JEE Journal of Ecological Engineering

Journal of Ecological Engineering, 2025, 26(10), 328–339
https://doi.org/10.12911/22998993/204695
ISSN 2299–8993, License CC-BY 4.0

Received: 2025.04.28
Accepted: 2025.07.01
Published: 2025.09.01

Optimization of culinary wastewater treatment using intermittent slow sand filter with bacterial augmentation to remove biochemical oxygen demand, chemical oxygen demand, and phosphate

Nurina Fitriani[1], Vindi Elsa Fatikasari[1], Ni'matuzahroh[1], Moch. Affandi[1], Eddy Setiadi Soedjono[2*], M. Bagas Pramudya Pratama[1], Radin Maya Saphira Binti Mohamed[3]

[1] Department of Biology, Faculty of Science and Technology, Universitas Airlangga, Dr. Ir. H. Soekarno Street, Surabaya, Indonesia
[2] Department of Environmental Engineering, Faculty of Civil Planning and Geo Engineering, Institut Teknologi Sepuluh Nopember, Teknik Kimia Street, Surabaya, Indonesia
[3] Department of Civil Engineering, Faculty of Civil Engineering and Built Environment, Universiti Tun Hussein Onn Malaysia, FKAAB UTHM Street, Parit Raja, Malaysia
* Corresponding author's e-mail: soedjono@enviro.its.ac.id

ABSTRACT

Culinary tourism centers generate wastewater that requires proper treatment to meet quality standards before discharge into receiving water bodies. One suitable treatment technology is the intermittent slow sand filter (ISSF), which can be enhanced with a grease trap pre-treatment unit and a roughing filter. This study investigates the effectiveness of modified ISSF media – comprising sand mixed with either *Anadara granosa* shell fragments or activated carbon – in reducing BOD, COD, and phosphate concentrations in culinary center wastewater. Additionally, the study aims to determine the optimal ISSF design using response surface methodology (RSM). The ISSF reactor was operated intermittently with a 48-hour detention time over 22 days. Wastewater quality parameters were analyzed using the SNI method, and experimental data were processed using an RSM optimal (custom) design. Independent variables included operational duration, bacterial augmentation with *Bacillus* sp. in the grease trap, and filter media type. The response variables were removal efficiencies of BOD, COD, and phosphate. Optimal treatment conditions were achieved using a sand and activated carbon media mixture, 1% *Bacillus* sp. addition, and an 11-day detention time, resulting in BOD, COD, and phosphate removal efficiencies of 62.50%, 72.54%, and 72.32%. Analysis of Variance (ANOVA, $p < 0.05$) of the 2FI model confirmed that all independent factors significantly influenced pollutant removal efficiency. These findings indicate that the proposed ISSF design offers a reliable and efficient approach for improving wastewater quality through integrated biological and physical treatment processes.

Keywords: activated carbon, anadara granosa, bacterial augmentation, culinary wastewater, intermittent slow sand filter, response surface methodology.

INTRODUCTION

Environmental pollution caused by wastewater in major Indonesian cities, including Surabaya, has become an increasingly serious concern. A significant contributor to river pollution in Surabaya – particularly in the Surabaya River – is the direct discharge of untreated liquid waste from various human activities into drainage channels that ultimately flow into the river (Basuki et al., 2024). It is estimated that approximately 60% of the pollution in the Surabaya River originates from domestic wastewater sources. Among these sources, culinary wastewater from food stalls, restaurants, and culinary tourism centers also contributes to the organic and nutrient load in urban wastewater, further exacerbating water quality degradation (Konkol et al., 2024).

Liquid waste generated by culinary centers falls under the category of domestic wastewater. Its primary characteristics are similar to those of wastewater from restaurants, originating mainly from the washing of kitchenware, food preparation, and food residues such as fats, rice, and vegetables (Ahmad et al., 2022). These food scraps and the soapy water used in cleaning activities often contain significant amounts of organic substances, including phosphorus and other nutrients (Pandey and Kumari, 2022). When discharged into water bodies without proper treatment, these organic materials can promote microbial growth, thereby increasing the biochemical oxygen demand (BOD) and chemical oxygen demand (COD) of the water (Lv et al., 2024). Elevated phosphate concentrations are particularly concerning, as they contribute to eutrophication processes, which can trigger harmful algal blooms and disrupt aquatic ecosystems (Lan et al., 2024).

An optimal and efficient treatment technology is essential to ensure that wastewater generated by culinary center activities meets environmental quality standards prior to discharge into receiving water bodies. A suitable solution is the implementation of a treatment system consisting of a grease trap followed by a slow sand filter equipped with a roughing filter unit. This configuration is favored for its simplicity, cost-effectiveness, and ease of operation. The slow sand filter functions by allowing raw wastewater to pass slowly through sand media, thereby removing suspended solids, colloidal particles, and pathogenic microorganisms (Abdiyev et al., 2023). The treatment process operates intermittently, allowing sufficient detention time for effective pollutant removal (Freitas et al., 2023). Given that culinary wastewater is produced in non-continuous cycles, the use of an intermittent slow sand filter (ISSF) is particularly well-suited for this application. ISSFs are compact, require minimal maintenance, do not rely on chemical additives, and can be operated without specialized technical expertise (Maiyo et al., 2023). Previous studies have reported that ISSFs are capable of achieving COD removal efficiencies up to 80%, BOD removal up to 73%, and phosphate reduction up to 78% (Alsaqqar et al., 2018; Chatterjee et al., 2018).

Filtration units can utilize a variety of media types, with commonly used materials including sand, activated carbon, silica sand, and anthracite (Cescon and Jiang, 2020). In this study, the ISSF unit was enhanced through the incorporation of *Anadara granosa* (blood clam) shell media and activated carbon. *A. granosa* shells possess a porous structure, which enables them to physically adsorb pollutants by trapping contaminants within the pores on their surface (Misran et al., 2024). In addition, activated carbon was employed due to its extensive internal pore network, which allows it to adsorb a wide range of contaminants, including both large and small molecules. Activated carbon serves as an effective adsorbent, particularly for the removal of metals such as manganese (Mn) and iron (Fe), and helps to reduce sediment buildup as polluted water passes through its porous structure (Das et al., 2023).

The data in this study were analyzed using response surface methodology (RSM) to determine the optimal conditions for wastewater treatment performance. RSM is a statistical and mathematical approach used to model and analyze processes in which a response is influenced by multiple independent variables, with the primary goal of optimizing the response (Chen et al., 2022). The domestic wastewater used in this research was sourced from the wastewater treatment plant (WWTP) of the Deles Culinary Tourism Center, located in Keputih, Sukolilo District, Surabaya City. This study aimed to identify the most effective configuration of domestic wastewater treatment units – comprising grease traps, horizontal roughing filters, and ISSF – with a focus on variations in filter media and their influence on BOD, COD, and phosphate removal. Sampling and analysis were specifically conducted at the outlets of the horizontal roughing filter and ISSF units.

METHODS

Reactor preparation

The materials used for reactor construction included 1 cm thick acrylic sheets for fabricating the horizontal roughing filter and 1 cm thick glass panels for constructing the ISSF. The dimensions of the ISSF reactor were determined based on the guidelines outlined in SNI 3891:2008 on the Design of Slow Sand Filter Installations, which were adapted for laboratory-scale application. The overall configuration of the treatment system is illustrated in Figure 1.

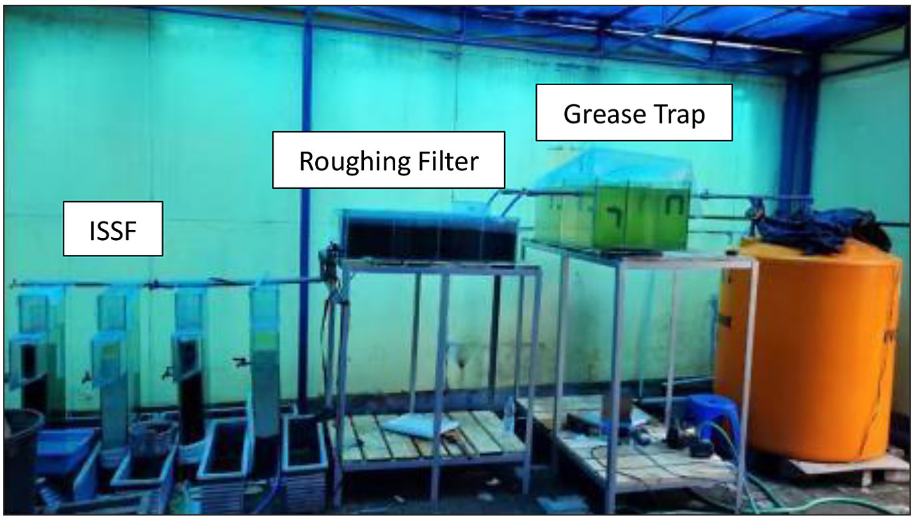

Figure 1. Reactor configuration of ISSF, roughing filter and grease trap

Wastewater sampling

The wastewater used in this study was sourced from the inlet of the Deles Culinary Center WWTP, representing typical domestic wastewater generated from culinary activities. The volume of wastewater collected was adjusted according to the capacity of the laboratory-scale reactor used in the experiments. In accordance with design criteria, the ISSF unit is capable of treating influent with a maximum turbidity of 50 NTU. Therefore, a pre-treatment stage using a horizontal roughing filter was employed to reduce turbidity levels prior to entering the ISSF unit (Hashimoto et al., 2019).

Filter media preparation

The roughing filter utilized a layered gravel media consisting of particles with diameters of 10 mm, 20 mm, and 30 mm. In the ISSF, gravel with diameters ranging from 10 to 30 mm was used as the supporting (buffer) layer (Fitriani et al., 2020). The main filter media in the ISSF consisted of two types of combinations: fine river sand stacked with *A. granosa* shells, and fine river sand stacked with activated carbon. The river sand used had a particle size range of 0.15–0.6 mm. The *A. granosa* shell particles were sized at 0.25 mm, while the activated carbon used had a particle size of 0.425 mm.

Acclimation

The acclimation process was conducted intermittently over a period of 12 days to facilitate the development of biofilm within the ISSF (Fitriani et al., 2023). During this phase, wastewater was introduced into the ISSF and maintained at a level 10 cm above the filter media surface. The wastewater was retained within the reactor for a detention time of 48 hours per cycle, allowing for optimal conditions to support microbial growth and biofilm formation on the media.

Reactor operation

The reactor operation was conducted continuously over a period of 21 days. Wastewater was intermittently introduced and retained in the system for a detention time of 48 hours per cycle. Treated wastewater samples were collected every two days in the morning from the outlets of both the horizontal roughing filter and the ISSF. These samples were then analyzed for biochemical oxygen demand (BOD), COD, and phosphate concentrations.

Sample analysis

Sample analysis was conducted in the laboratory to determine BOD, COD, and phosphate concentrations. BOD analysis was performed using the iodometric titration method with azide modification, which measures dissolved oxygen levels. COD was analyzed using the closed reflux method combined with spectrophotometric detection. The procedure involved the use of a digestion solution and sulfuric acid reagent, followed by heating the samples in a COD reactor at 150 °C for 2 hours. Absorbance measurements were taken at 600 nm for concentrations between 100–900 mg.L^{-1} COD and at 420 nm for concentrations ≤ 90 mg.L^{-1} COD. Phosphate levels were determined using the UV-Vis spectrophotometric method. The analysis employed ammonium molybdate and stannous chloride ($SnCl_2$) as reagents, producing a blue color complex. Absorbance was measured at a wavelength of 690 nm.

Statistical analysis

The statistical analysis in this study was conducted using analysis of variance (ANOVA) to evaluate the suitability of the proposed model. The selected model was a two-factor interaction (2FI) model. A final equation, expressed in terms of actual factors, was developed as a mathematical representation of the model and can be used to predict and estimate response values under field conditions. The interactions between individual or combined independent variables and the response were visualized through contour plots and three-dimensional (3D) surface plots.

Model optimisation

The model optimisation using response surface methodology (RSM) was conducted with Design-Expert version 11 software, employing an optimal (custom) design approach. The variables used in the model are referred to as independent factors, which influence the resulting responses. The three independent factors entered into the software were detention time (Factor A), bacterial augmentation in wastewater (Factor B), and type of filter media (Factor C).

Factor A was expressed in units of days with two levels: 1 day (low level, L[1]) and 11 days (high level, L[2]). Factor B, representing bacterial augmentation, was expressed as a percentage of added bacteria, with two levels: 0% (low level, L[1]) and 1% (high level, L[2]). Factor C, representing the filter media used in the intermittent slow sand filter (ISSF), was categorized into two combinations: sand + activated carbon (P+AC) as the low level (L[1]), and sand + *A. granosa* shells (P+KR) as the high level (L[2]). Optimization of ISSF operational conditions was performed using the optimization module in the Design-Expert software. The purpose of this module is to identify the combination of independent factor levels that simultaneously fulfill the desired criteria for each response variable. The optimization objective was to maximize the removal efficiency of BOD, COD, and phosphate, ideally approaching 100%. The optimal solution was determined based on the highest desirability value generated by the software.

RESULTS AND DISCUSSION

Effect of filter media variations on ISSF performance

This study used four ISSF reactors with variations that can be seen in Table 1. ISSF 1.1 utilized sand and shell filter media, combined with a 1% augmentation of *Bacillus* sp. in the grease trap pre-treatment unit. ISSF 1.2 employed sand and activated carbon filter media, also with a 1% *Bacillus* sp. augmentation in the grease trap. In contrast, ISSF 2.1 useed sand and *A. granosa* shell filter media without any bacterial augmentation, while ISSF 2.2 combined sand and activated carbon media, likewise without augmentation. The 1% *Bacillus* sp. augmentation is performed by removing approximately 843 mL of liquid waste from the grease trap and replacing it with an equal volume of *Bacillus* sp. culture, previously diluted in physiological saline (Figure 2).

The BOD removal efficiency values for ISSF 1.1, ISSF 1.2, ISSF 2.1, and ISSF 2.2 ranged from 27–50%, 27–62%, 25–44%, and 25–55%, respectively, with corresponding average efficiencies of 34.28 ± 9.37%, 40.89 ± 11.44%, 33.93 ± 7.11%, and 38.71 ± 11.40%. These results align with the findings of Odugbose et al. (2020), reporting BOD removal efficiencies ranging from

Table 1. ISSF unit variations used for the research

Unit	Bacterial augmentation	Media	
		Sand + activated carbon	Sand + *A. granosa* shell
ISSF 1.1	v		v
ISSF 1.2	v	v	
ISSF 2.1			v
ISSF 2.2		v	

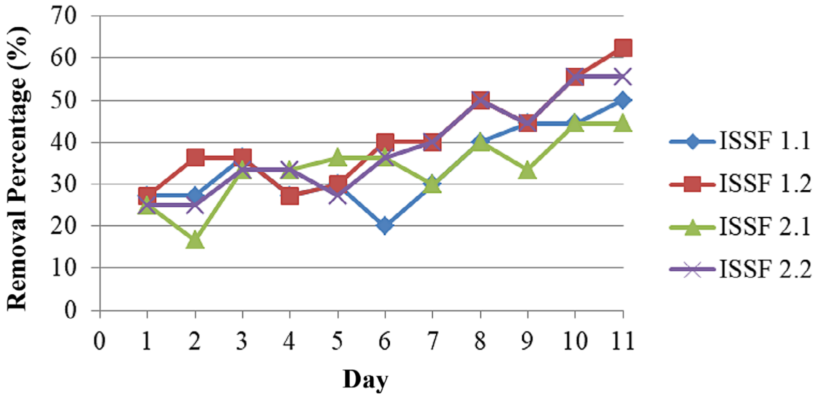

Figure 2. Average daily BOD removal efficiency (%) by ISSF 1.1, ISSF 1.2, ISSF 2.1, and ISSF 2.2

38% to 57%. BOD removal in this study is attributed to the microbial activity within the schmutzdecke layer (Ranjan and Prem, 2018). In this layer, organic matter in the wastewater is utilized by microbes as a nutrient source for metabolism and growth (Srivastava et al., 2020).

Besides, the observed fluctuations in BOD removal efficiency may be due to residual organic content from activated carbon and shell media. The inconsistency could also stem from an underdeveloped schmutzdecke layer, which plays a crucial role in biological filtration (Bryant and Tetteh-Narh et al., 2015). Based on the graph above, ISSF 1.1 demonstrates higher BOD removal efficiency than ISSF 2.1, and ISSF 1.2 outperforms ISSF 2.2. This indicates that 1% bacterial augmentation of *Bacillus* sp. positively influences BOD removal in the ISSF units. The presence of *Bacillus* sp. enhances and accelerates the decomposition of organic matter in the wastewater, thereby improving BOD removal efficiency (Liu et al., 2023) (Figure 3).

The COD removal efficiency values for ISSF 1.1, ISSF 1.2, ISSF 2.1, and ISSF 2.2 ranged from 28–59%, 36–71%, 33–46%, and 33–53%, respectively. The corresponding average efficiencies were 34.28 ± 9.37%, 40.89 ± 7.11%, 33.93 ± 7.11%, and 38.71 ± 11.40%. These findings are consistent with those reported by Azis et al. (2020), where COD removal efficiencies ranged from 76.5% to 88.22% using activated carbon media. The schmutzdecke plays a vital role in treatment performance. This layer facilitates the absorption of dissolved substances, followed by microbial decomposition and oxidation (Saini et al., 2023). Dissolved organic matter is quickly eliminated, while adsorbed colloidal particles are enzymatically broken down, transported across microbial cell membranes, and converted into simpler end products (Patel et al., 2022). With continuous loading, some of these end products percolate deeper into the filter bed and are eventually removed from the system.

Furthermore, wastewater containing dissolved organic matter and particulates is retained through filtration, mechanical straining, and contact with the filter media (Brar et al., 2022). Designing filter media with coarser pore channels can slow the flow rate, thereby increasing the contact time between pollutants and the media

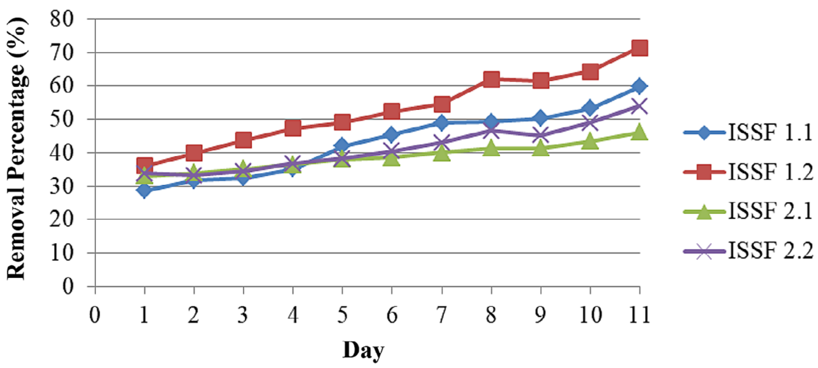

Figure 3. Average daily COD removal efficiency (%) by ISSF 1.1, ISSF 1.2, ISSF 2.1, and ISSF 2.2

surface (Maiyo et al., 2023). This enhanced contact promotes greater removal efficiency of COD. Based on the graph above, ISSF 1.1 demonstrates higher COD removal efficiency than ISSF 2.1, and ISSF 1.2 outperforms ISSF 2.2. This also suggests that the bacterial augmentation of *Bacillus* sp. contributes positively to ISSF performance (Figure 4).

The phosphate removal efficiency values for ISSF 1.1, ISSF 1.2, ISSF 2.1, and ISSF 2.2 ranged from 43–51%, 55–73%, 31–48%, and 43–58%, respectively. The corresponding average efficiencies were 34.28 ± 9.37%, 40.89 ± 7.11%, 33.93 ± 7.11%, and 38.71 ± 11.40%. These results are generally consistent with the findings of Bryant & Tetteh-Narh (2015), who reported phosphate removal efficiencies of approximately 67.61 ± 3.26% using activated carbon media. Phosphate removal in the ISSF system primarily occurs through biological processes within the schmutzdecke layer, where microorganisms play a key role in phosphate decomposition (Verma et al., 2017). Moreover, the adsorption capacity of the filter media contributes to phosphate reduction as well. The use of activated carbon, for instance, facilitates phosphate adsorption when wastewater flows through the filter column, ensuring sufficient contact and pressure between the adsorbent and the liquid waste (Luo et al., 2023).

Phosphate removal is also influenced by Van der Waals forces—attractive interactions between charged particles. In this study, it is assumed that microorganisms on the media surface carry a positive charge, allowing them to bind to negatively charged phosphate compounds. This electrostatic interaction aids in reducing phosphate concentrations in the treated wastewater (Priya et al., 2022). Based on the graph above, ISSF 1.1 exhibits higher phosphate removal efficiency than ISSF 2.1, and ISSF 1.2 outperforms ISSF 2.2. This indicates that the bacterial augmentation of *Bacillus* sp. positively influences phosphate removal in the ISSF. *Bacillus* sp. enhances phosphate solubilization through the secretion of organic acids, which form stable complexes with phosphate-binding cations, thereby releasing phosphate into a more soluble form (Rawat et al., 2021). *Bacillus* sp. possesses a phosphate solubilization mechanism involving the activity of the phytase enzyme, which further contributes to the breakdown and release of bound phosphate compounds (Gomez-Ramirez and Uribe-Velez, 2021).

Statistical analysis and data modelling

Based on the results of the ANOVA test employing the 2FI model presented in Table 2, 3, and 4, the p-value of less than 0.05 indicates that detention time, bacterial augmentation, and filter media significantly influence BOD, COD, and phosphate removal. Furthermore, the model itself is deemed significant, as reflected by the p-value below 0.05, confirming that it effectively represents the actual process. The lack of fit test also shows a p-value greater than 0.05, suggesting that the lack of fit is not significant when compared to pure error (Astuningsih et al., 2022). This finding indicates a strong correspondence between the model and the experimental data. A non-significant lack of fit is advantageous, as it validates the model's appropriateness and its ability to reliably predict response values across different conditions. The statistical models for BOD, COD, and phosphate removal efficiency in the ISSF are visualized in 3D graphs respectively in Figure 5, 6, and 7.

The adjusted determination coefficients (Adjusted R^2) are 0.9671, 0.9686, and 0.9447, while the predicted determination coefficients

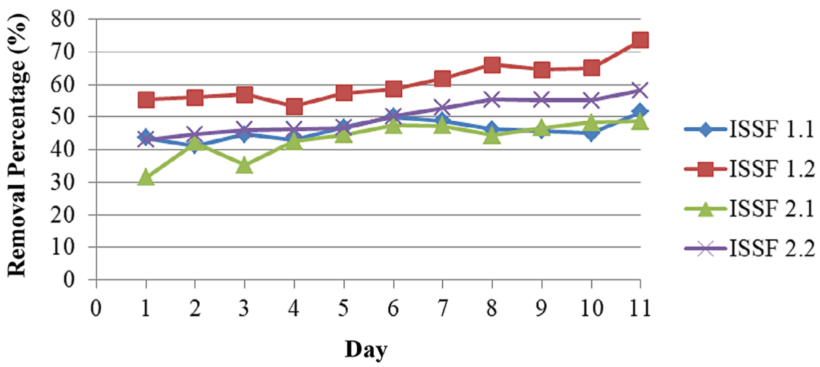

Figure 4. Average daily phosphate removal efficiency (%) by ISSF 1.1, ISSF 1.2, ISSF 2.1, and ISSF 2.2

Table 2. ANOVA result for BOD removal

Source	F-value	p-value	Note
Model	152.91	< 0.0001	Significant
A – Detention time (day)	787.81	< 0.0001	
B – Bacterial augmentation	16.61	0.0004	
C – Filter media	64.31	< 0.0001	
Lack of fit	-	-	-

Table 3. ANOVA result for COD removal

Source	F-value	p-value	Note
Model	160.59	< 0.0001	Significant
A – Detention time (day)	683.36	< 0.0001	
B – Bacterial augmentation	101.80	< 0.0001	
C – Filter media	85.86	< 0.0001	
Lack of fit	0.5968	0.7819	Not significant

Table 4. ANOVA result for phosphate removal

Source	F-value	p-value	Note
Model	89.31	< 0.0001	Significant
A – Detention time (day)	170.80	< 0.0001	
B – Bacterial augmentation	110.07	< 0.0001	
C – Filter media	237.47	< 0.0001	
Lack of fit	1.71	0.1661	Not significant

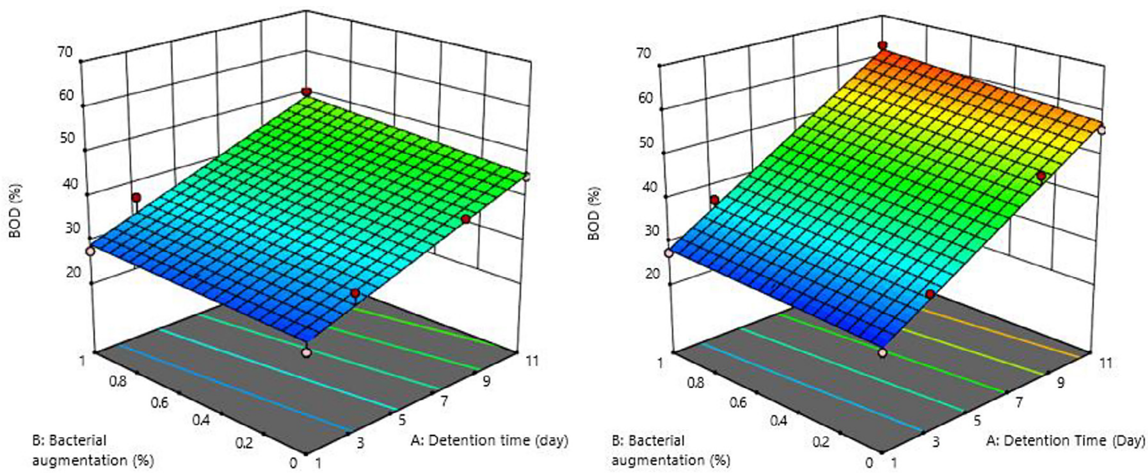

Figure 5. 3D surface graph of BOD removal efficiency of ISSF that utilized (left) sand and *A. granosa* shells; (right) sand and activated carbon as filter media

(predicted R^2) are 0.9584, 0.9549, and 0.9246. The differences between adjusted R^2 and predicted R^2 are less than 0.2, indicating no significant deviation between the model and the data, thus confirming that the model is acceptable (Dahish and Almutairi, 2023). This also suggests a strong correlation between the independent factors and the response variable in the research model. The adeq precision values of 37.1171, 43.7712, and 32.0901, all greater than 4, further support that the developed equations are reliable for predicting the response variables within the design space

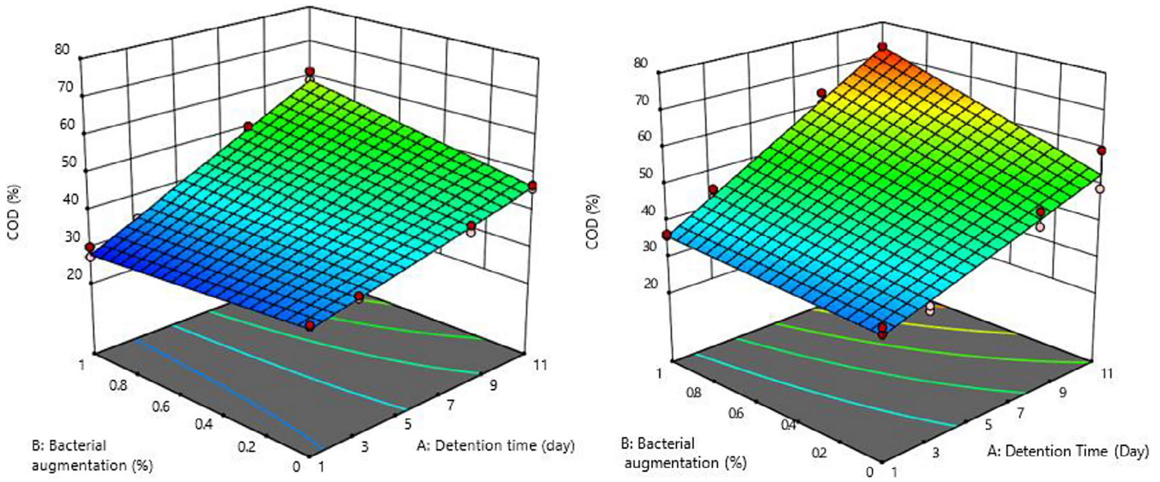

Figure 6. 3D surface graph of COD removal efficiency of ISSF that utilized (left) sand and *A. granosa* shells; (right) sand and activated carbon as filter media

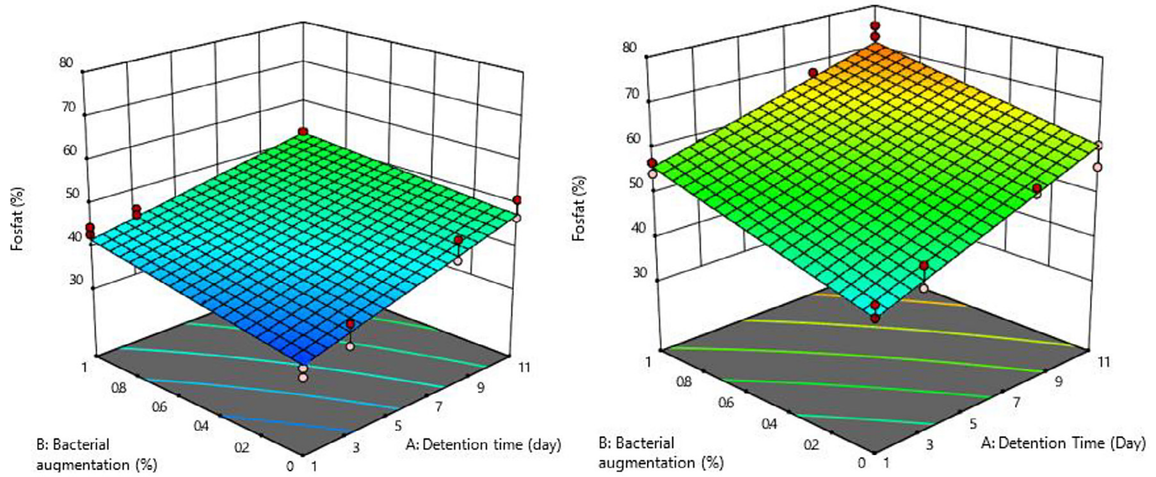

Figure 7. 3D surface graph of phosphate removal efficiency of ISSF that utilized (left) sand and *A. granosa* shells; (right) sand and activated carbon as filter media

(Hu et al., 2024). The mathematical models are as follows (Table 5).

The optimal configuration of ISSF for the removal of BOD, COD, and phosphate from culinary wastewater

Design-Expert 11 provides optimization tools that formulate combinations of independent factor levels to simultaneously fulfill the desired criteria for both factors and responses (Odutola and Oduola, 2023). Using point optimization, five optimal solution suggestions were generated.

Based on Table 6, the optimal combination of independent factors for maximizing BOD, COD, and phosphate removal is represented by the first solution – corresponding to the 11th simulation. This solution involves the addition of 1% *Bacillus* sp. in the grease trap and the use of sand and activated carbon as filter media in the ISSF. It is predicted to achieve removal efficiencies of 61.543% for BOD, 72.517% for COD, and 70.991% for phosphate. This solution has a desirability value of 0.474, where desirability ranges from 0 to 1.0, with values closer to 1.0 indicating a stronger ability of the optimization model to predict near-optimal outcomes (Zhang et al., 2024).

Overlay plots are used to evaluate the accuracy of predicted results against actual outcomes and to visualize the regions of independent factor levels that yield the highest average removal efficiencies across all tested parameters (Dargahi et al., 2021). Based on Figures 8 and 9, validation experiments

Table 5. Mathematical models presenting the performance of ISSF in removing BOD, COD, and phosphate

ISSF utilizing sand and *A. granosa* shell filter media	
Target parameter	Mathematical model
BOD (%)	25.51282 + 1.77038A + 1.45985B + 0.218287AB
COD (%)	30.81205 + 1.40747A – 5.89441B + 1.65707AB
Phosphate (%)	31.77652 + 1.42474A + 8.77884B – 0.385667AB
ISSF utilizing sand and activated carbon filter media	
Target parameter	Mathematical model
BOD (%)	23.04957 + 3.11703A + 1.80485B + 0.218287AB
COD (%)	30.60026 + 2.01169A + 1.56059B + 1.65707AB
Phosphate (%)	39.78721 + 1.89831A + 14.56509B – 0.385667AB

Note: *A* – detention time (day), *B* – bacterial augmentation (%).

Table 6. Suggested optimal configurations of ISSF

No.	Detention time (day)	Bacterial augmentation (%)	Filter media	Phosphate removal (%)	BOD removal (%)	COD removal (%)	Desirability value
1	11.000	1.000	P+AC	70.991	61.543	72.517	0.474
2	10.957	1.000	P+AC	70.926	61.398	72.358	0.472
3	11.000	0.976	P+AC	70.749	61.444	72.052	0.468
4	10.848	1.000	P+AC	70.762	61.037	71.961	0.464
5	11.000	0.825	P+AC	69.183	60.806	69.051	0.427

Note: *P* – sand, AC – activated carbon.

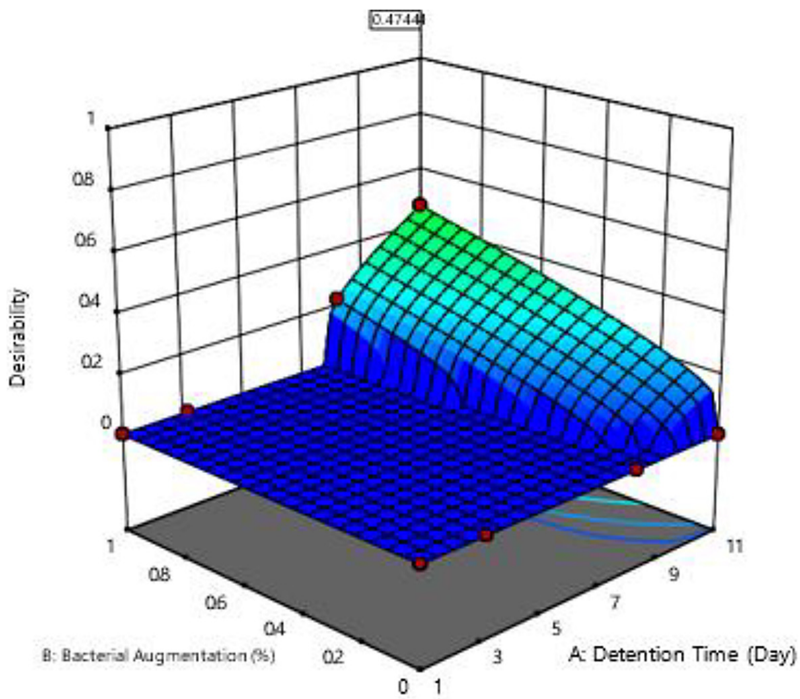

Figure 8. Desirability value 3D surface graph

were carried out to verify whether the predicted values generated by the model aligned with the actual field results and achieved maximum removal efficiencies for BOD, COD, and phosphate. The outcomes of these validation experiments are presented in Table 7. The observed results demonstrated removal efficiencies of 72.32% for phosphate, 62.50% for BOD, and 72.54% for COD. While

Table 7. Validation test result

Solution 1 of 5 responses	Predicted mean (%)	Observed (%)	Std Dev	95% PI low	Data mean (%)	95% PI high
Fosfat	70.99	72.32	2.52	65.10	73.64	76.88
BOD	61.54	62.50	2.04	56.78	62.50	66.31
COD	72.52	72.54	2.18	67.43	71.45	77.61

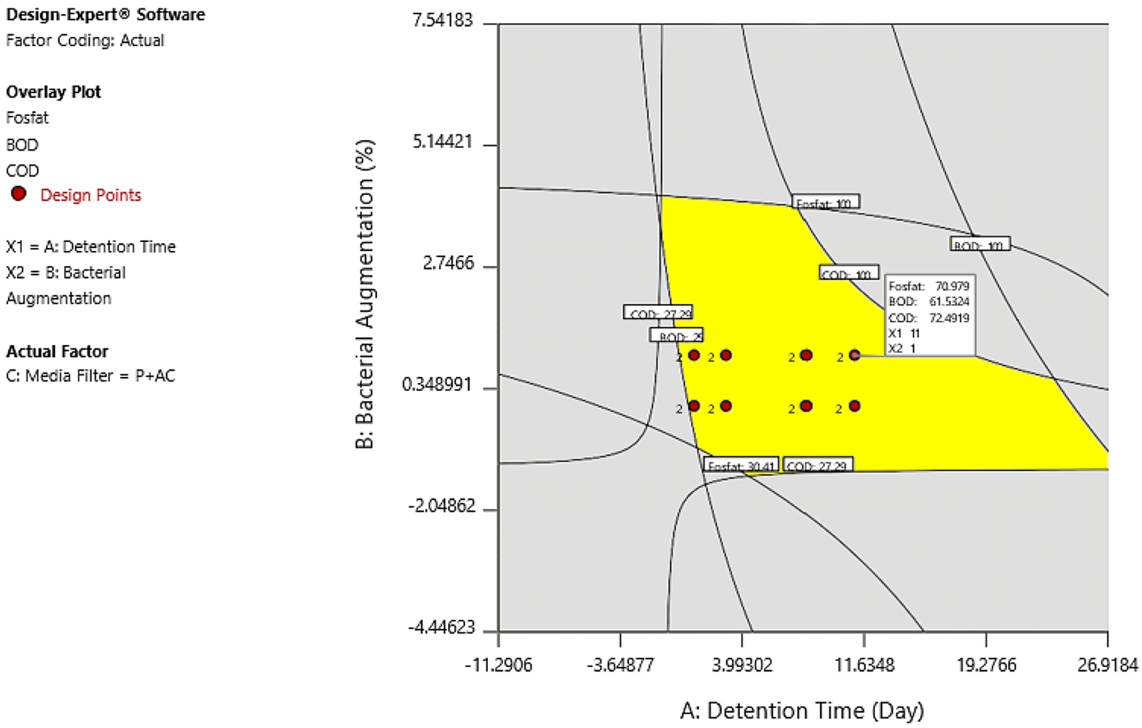

Figure 9. Overlay plot

these values exceeded the predicted outcomes, they remained within the acceptable range (within the PI low and high), indicating that the system operated under optimal conditions.

CONCLUSIONS

The results of this study demonstrate that the optimal configuration of the intermittent slow sand filter (ISSF) system for reducing BOD, COD, and phosphate concentrations, as determined using response surface methodology with the optimal (custom) design in Design Expert 11, consists of a filter media combination of sand and activated carbon, a detention time of 11 days, and the addition of 1% *Bacillus* sp. in the grease trap unit (ISSF 1.2). Validation experiments confirmed the effectiveness of this configuration, yielding removal efficiencies of 62.50% for BOD, 72.54% for COD, and 72.32% for phosphate, closely aligning with the predicted values of 61.54%, 72.52%, and 70.99%, respectively. These findings indicate that the proposed ISSF design offers a reliable and efficient approach for improving wastewater quality through integrated biological and physical treatment processes.

Acknowledgement

This research was supported by Universitas Airlangga through the Riset Kolaborasi Mitra Luar Negeri scheme, under grant number 424/UN3.14/PT/2020.

REFERENCES

1. Basuki, T. M., Indrawati, D. R., Nugroho, H. Y. S. H., Pramono, I. B., Setiawan, O., Nugroho, N. P.,..., Purwanto, J. S. (2024). Water pollution of some Major Rivers in Indonesia: the status, institution, regulation, and recommendation for its

mitigation. *Polish Journal of Environmental Studies*, *33*(4), 3515–3530.

2. Konkol, I., Kuligowski, K., Szafranowicz, P., Vorne, V., Reinikainen, A., Effelsberg, N.,..., Cenian, A. (2024). Review of the seasonal wastewater challenges in Baltic coastal tourist areas: insights from the NURSECOAST-II project. *Sustainability*, *16*(22), 9890.
3. Ahmad, I., Abdullah, N., Koji, I., Yuzir, A., Mohamad, S. E., Show, P. L.,..., Khoo, K. S. (2022). The role of restaurant wastewater for producing bioenergy towards a circular bioeconomy: A review on composition, environmental impacts, and sustainable integrated management. *Environmental Research*, *214*, 113854.
4. Pandey, S., Kumari, N. (2022). Sustainable utilization and management of agricultural and kitchen waste. *Agricultural and Kitchen Waste*, 127–163.
5. Lv, Z., Ran, X., Liu, J., Feng, Y., Zhong, X., Jiao, N. (2024). Effectiveness of chemical oxygen demand as an indicator of organic pollution in aquatic environments. *Ocean-Land-Atmosphere Research*, *3*, 0050.
6. Lan, J., Liu, P., Hu, X., Zhu, S. (2024). Harmful algal blooms in eutrophic marine environments: causes, monitoring, and treatment. *Water*, *16*(17), 2525.
7. Abdiyev, K., Azat, S., Kuldeyev, E., Ybyraiymkul, D., Kabdrakhmanova, S., Berndtsson, R.,..., Sultakhan, S. (2023). Review of slow sand filtration for raw water treatment with potential application in less-developed countries. *Water*, *15*(11).
8. Freitas, B. L. S., Terin, U. C., Sabogal-Paz, L. P. (2023). Household slow sand filters in intermittent and continuous flow for a long-term surface water treatment: efficiencies assessment and operational challenges. *Journal of Environmental Chemical Engineering*, *11*(3), 110090.
9. Maiyo, J. K., Dasika, S., Jafvert, C. T. (2023). Slow sand filters for the 21st century: A review. *International journal of environmental research and public health*, *20*(2), 1019.
10. Alsaqqar, A. S., Khudair, B. H., Al-Sulaiman, A. M. (2018). Slow sand filtration as a tertiary treatment for the secondary effluent from sewage treatment plant. *Association of Arab Universities Journal of Engineering Sciences*, *25*(3), 169–179.
11. Vairagi, P. D., Dash, R. R. (2018). Evaluation of dolochar as a filter media in slow sand filtration. In *Water Quality Management: Select Proceedings of ICWEES-2016,* 221–230. Springer Singapore.
12. Cescon, A., Jiang, J. Q. (2020). Filtration process and alternative filter media material in water treatment. *Water*, *12*(12), 3377.
13. Misran, E., Supardan, M. D., Iryani, D. A., Pramananda, V., Sihombing, A. F., Sitorus, D. V. (2024). Ultrasonic assisted adsorption of methylene blue using blood clam shell as a low-cost adsorbent. *Results in Engineering*, *23*, 102715.
14. Das, S., Mishra, S., Sahu, H. (2023). A review of activated carbon to counteract the effect of iron toxicity on the environment. *Environmental Chemistry and Ecotoxicology*, *5*, 86–97.
15. Chen, W. H., Uribe, M. C., Kwon, E. E., Lin, K. Y. A., Park, Y. K., Ding, L., Saw, L. H. (2022). A comprehensive review of thermoelectric generation optimization by statistical approach: Taguchi method, analysis of variance (ANOVA), and response surface methodology (RSM). *Renewable and Sustainable Energy Reviews*, *169*, 112917.
16. Hashimoto, Y., Takashima, H., Jayamohan, S. (2019). Application of roughing filter to pre-treat 1,000 NTU raw water for slow sand filter. *Water Practice & Technology*, *14*(2), 355–364.
17. Fitriani, N., Ardiyanti, P. E., Kuncoro, E. P., Budiyanto, W. D., Isnadina, D. R. M., Wahyudianto, F. E., Mohamed, R. M. S. R. (2020). Behavior of schmutzdecke with varied filtration rates of slow sand filter to remove total coliforms. *Heliyon*, *6*(4).
18. Fitriani, N., Theresia, L., O'Marga, T. T. N., Kurniawan, S. B., Supriyanto, A., Abdullah, S. R. S., Rietveld, L. C. (2023). Performance of a modified and intermittently operated slow sand filter with two different mediums in removing turbidity, ammonia, and phosphate with varying acclimatization periods. *Heliyon*, *9*(12).
19. Odugbose, B. D., Lawal, N. S., Adetifa, B. O, Adeyemi, H. O., Mangey J. A., Adegoke, A. T., dan Afolabi O. S. (2020). Efficacy of slow sand filtration system embedded with activated carbon for agro-industrial wastewater treatment. *Mindanao Journal of Science and Technology*, *18*(2), 224–242.
20. Ranjan, P., Prem, M. (2018). Schmutzdecke-a filtration layer of slow sand filter. *International Journal of Current Microbiology and Applied Sciences*, *7*(7), 637–645.
21. Srivastava, R. K., Shetti, N. P., Reddy, K. R., Aminabhavi, T. M. (2020). Sustainable energy from waste organic matters via efficient microbial processes. *Science of the Total Environment*, *722*, 137927.
22. Bryant, I. M., Tetteh-Narh, R. (2015). Using slow sand filtration system with activated charcoal layer to treat salon wastewater in a selected community in Cape Coast Ghana. *Journal of Advance Chemical Engineering*, *5*(135).
23. Liu, C., Ma, S., Wang, X., Ou, Y., Du, H. (2023). Biodegradation of organic compounds in the coal gangue by Bacillus sp. into humic acid. *Biodegradation*, *34*(2), 125–138.
24. Azis, K., Mavriou, Z., Karpouzas, D. G., Ntougias, S., Melidis, P. (2021). Evaluation of sand filtration and activated carbon adsorption for the

post-treatment of a secondary biologically-treated fungicide-containing wastewater from fruit-packing industries. *Processes*, *9*(7), 1223.

25. Saini, S., Tewari, S., Dwivedi, J., Sharma, V. (2023). Biofilm-mediated wastewater treatment: a comprehensive review. *Materials Advances*, *4*(6), 1415–1443.
26. Patel, H. K., Kalaria, R. K., More, B. S., Jokhakar, P. H., Khimani, M. R. (2022). Microbial ecology of biofiltration. In *An Innovative Role of Biofiltration in Wastewater Treatment Plants (WWTPs)* 235–266. Elsevier.
27. Brar, K. K., Raza, H., Magdouli, S., Brar, S. K. (2022). Role and importance of filtration system in modular drinking water treatment system. In *Modular Treatment Approach for Drinking Water and Wastewater* 239–265. Elsevier.
28. Verma, S., Daverey, A., Sharma, A. (2017). Slow sand filtration for water and wastewater treatment–a review. *Environmental Technology Reviews*, *6*(1), 47–58.
29. Luo, D., Wang, L., Nan, H., Cao, Y., Wang, H., Kumar, T. V., Wang, C. (2023). Phosphorus adsorption by functionalized biochar: a review. *Environmental Chemistry Letters*, *21*(1), 497–524.
30. Priya, E., Kumar, S., Verma, C., Sarkar, S., Maji, P. K. (2022). A comprehensive review on technological advances of adsorption for removing nitrate and phosphate from waste water. *Journal of Water Process Engineering*, *49*, 103159.
31. Rawat, P., Das, S., Shankhdhar, D., Shankhdhar, S. C. (2021). Phosphate-solubilizing microorganisms: mechanism and their role in phosphate solubilization and uptake. *Journal of Soil Science and Plant Nutrition*, *21*(1), 49–68.
32. Gomez-Ramirez, L. F., Uribe-Velez, D. (2021). Phosphorus solubilizing and mineralizing Bacillus spp. contribute to rice growth promotion using soil amended with rice straw. *Current Microbiology*, *78*(3), 932–943.
33. Astutiningsih, F., Anggrahini, S., Fitriani, A., Supriyadi, S. (2022). Optimization of saffron essential oil nanoparticles using chitosan-arabic gum complex nanocarrier with ionic gelation method. *International Journal of Food Science*, *2022*(1), 4035033.
34. Dahish, H. A., Almutairi, A. D. (2023). Effect of elevated temperatures on the compressive strength of nano-silica and nano-clay modified concretes using response surface methodology. *Case Studies in Construction Materials*, *18*, e02032.
35. Hu, G., Chen, X., Cao, Z., Yang, L. (2024). Optimization design of cotton-straw-fiber-modified asphalt mixture performance based on response surface methodology. *Buildings*, *14*(11), 3670.
36. Odutola, T., Oduola, K. (2023). An experimental design approach for investigating the influence of various factors on wax deposition in production tubing and pipelines. *Global Journal of Engineering and Technology Advances*, *14*(03), 99–110.
37. Zhang, Y., Hui, B., Ma, Z., Li, Y., Chou, J., Wang, H. (2024). RSM-based design optimization of anti-abrasive seal considering the interaction between particle size and base type. *Construction and Building Materials*, *430*, 136332.
38. Dargahi, A., Samarghandi, M. R., Shabanloo, A., Mahmoudi, M. M., Nasab, H. Z. (2021). Statistical modeling of phenolic compounds adsorption onto low-cost adsorbent prepared from aloe vera leaves wastes using CCD-RSM optimization: effect of parameters, isotherm, and kinetic studies. *Biomass Conversion and Biorefinery*, 1–15.