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# Kinetics study of nutrients removal from synthetic wastewater using media as submerged in continuous activated sludge system

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**Abstract.** Domestic wastewater effluents are one of the main sources of environmental contaminants such as nutrients. Wastewater has been treated with biological processes for over a century to remove contaminants. Conventional wastewater treatment plants continue to struggle to meet Malaysian discharge limits. Stringent regulation enforced by governing authorities makes it obligatory to comply with discharge guidelines to fulfill ammonia and nitrate levels. To assist the system in meeting these limits, it is recommended that a submerged attached growth Palm Oil Clinker (POC) can be incorporated into the conventional treatment system. The study was conducted in a continuous submerged attach growth conventional activated sludge which was evaluated for the treatment of wastewater (CSAR). A basket was installed in the aeration tank of the reactor to submerge (POC). Two identical reactors were operated for each reactor of study which (A) was referred to as submerged media reactor while (B) was referred to as control. The studies were carried out at various influent flow rates between 5 and 30 L/d, and constant organic load rate OLR. Parameters such as $NH_4$-N, and $NO_3$-N, were monitored. Generally, Ammonia and Nitrate were highly removed. At all conditions of flow rate (5-30 L/d), the maximum and minimum $NH_4$-N removal is 92% and 85%. The experimental data were validated through well-established mathematical bio-kinetic models such as the First order model, and Monod models. The kinetic coefficients $R^2$ of the first-order model of the substrate removal rate were 0.97 for Ammonia. The steady-state data was fitted to both models obtained at various flowrate. Monod's kinetic model was appropriate for describing experimental results in terms of microbial growth parameters. The kinetic coefficients $R^2$ (0.984) and Ks 303 for the removal of Ammonia, respectively. While $\mu_{max}$ 10 g/L.d for Ammonia removal respectively.

## Introduction

Drop water level of quality and Increasing water requirements for human use for necessary enhancement of cost-efficient wastewater treatment technologies. the biological mechanisms have been providing currently much publicity owing to the price, simpler operation, better management, and less adverse impact on the environment [1]. Suspended and attach growth systems are a type of biological process [2, 3]. Activated sludge the most common process frequently used in developing nations, removed biological solids by sedimentation, low settlement of solid contaminants will result in higher costs of treatment of solids, the total concentrations of effluent solids realized, decreased efficiencies in disinfecting, increasing downstream threats environments and health [4, 5]. When discharged without sufficient treatment, these pollutants in wastewater have a harmful influence on aquatic bodies [6, 7]. Organics, in particular, reduce oxygen levels in normal water systems while meeting their biochemical oxygen demand (BOD), causing aquatic life to suffer [8, 9]. Consequently, the anaerobic decomposition of organics additionally leads to the production of foul-smelling gases [10, 11]. Through this, emerging contaminants and heavy metals build in flora and fauna inside the water, eventually affecting the human food chain Moreover, apart from solid media to suspended growth to have biofilm attached to a surface, the growth process is such a successful process, hence improve and increase microbial concentration and rates of pollutant deterioration [12, 13]. Biofilms benefit from an amount of removal of process mechanisms such as biodegradation [14]. Biofilm is shaped on rigid media such as rocks, plastic profiled, or membranes in a fixed bed system. Both biofilm processes with constantly moving media, sustained by high air were moving bed systems [6, 15]. Nutrients and the aqueous bulk in the conditioning film are used by surface-attached bacterial cells to expand and generate further EPS, contributing to the development of microorganisms [16]. In the end, the microorganisms gradually structure a layer covering the surface [1]. It was proposed that the rock particles should be standardized so that 95% of the particles be between 7 and 10 cm in diameter. Due to, the porous surface, the appropriate attachment of biomass is ideal for a specific area and void ratio for Palm Oil Clinker. The size is not too vital, but the media recommended to be uniform to allow sufficient ventilation across the void space, accessible locally, and cost-effective. Due to the economic benefit, the simplicity of availability, and the high potential for linking biofilm, the use of palm oil clinker media seems to be feasible. Its use as a filter media for wastewater treatment in attached growth reactors is not a new concept [12, 17]. Moreover, there are very few literatures available on conventional methods utilized to search biofilm in such bioreactors and on comparative studies on the efficiency of fixed-film reactors and suspended growth reactors in wastewater treatment. The present research was made to use palm oil clinker in the attached growth system as submerged attached media. Biofilms can be developed in most moist environments on surfaces (biotic and abiotic) [18, 19]. Bacteria move through chemotaxis or Brownian motion with mass transport to the substrate during biofilm progression, producing a temporary bacteria-surface association [20]. The nutrients in the conditioning film and the aqueous bulk are used by bacterial cells attached to the surface to grow and develop further EPS, resulting in microcolony forming [21, 22].

The Malaysian Department of Environment (DOE) establishes criteria that must be met to comply with discharge guidelines. New wastewater discharges must be designed to meet the ammonia and nitrate limits [23, 24]. However, the present conventional treatment systems will not be able to meet the limits as conventional treatment systems were not designed to meet the ammonia and nitrate limits. It is proposed that a submerged attached growth system is to be introduced into the conventional treatment system to help the system to meet these limits [25, 26]. Palm (POC) is a waste material that comes from the steam boiler of the palm oil industry. The POC is dumped at dumpsites or landfills. In this research, the POC by-product, the residue from the steam boiler of the palm oil mill, is to be used as an attached growth system [27, 28]. The POC will be processed before being used as an attached growth system. The performance of POC as a media as an attached growth treatment process will be evaluated. The effectiveness and efficiency of using POC as attached growth media in the combined attached growth/conventional system in the removal of ammonia and nitrates will be evaluated. Consequently, the current research was planned to utilize the palm oil clinker as a supporting media biofilm in submerged attached growth reactors to investigate the efficiency of palm oil clinker as media in an attached submerged growth system in traditional treatment system in the aerobic system in removal of organic and ammonia matter. Monitoring of biofilm growth in succession on palm oil clinker media subjected to activated sludge and evaluation of the stability of biofilm growth promoting POC in aerobic conditions to be used for biological treatment of wastewater in attached growth reactors was also considered in-depth for the removal of organic and nutrient from activated sludge under aerobic conditions to be used in attached growth.

## Materials Methods

*Palm Oil Clinker Preparation*

POC was crushed to obtain the nominal size of 20mm, and comply with a classification of aggregates in Particle shape and surface texture following the British Standard BS 812: Part 1: 1975[29, 30]. Palm Oil Clinker with a nominal size of 35 to 25 mm was utilized as sunken media in this project. The load-bearing capacity of Palm Oil Clinker is significantly affected by its porous structure and weight [31]. The highly porous nature of the Palm Oil Clinker aggregate easily induces crack propagation. Raw wastewater taken from Universiti Teknologi Petronas (UTP)'s Sewage Treatment Plant (STP) was used as the influent to both reactors. A packing media enable the continuous usurp of bacteria to inhibit plug issues and introduce the greatest surface area for ventilation, attaching, and linking to wastewater [32].

*Synthetic Wastewater Preparation*

To resemble domestic wastewater of medium strength, domestic wastewater was synthesized and acclimatized according to Metcalf and Eddy [33]. The wastewater concentration was customized to the medium strength of the domestic wastewater. Purian Alpo High protein puppy dog diet was used to imitate medium-strength domestic wastewater. Due to its compositional similarity to primary sludge, the Alpo dog food was primarily picked [34]. The recipes include grinding the dog food for about 10 minutes in a blender. About 6.5 to 7 grams of the dog food formula was mixed with 1 g of an ammonium salt and mixed with 100 mL of distilled water for approximately 10 minutes.100 mL of the formulated stock solution was weighed once the reactors were to be fed and then mixed with about 10 liters of tap water. The prepared synthetic wastewater recipe was poured into the influent tanks and was mixed well to be kept suspended using pneumatic mixers. The wastewater was continually pumped into both reactors A and B using a Masterflex Precision Pump [35].

*Reactors Set-up and Experimental*

This study discussed the results obtained from the biological treatment system; continuous flow (complete mixed activated sludge process) was carried out to investigate the viability of utilizing POC as a submerged media in treating medium synthetic wastewater for the removal of nutrients. Two reactors were used (A) referred to as the submerged media reactor while (B) referred to as the control, reactor is rectangular shaped and was made with Plexiglas with dimensions $36.5 \times 16.0 \times 24\ cm^3$. The reactor's operational capacity was 10L. The air is delivered using an air pump from Hailea® (Model HAP-100), with a 100 L/min maximum output. Both reactors feed from wastewater treatment (STP). The biomass utilized as inoculum in the reactor was taken from return activated sludge (RAS) pipe, at the institutional wastewater treatment plant (IWTP), UTP. The solids retention time (SRT) and the chosen mixed liquid suspended solids (MLSS) of the inoculum were 1500 mg/L and 5 days, respectively. The experiments were then started. In this continuous flow study, synthetic wastewater was fed to both reactors [36]. The design provides influent to flow into both reactors continuously. Change in the flow rate (5-30 L/d). The tests will be conducted according to the Standard Methods for the examination of water and wastewater [29, 37]

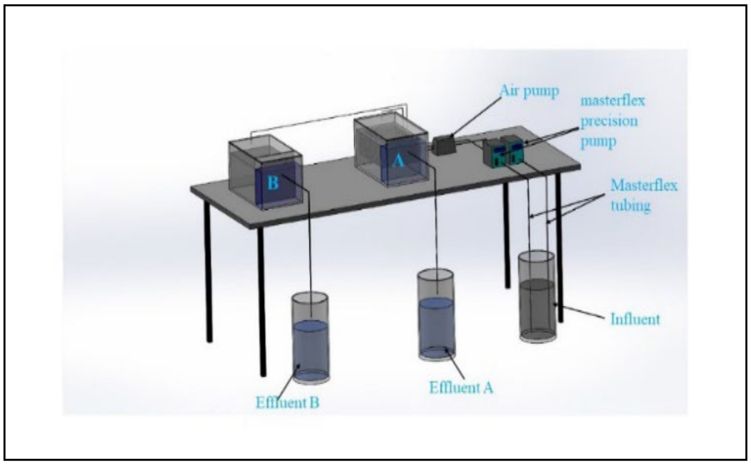


*Fig. 1: continuous activated sludge reactor*

*Kinetic Models*
In the study of biological processes at their most fundamental level, Mathematical models have been used to test theories, examine parameter interactions, drive experimental design, and estimate experiment results. These models could also be used to monitor and investigate the performance of the treatment process, as well as to enhance the plant setup and the effect of pilot scale-up experiments [38]. In this research, the steady-state data were suited to two biokinetic models namely, the Monod Kinetic Model and First Order Model**.**

**Results and Discussions**
This study discussed the results obtained from two identical reactors that were operated for each reactor of study in which (A) was referred to as submerged media reactor while (B) was referred to as control. The results obtained from both reactors were discussed according to all the monitored parameters discussed including $NH_4$-N, and $NO_3$-N.

*Experimental Result for Removal of $NH_4$-N and $NO_3$-N*
For the entire study time, the removal of $NH_4$-N from the reactors was monitored. The removal of $NH_4$-N from wastewater typically requires two phases, involving the process of nitrification and denitrification. There was no denitrification in this analysis since the anoxic component was not used in the design of the reactors. However, since the rectors were run in the conventional plug flow process, nitrification was expected. During the decomposition of organic materials by biomass, Ammonia is produced in the reactor, and the influent $NH_4$ plus the produced ammonia area is degraded in the aeration tank. The concentration of ($NH_4$-N) and ($NO_3$-N) from the effluent in all reactors was determined during the research period. However, the oxidation of influent organic matter along with endogenous respiration and cell growth of the microorganism includes concentrations of dissolved oxygen [39]. The dissolved oxygen level in the reactors was held and monitored during the research. This was to provide oxygen and enough mixing for nitrification within the reactors. Fig 2, and 3 indicated the concentration of ammonia and nitrate experiments from the reactors in the study.

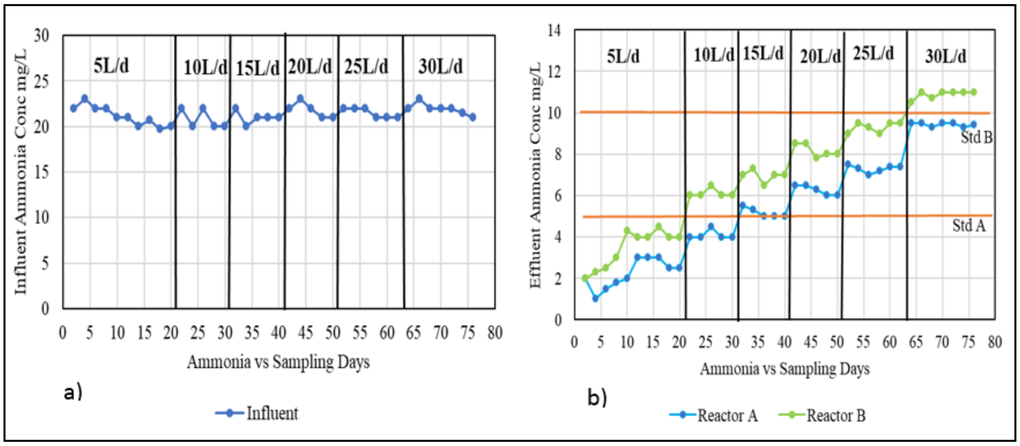


*Fig.2: a) Influent of Ammonia Concentration vs Sampling Days, b) Effluent of Ammonia Concentration vs Sampling Days*

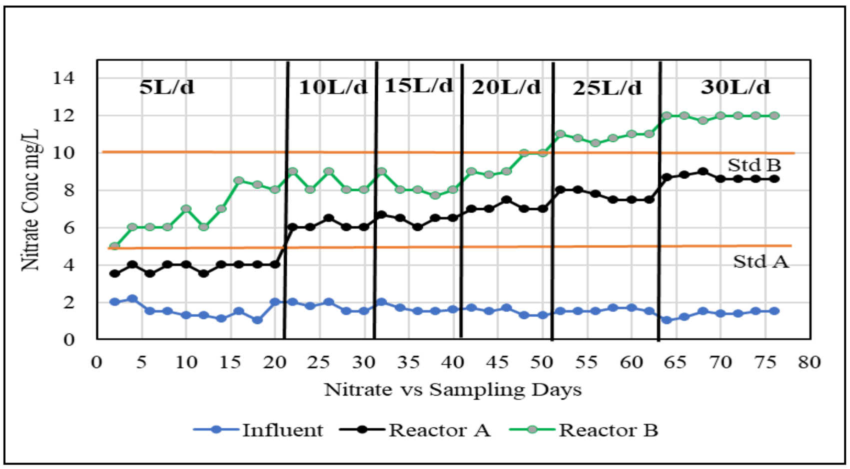


*Fig.3: Nitrate Concentration vs Sampling Days*

It can be noted from Fig 2, and Fig 3, that successful ammonia oxidization occurred after the startup of the reactors from day 10. The oxidized ammonia was transformed by Nitrosomonas bacteria to nitrate. Although some fluctuation in the $NH_4$-N and $NO_3$-N concentrations of the reactors have occurred through the first start days, the ammonia effluent concentration of both reactors has been adequately enough decreased by less than 5 mg/L. This shows that ammonia was used by the biomass as a nutrient to break down the biodegradable organic matter. The $NH_4$-N in (Reactor B) is almost fully nitrified during the study time. Reactor B effluent nitrate concentration begins to rise steadily and then stable from day 26 to day 30. This suggests that ammonia is used as a nutrient efficiently by the microbes. This was apparent in the growing trend in nitrate concentration from the reactor effluent. A sign of good system efficiency is the presence of high $NO_3$ with decreased $NH_4$ in the discharge of the treatment system [40].

Increament in the effluents of ammonia concentrations of the reactors was detected when the influencing flow rate increased the flow rate of both reactors. This suggests that the behaviors of the nitrifying microorganisms were not inhibited due to the increasing flow rate. The concentration of nitrate in the reactor effluent has been found to increase dramatically as the flow rate increases. The increase was due to oxidized ammonia, which was transformed into $NO_2$ and then $NO_3$. The mean discharge $NH_4$ concentration of the reactors was determined to be 2,4,5,6,7, and 9±0.5 mg/L and 4, 6, 7, 8, 9, and 11±0.5 mg/L, respectively, for reactors A and B. The mean concentration of effluent nitrates in the reactors was determined to be 5±1 mg/L and 7±1 mg/L for the A and B reactors, respectively. In comparison, nitrifiers in the mixed liquor are small and have a sluggish growth rate relative to heterotrophic microorganisms. Additionally, Small numbers of nitrifiers are present in mixed liquor, and they develop slowly in comparison to heterotrophic bacteria. The substrate removal rate and the biokinetic coefficients for Ammonia removal were determined by put in the application of the steady-state data to various kinetic models.

*Table 1 Steady-state results for Ammonia removal*

| Influent rate L/d | HRT (days) | Effluent A % | Effluent A (mg/L) | Effluent B (%) | Effluent B (mg/L) |
|---|---|---|---|---|---|
| 5 | 2 | 92 | 2.5 | 80 | 4 |
| 10 | 1 | 88 | 4 | 70 | 6 |
| 15 | 0.7 | 80 | 5 | 67 | 7 |
| 20 | 0.5 | 76.2 | 6 | 62 | 8 |
| 25 | 0.4 | 65 | 7.4 | 55 | 9.5 |
| 30 | 0.3 | 57 | 9.5 | 48 | 11 |

*First-Order Kinetic*

The first-order kinetic model shows how adjustments in HRT affect system efficacy. Many scholars have used their literature, on the first-order kinetic model to describe bioreactors. The first-order bio-kinetic model coefficients $k_1$ and $R^2$ were calculated from the slope of the line at steady-state by plotting ($S_0$–Se) /HRT versus Se wastewater. The plot of ($S_0$ –Se) /HRT and Se yielded a straight line as depicted in Fig 4. Ammonia removal constants, $k_1$ were found to be 5 and 3.9 per day, whereas $R^2$ was 0.97 [41, 42]. For first-order kinetics, the $k_1$ value was low, and the higher the $k_1$ value, the larger the degrading capability of the microorganism. [43]. Although the first-order model parameter in the current study was little, it was bigger than the values reported by other studies. Variations in $k_1$ levels may be caused by changes in operative circumstances and effluent type [44].

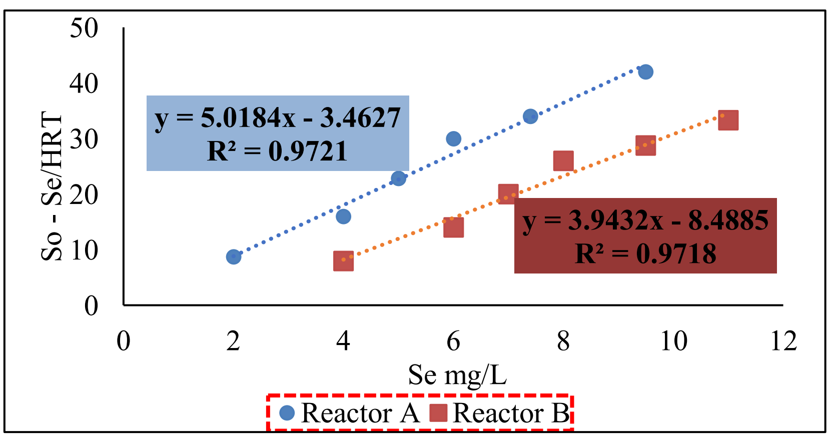


*Fig. 4: First-order substrate removal plot for Ammonia*

*Monod Model*

In Fig 5 plot of X*HRT/(So-Se) VS 1/Se, the steady-state data were fitted. The intercept and slope of the plot were then used to calculate the half-saturation constant (Ks) and the maximal specific growth rate (max). For reactors A and B, Ks were determined to be 303 and 600 g/m$^3$, respectively, whereas (max) 10 and 15 per day were observed with correlation coefficients ($R^2$) of 0.984 and 0.980, respectively. The biomass yield (Y) and death rate constant ($K_d$) are kinetic parameters that can be influenced by the DO concentration in the bioreactor. A low Ks, value is widely recognized to imply a stronger affinity between bacteria and substrate [45]. The low KS found in this model suggests that the microbes' affinity for the substrate was great and suggests that (CASR) can effectively remove contaminants at high efficiency under various operating conditions of flow rate.

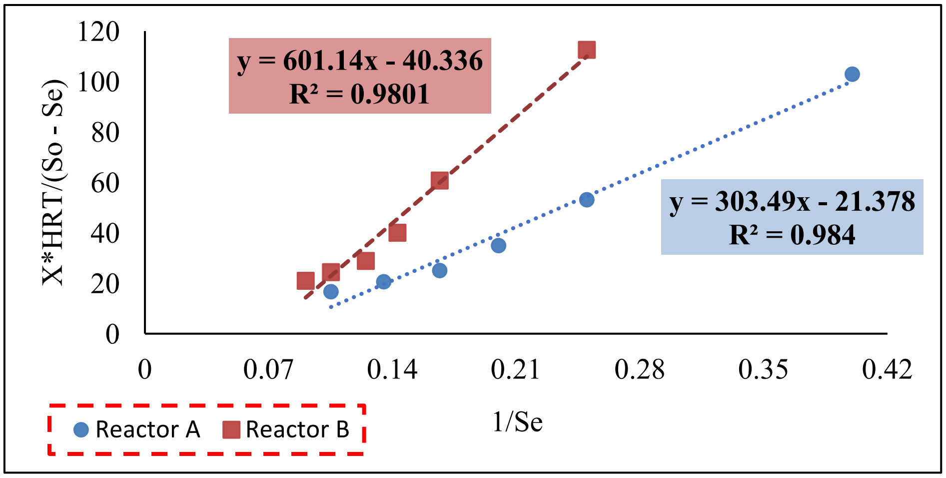


*Fig.5: $\mu_{max}$ and $K_B$ Plot*

The kinetic constants for the substrate removal and growth models are illustrated in Table 2.

*Table 2 Kinetic constants for Ammonia removal for all models*

| kinetic model | Kinetic parameter | Kinetic value | | $R^2$ | |
|---|---|---|---|---|---|
| | | A | B | A | B |
| First-order | $K_1$ (1/d) | 5 | 3.9 | 0.972 | 0.972 |
| Monod | Ks ($g/m^3$) | 303 | 600 | 0.984 | 0.981 |
| | $\mu_{max}$ (1/d) | 10 | 15 | 0.984 | 0.981 |

The kinetic constants obtained in this phase show that the first-order kinetic model appropriately described the experimental data in terms of substrate removal. For the microbial growth parameters, the Monad model appropriately described the experimental data in terms of the maximum specific growth rate (Table 2). This suggests that microbial growth was linked to the concentration of the medium's limiting nutrient. The first-order and Monad kinetic models also have correlation coefficients ($R^2$) greater than 0.9, implying that these models can be applied to a wide variety of bioreactors. In biological treatment systems, the rate of product formation is influenced by microbial population, environmental factors, temperature, media type, and morphology [46].

**Conclusion**

Treatment of wastewater (synthetic) was successfully done in a reactor. Ammonia, Nitrate was highly removed at all experimental conditions investigated. In the subsequent stage of the study, the effect of medium synthetic domestic wastewater (DWW) and the hydraulic retention time (HRT) was investigated to examine the performance of conventional activated sludge reactor (CAS) and submerged attached growth activated sludge reactor with similar operating conditions of 1500 mg/L mixed liquor suspended solids (MLSS) as inoculum, in a continuous flow mode. The result revealed that the maximum $NH_4^+$–N removal by using POC was 92%, higher than using the conventional treatment. Thus, indicating that the biofilm attached to the POC improved the

$NO_3$, and $NH_4^+$–N removal in treated wastewater. Thus, it was evident that the POC performance was better than CAS due to the submerged attached growth POC.

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## References

[1] I. Naz, S. Seher, I. Perveen, D. P. Saroj, and S. Ahmed, "Physiological activities associated with biofilm growth in attached and suspended growth bioreactors under aerobic and anaerobic conditions," Environ Technol, vol. 36, no. 13-16, pp. 1657-71, Jul-Aug 2015. https://doi.org/10.1080/09593330.2014.1003614

[2] L. Machineni, "Review on biological wastewater treatment and resources recovery: attached and suspended growth systems," Water Science and Technology, vol. 80, no. 11, pp. 2013-2026, 2019. https://doi.org/10.2166/wst.2020.034

[3] A. A. H. Saeed et al., "Pristine and magnetic kenaf fiber biochar for Cd2+ adsorption from aqueous solution," International journal of environmental research and public health, vol. 18, no. 15, p. 7949, 2021. https://doi.org/10.3390/ijerph18157949

[4] F. Sher et al., "Removal of micropollutants from municipal wastewater using different types of activated carbons," Journal of Environmental Management, vol. 278, p. 111302, 2021. https://doi.org/10.1016/j.jenvman.2020.111302

[5] A. Jagaba et al., "Derived hybrid biosorbent for zinc (II) removal from aqueous solution by continuous-flow activated sludge system," Journal of Water Process Engineering, vol. 34, p. 101152, 2020. https://doi.org/10.1016/j.jwpe.2020.101152

[6] B. N. S. Al-dhawi et al., "Treatment of synthetic wastewater by using submerged attached growth media in continuous activated sludge reactor system," 2022.

[7] J. N. Edokpayi, J. O. Odiyo, and O. S. Durowoju, "Impact of wastewater on surface water quality in developing countries: a case study of South Africa," Water quality, vol. 10, p. 66561, 2017. https://doi.org/10.5772/66561

[8] N. K. Singh and A. A. Kazmi, "Environmental performance and microbial investigation of a single stage aerobic integrated fixed-film activated sludge (IFAS) reactor treating municipal wastewater," Journal of environmental chemical engineering, vol. 4, no. 2, pp. 2225-2237, 2016. https://doi.org/10.1016/j.jece.2016.04.001

[9] N. K. Singh, A. A. Kazmi, and M. Starkl, "Treatment performance and microbial diversity under dissolved oxygen stress conditions: Insights from a single stage IFAS reactor treating municipal wastewater," Journal of the Taiwan Institute of Chemical Engineers, vol. 65, pp. 197-203, 2016. https://doi.org/10.1016/j.jtice.2016.05.002

[10] M. Ali, N. K. Singh, A. Bhatia, S. Singh, A. Khursheed, and A. A. Kazmi, "Sulfide production control in UASB reactor by addition of iron salt," Journal of Environmental Engineering, vol. 141, no. 6, p. 06014008, 2015. https://doi.org/10.1061/(ASCE)EE.1943-7870.0000911

[11] R. K. Sinha, S. Herat, G. Bharambe, and A. Brahambhatt, "Vermistabilization of sewage sludge (biosolids) by earthworms: converting a potential biohazard destined for landfill disposal into a pathogen-free, nutritive and safe biofertilizer for farms," Waste Management & Research, vol. 28, no. 10, pp. 872-881, 2010. https://doi.org/10.1177/0734242X09342147

[12] G. Tchobanoglous et al., "Waterwater Engineering: Treatment and Resource Recovery, Metcalf and Eddy Inc," ed: McGraw-Hill, New York, 2014.

[13] A. A. Hezam Saeed, N. Y. Harun, S. Sufian, and M. F. Bin Aznan, "Effect of adsorption parameter on the removal of nickel (II) by low-cost adsorbent extracted from corn cob," International Journal of Advanced Research in Engineering and Technology (IJARET), vol. 11, no. 9, 2020.

[14] S. Pal, U. Sarkar, and D. Dasgupta, "Dynamic simulation of secondary treatment processes using trickling filters in a sewage treatment works in Howrah, west Bengal, India," Desalination, vol. 253, no. 1-3, pp. 135-140, 2010. https://doi.org/10.1016/j.desal.2009.11.019

[15] J. Bassin, I. Dias, S. Cao, E. Senra, Y. Laranjeira, and M. Dezotti, "Effect of increasing organic loading rates on the performance of moving-bed biofilm reactors filled with different support media: Assessing the activity of suspended and attached biomass fractions," Process Safety and Environmental Protection, vol. 100, pp. 131-141, 2016. https://doi.org/10.1016/j.psep.2016.01.007

[16] S. Pandit, S. Sarode, and K. Chandrasekhar, "Fundamentals of bacterial biofilm: Present state of art," in Quorum Sensing and its Biotechnological Applications: Springer, 2018, pp. 43-60. https://doi.org/10.1007/978-981-13-0848-2_3

[17] A. A. H. Saeed et al., "Moisture content impact on properties of briquette produced from rice husk waste," Sustainability, vol. 13, no. 6, p. 3069, 2021. https://doi.org/10.3390/su13063069

[18] J. A. Glaser, "Biological degradation of polymers in the environment," in Plastics in the Environment: IntechOpen, 2019. https://doi.org/10.5772/intechopen.85124

[19] A. A. H. Saeed, N. Y. Harun, and N. Zulfani, "Heavy metals capture from water sludge by kenaf fibre activated carbon in batch adsorption," Journal of Ecological Engineering, vol. 21, no. 6, 2020. https://doi.org/10.12911/22998993/123249

[20] H. J. Busscher, W. Norde, P. K. Sharma, and H. C. Van der Mei, "Interfacial re-arrangement in initial microbial adhesion to surfaces," Current Opinion in Colloid & Interface Science, vol. 15, no. 6, pp. 510-517, 2010. https://doi.org/10.1016/j.cocis.2010.05.014

[21] K. Biswas and S. J. Turner, "Microbial community composition and dynamics of moving bed biofilm reactor systems treating municipal sewage," Applied and environmental microbiology, vol. 78, no. 3, pp. 855-864, 2012. https://doi.org/10.1128/AEM.06570-11

[22] N. Y. Harun, A. A. H. Saeed, A. Vegnesh, and L. A. Ramachandran, "Abundant nipa palm waste as Bio-pellet fuel," Materials Today: Proceedings, vol. 42, pp. 436-443, 2021. https://doi.org/10.1016/j.matpr.2020.10.169

[23] S. Tabassum, Y. Zhang, and Z. Zhang, "An integrated method for palm oil mill effluent (POME) treatment for achieving zero liquid discharge-a pilot study," Journal of Cleaner Production, vol. 95, pp. 148-155, 2015. https://doi.org/10.1016/j.jclepro.2015.02.056

[24] B. Al-dhawi, S. R. Kutty, N. Almahbashi, A. Noor, and A. H. Jagaba, "Organics removal from domestic wastewater utilizing palm oil clinker (POC) media in a submerged attached growth systems," International Journal of Civil Engineering and Technology, vol. 11, no. 6, pp. 1-7, 2020. https://doi.org/10.34218/IJCIET.11.6.2020.001

[25] B.-T. Dang et al., "Non-submerged attached growth process for domestic wastewater treatment: Influence of media types and internal recirculation ratios," Bioresource Technology, vol. 343, p. 126125, 2022. https://doi.org/10.1016/j.biortech.2021.126125

[26] N. Y. Harun, T. J. Han, T. Vijayakumar, A. Saeed, and M. T. Afzal, "Ash deposition characteristics of industrial biomass waste and agricultural residues," Materials Today: Proceedings, vol. 19, pp. 1712-1721, 2019. https://doi.org/10.1016/j.matpr.2019.11.201

[27] J. Kanadasan and H. Abdul Razak, "Utilization of palm oil clinker as cement replacement material," Materials, vol. 8, no. 12, pp. 8817-8838, 2015. https://doi.org/10.3390/ma8125494

[28] A. H. Jagaba et al., Palm oil clinker as a waste by-product: Utilization and circular economy potential. IntechOpen London, 2021.

[29] A. P. H. Association, A. W. W. Association, W. P. C. Federation, and W. E. Federation, Standard methods for the examination of water and wastewater. American Public Health Association., 1915.

[30] M. Z. Jumaat, U. J. Alengaram, R. Ahmmad, S. Bahri, and A. S. Islam, "Characteristics of palm oil clinker as replacement for oil palm shell in lightweight concrete subjected to elevated temperature," Construction and Building Materials, vol. 101, pp. 942-951, 2015. https://doi.org/10.1016/j.conbuildmat.2015.10.104

[31] J. Kanadasan, A. F. A. Fauzi, H. A. Razak, P. Selliah, V. Subramaniam, and S. Yusoff, "Feasibility studies of palm oil mill waste aggregates for the construction industry," Materials, vol. 8, no. 9, pp. 6508-6530, 2015. https://doi.org/10.3390/ma8095319

[32] S. A. Kabir, U. J. Alengaram, M. Z. Jumaat, S. Yusoff, A. Sharmin, and I. I. Bashar, "Performance evaluation and some durability characteristics of environmental friendly palm oil clinker based geopolymer concrete," Journal of cleaner production, vol. 161, pp. 477-492, 2017. https://doi.org/10.1016/j.jclepro.2017.05.002

[33] F. L. Burton and G. Tchobanoglous, Wastewater Engineering: treatment, disposal, and reuse. McGraw-Hill, 2018.

[34] C. W. Teo and P. C. Y. Wong, "Enzyme augmentation of an anaerobic membrane bioreactor treating sewage containing organic particulates," Water research, vol. 48, pp. 335-344, 2014. https://doi.org/10.1016/j.watres.2013.09.041

[35] K. Gajanan, "Nutrients Requirements in Biological Industrial Waste Water Treatment," 2015.

[36] J. T. Novak, S. Banjade, and S. N. Murthy, "Combined anaerobic and aerobic digestion for increased solids reduction and nitrogen removal," Water research, vol. 45, no. 2, pp. 618-624, 2011. https://doi.org/10.1016/j.watres.2010.08.014

[37] E. W. Rice, R. B. Baird, A. D. Eaton, and L. S. Clesceri, Standard methods for the examination of water and wastewater. American public health association Washington, DC, 2012.

[38] D. Manu and A. K. Thalla, "Artificial intelligence models for predicting the performance of biological wastewater treatment plant in the removal of Kjeldahl Nitrogen from wastewater," Applied Water Science, vol. 7, no. 7, pp. 3783-3791, 2017. https://doi.org/10.1007/s13201-017-0526-4

[39] L. Metcalf, H. P. Eddy, and G. Tchobanoglous, Wastewater engineering: treatment, disposal, and reuse. McGraw-Hill New York, 1979.

[40] M. E. Argun, S. Dursun, C. Ozdemir, and M. Karatas, "Heavy metal adsorption by modified oak sawdust: Thermodynamics and kinetics," Journal of hazardous materials, vol. 141, no. 1, pp. 77-85, 2007. https://doi.org/10.1016/j.jhazmat.2006.06.095

[41] M. M. Amin, M. H. Khiadani, A. Fatehizadeh, and E. Taheri, "Validation of linear and non-linear kinetic modeling of saline wastewater treatment by sequencing batch reactor with adapted and non-adapted consortiums," Desalination, vol. 344, pp. 228-235, 2014. https://doi.org/10.1016/j.desal.2014.03.032

[42] P. Mullai and M. Yogeswari, "Substrate removal kinetics of hydrogen production in an anaerobic sludge blanket filter," Separation Science and Technology, vol. 50, no. 7, pp. 1093-1100, 2015. https://doi.org/10.1080/01496395.2014.969806

[43] R. Bhattacharya and D. Mazumder, "Evaluation of nitrification kinetics for treating ammonium nitrogen enriched wastewater in moving bed hybrid bioreactor," Journal of Environmental Chemical Engineering, vol. 9, no. 1, p. 104589, 2021. https://doi.org/10.1016/j.jece.2020.104589

[44] Y. J. Chan, M. F. Chong, and C. L. Law, "Performance and kinetic evaluation of an integrated anaerobic-aerobic bioreactor in the treatment of palm oil mill effluent," Environmental technology, vol. 38, no. 8, pp. 1005-1021, 2017. https://doi.org/10.1080/09593330.2016.1217053

[45] H. A. Hasan, S. R. S. Abdullah, S. K. Kamarudin, N. T. Kofli, and N. Anuar, "Kinetic evaluation of simultaneous COD, ammonia and manganese removal from drinking water using a biological aerated filter system," Separation and Purification Technology, vol. 130, pp. 56-64, 2014. https://doi.org/10.1016/j.seppur.2014.04.016

[46] S. Katoh, F. Yoshida, and J.-i. Horiuchi, Biochemical engineering. Wiley Online Library, 2015. https://doi.org/10.1002/9783527684984