unable to optimally degrade pollutants, thus resulting in the removal efficiency at the beginning of HRT being low, until on the 30th day (the 10th day of operation with HRT 3 hours) or for 80 times HRT has experienced stable conditions with a difference in efficiency of ± 5%, where HRT can be reduced to 2 hours. It meets quality criteria unlike the 2009 EPA guidelines. HRT 3 hour phosphate discharge exceeds Government Regulation No. 22/2021 class III river water limits.

At HRT 2, phosphate removal efficiency averaged 75.55%, with input at 13.50 mg/L and departure at 3.29 mg/L. After 2 hours of HRT, the MBBR can process 0.12 kilogram $PO4/m^3$/day of phosphate, whereas the medium can process 0.004 kg $PO4/m^2$/day. The efficiency of the removal of phosphates followed a fluctuation pattern in the first days of the reactor operation between days 36 and 40, until on day 43 (9^{th} day of the reactor operation where HRT had a 2-hour duration), the HRT might be lowered to 0.75 hours as the HRT was in a stable state with a variation of efficiency within a range of plus and minus 5 percent. Outlet concentration violates 2009 EPA and Government Regulation No. 22/2021 class III river water regulations.

At 0.75 hours, the mean input concentration was 15.21mg/L and the output concentration was 4.41MG/L, indicating 70.82% elimination efficiency. A 0.75-hour MBBR can process 0.35 kilogram PO4/m^3/day of phosphate, whereas the medium can handle 0.01 kg PO4/m^2/day. At the beginning of the operation of the reactor, there were fluctuations in the efficiency of phosphate removal on the 50th day, until the 51st day, until on the 52nd day (the 4th day of operation with HRT 0.75 hours), or for 128 times HRT has experienced a stable condition with a difference in efficiency of ± 5%. Outflow concentration is below 2009 EPA and GR 22/2021 class III river water requirements.

Based on the research, processing of greywater waste with an MBBR system using plastic carriers (Biomedia) resulted in a relatively low 12% phosphate removal efficiency at an HRT of 4 hours and a 14% media volume [14]. Domestic waste treatment utilising a polyurethane sponge (20% media volume) achieved 44.9% phosphate removal with an optimum HRT of 6 hours [15].

When compared with previous studies, domestic wastewater treatment with MBBR reactors can remove phosphate concentrations with the best removal at HRT 4 hours, namely with an efficiency of 89.86%. The phosphate concentration has not achieved the quality standards as specified in PP No. 22 of 2021 about quality river water in class III.

3.3.2 HRT Impact on Ammonia Removal

The concentration of ammonia in the first test prior to treatment was between 0.52 and 0.77mg/L. When compared to the effluent standard in Regulation of Indonesia Ministry of Environment and Forestry No. 68 of 2016, which is 10 mg/L, the inlet ammonia concentration has met the effluent standard. The quality standard that is offered in Government Regulation No. 22 of 2021 in the river water class III is compared to be 0.5 mg/L. Figure 4 shows test results at 4, 3, 2, and 0.75 hours HRT.

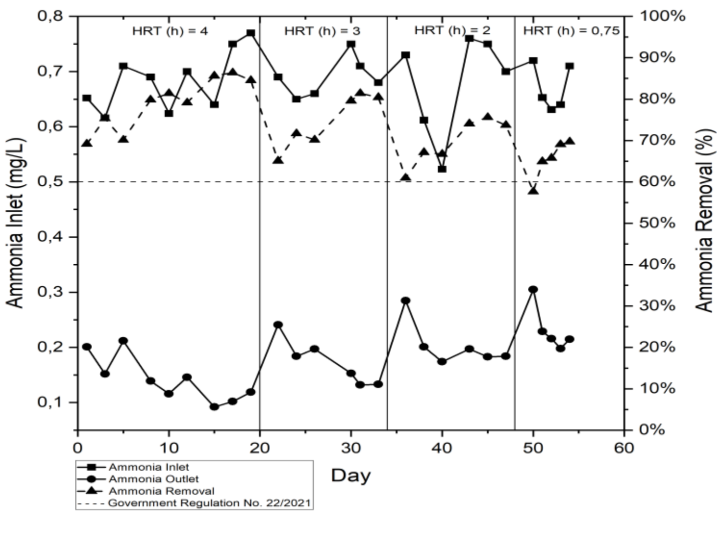


Figure 4. Graph of ammonia removal to HRT

The graph shows how long it takes for 30% K3 Kaldnes medium to get rid of ammonia compared to HRTs for 4, 3, 2, and 0.75 hours. SPALD-T Sentra Primer Barat removed 79.07% ammonia with a mean input concentration of 0.68mg/L and an exit concentration of 0.14mg/L. The MBBR at HRT 4 hours can process ammonia at a rate of 0.003 kg NH_3/m^3/day, while the media in the MBBR reactor can process ammonia at a rate of 0.0001 kg NH_3/m^2/day. On days 15 to 19 or for 90 HRT times, the removal efficiency reached 84.55% to 86.40%, showing a difference in efficiency of ± 1.85%. So, it can be continued with the 3-hour HRT operation.

The mean outlet concentration at HRT 3 hours was 0.17mg/L and the mean inlet concentration was 0.69mg/L and this gave a mean ammonia removal efficiency of 74.73%. The MBBR at HRT 3 hours can process ammonia at a rate of 0.004 kg NH_3/m^3/day, while the media in the MBBR reactor has a rate of 0.0001 kg NH_3/m^2/day. The HRT lowered the removal efficiency at the onset of functioning, then it fluctuated during days 22 to 26, although on the 10 th day of activity (Day 30), with a 3-hour HRT, the HRT was stabilized to 80 times that of removing phosphate. Therefore, it can be continued with a 2-hour HRT.

With 70.59% ammonia elimination efficiency, HRT 2 averaged 0.68 mg/L input and 0.20 mg/L output. The MBBR at HRT 2 hours can process ammonia at a rate of 0.006 kg NH_3/m^3/day, while the media in the MBBR reactor can process ammonia at a rate of 0.0002 kg NH_3/m^2/day. On the 43rd day (9th day of operation with HRT at 2 hours) or after 108 HRT cycles, the efficiency has stabilised with a difference in efficiency of ±5 %. Hence, it can be continued with HRT for 0.75 hours.

The average inlet and outlet concentrations at the HRT of 0.75 hours were 0.67mg/L and 0.23mg/L respectively, with the average percentage removal being 65.42%. The MBBR at HRT 0.75 hours can process ammonia at a rate of 0.014 kg NH_3/m^3/day, and the media in the MBBR reactor has a capacity of 0.0005 kg NH_3/m^2/day. On the 52nd day (the 4th day of operation of HRT at 0.75 hours) or after 128 HRT cycles, the efficiency has reached a stable condition of 69.06% to 69.72%. This HRET had the highest ammonia removal efficiency of 69.72 percent at 0.71 and 0.22 mg/L intake and output concentrations.

Ammonia content may decrease since Government Regulation No. 22/2021 class III river water quality norms of 0.5 mg/L were met at 0.75 hours.

Treatment of office building domestic wastewater using an MBBR integrated septic tank with K1 media (20% media volume) achieved 61% ammonia removal, with the optimum performance requiring an extended Hydraulic Retention Time (HRT) of 36 hours [16]. For dairy wastewater, utilizing K1 media at a 25% media volume and a significantly shorter HRT of 8.5 hours yielded optimal performance, demonstrating a 77.3% removal of ammonia [17].

Compared to previous research, MBBR in residential wastewater at 40% kaldnes 3 medium eliminates ammonia in 2 hours, meeting Regulation of Indonesia Ministry of Environment and Forestry No. 68 of 2016 and Government Regulation No. 22 of 2021 class III river water discharge guidelines. In the meantime, the maximum removal rate of 86.40% was attained at the optimum HRT of 4 hours.

3.4 Kinetics Study

The treatment of the wastewater through the use of biological reactors can be explained and predicted by kinetics analysis [18]. The substrate elimination kinetics rate and biological kinetics coefficient were calculated using second-order models (Grau and Stover-Kincannon) [11,12,19–21].

3.4.1 Second Order Kinetics

Biological treatment substrate utilization rates may be calculated using the second-order kinetic model (Grau). Equation (2.1) can be plotted [(Si x HRT)/Si - Se]/HRT on the y and x axes, respectively. Figure 5 shows the model plot resulting in a high correlation coefficient (R^2) of phosphate of 0.999. This finding is an indication of the effectiveness of the model in this research. The value of K of phosphate is 1.17/day.

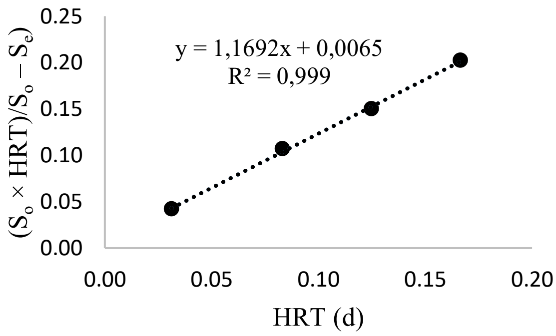


Figure 5. Second-order kinetics of Phosphate

3.4.2 Stover-Kincannon Kinetics

The Stover-Kincannon model predicted RBC biomass growth first. The model was developed to characterise and predict bioreactors. [22–24]. Display Equation (2.2) as V/[Q(S0 – S)] on the y-axis and (V/QS0) on the x-axis before finding μ_{max} and K_s. In Figure 6, phosphate parameters are 14.45 mg/L.day for μ_{max} and 12.46 mg/L.day for K_s. The validity of this model is supported by the fact that the kinetics of a phosphate removal is indicated by the regression coefficients (R^2 values) of 0.999.

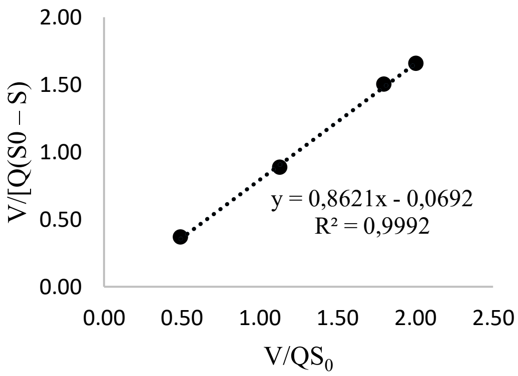


Figure 6. Stover-Kincannon kinetics of Phosphate removal

4. Conclusion

K3 Kaldnes media occupying 40% of the reactor volume in the Moving Bed Biofilm Reactor (MBBR) achieved the highest removal efficiencies for phosphate and ammonia at a HRT of 2 hours. The effluent ammonia concentration complied with the discharge standards established by United States EPA (2009), Regulation No. 68/2016 of the Indonesian Ministry of Environment and Forestry, and the water quality criteria for Class III rivers specified in Government Regulation No. 22/2021 of Indonesia. However, the effluent phosphate concentration did not yet meet the Class III river water quality standard defined in Government Regulation No. 22/2021. Kinetic analysis of phosphate removal showed that the highest coefficient of determination (R^2 = 0.9992) was obtained using the Stover–Kincannon Kinetics model. Overall, the reactor demonstrated favorable nutrient removal kinetics; however, further optimization is required to achieve full compliance with government regulation No. 22/2021.

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