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Application of Response Surface Methodology (RSM) for Optimization of COD Removal from POME by Activated Sludge Simulation Program (ASIM)

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Abstract: Indonesia is the world's biggest producer at a time as an exporter of palm oil. Palm oil processing is implemented in palm oil mills, where the oil is extracted from palm fruit bunches. A major amount of water is utilized during the extraction of crude palm oil from fresh fruit bunches, and about 50% of this water is generated as palm oil mill effluent (POME). POME is a viscous liquid that conceives upper amounts of contaminants such as COD, BOD, TSS, and Ammonia. Exile of this highly defacing waste becomes a significant matter if it is not handled accurately other than the strict standard limits imposed by the Indonesian Ministry of Environment. In this research, a simulation of the POME Activated Sludge Simulation (ASIM) waste treatment process will be carried out to determine the optimum process for treating POME. POME processing is carried out with 4 main process equipment units, namely anaerobic tanks, anoxic tanks, aeration tanks and clarifiers. The experimental design was carried out utilizing the Standard Response Surface Method (RSM) design, namely the 2-level factorial 2^3 design to decide the optimum process variable for COD removal using Minitab v.20 software. Influent data were obtained from PTPN V Sei Pagar, Riau Province with water quality standards waste based on the 2014 LH Regulation, namely COD 500 mg/L. The variables used in this research are HRT, recirculation rate, and sludge retention time. The research results can be used to design the WWTP for the Palm Oil Industry. The outcomes clearly showed that HRT, SRT, and IRR had a significant impact on the COD elimination of POME. From the optimization, the maximum COD removal efficiency was derived at initial SRT 8,63 hours, HRT 5,07 hours and IRR 1,75Q.

Keywords: ASIM, COD, WWTP, RSM.

Introduction

Indonesia, Thailand, Malaysia, and other nations have established their palm oil (PO) industries (Nawaz et al., 2021; Saad et al., 2021). The palm oil (PO) industry in these countries generates 48–72 million metric tonnes of POME yearly. Wastewater from raw POME is a colloidal suspension that contains 95–96% water, 0.6-0.7% oil, 4-5% total solids, including 2-4% suspended solids, as well as high concentrations of nitrogenous compounds, carbohydrates, minerals, protein, and lipids that microbes can use to create valuable materials. It must be a crucial answer to uphold the balance between environmentally sound practices and renewable energy that can be generated from nutrient-rich components in the POME (Wu et al., 2007). It has a negative effect on the ecosystem if this untreated POME is dumped there. However, The treatment and eradication of so many POME is the most important issue in these countries (Iskandar et al., 2018; Susanto et al., 2022). The oil palm industry must treat POME before being released into the environment. POME treatment has been investigated utilizing several conventional methods, including coagulation, adsorption, membrane filtering, aerobic and anaerobic digestion, and electrocoagulation (EC) (Audu et al., 2020; Saad et al., 2021; Salimin et al., 2020; Yashni et al., 2020). Due to the difficulties of current treatment procedures in fulfilling the requirements for discharge restrictions, researchers

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have recently shown a greater interest in creating effective remediation solutions for treated POME (Nawaz et al., 2021). Researchers have increasingly focused on improving the technology's effectiveness and environmental impact in recent years (Nabgan et al., 2021; Xu et al., 2017).This study uses optimization to find the optimum condition to reach COD reduction very efficiently with high removal percentage. RSM is used to analyze the optimum process to determine the effect of HRT, SRT and recirculation rate on COD removal which is simulated using ASIM. ASIM is a dynamic simulation program designed specifically for biological wastewater treatment modelling. It offers support for activated sludge systems with up to 10 reactors in series (anoxic, anaerobic, aerobic), including batch reactors, sludge return, internal recirculation streams, and chemostat reactors.

Materials and Methods

Study area

Materials and Method

The desired sample was obtained from WWTP PTPN V Sei Pagar, Riau. POME at PTPN Sei Pagar comes from CPO clarification/refining units, stew/condensate, Kernel/Hydro Cyclone/clay bath and factory utilities. POME characteristics collected from PTPN V, Sei Pagar Riau based on operational data can be seen in Table 1.

Table 1. Characteristics of POME PTPN V Sei Pagar, Riau

Indicator	Result (mg/L)	Standard* (mg/L)
TSS	**15.720**	250
COD	81.947	350
BOD	11.095	-
pH	5	6-9
Ammonia	63,04	50

*Regulation of The Minister of Environment Republic of Indonesia No. 5/2014

Procedures

ASIM software (www.eawag.ch) is selected as the simulator with ASM3_swiss as the model. An anaerobic, anoxic, aeration tank, as well as a final clarifier, are utilizeded in this biological therapy. COD is eliminated using the aerobic tank. Denitrification is the process used to eliminate nitrate in an anoxic tank. A part of the final sludge from the final clarifier is also mixed in the anoxic tank.

Gravity transports the anoxic basin's wastewater to an aeration tank. This tank filters out biodegradable material and nitrates ammonia. The dissolved oxygen is fed by the aeration blower. Gravity-flowing activated sludge and wastewater undergoing biological treatment enter the final clarifier, where sludge and supernatant are separated. The final clarifier mechanism scrapes the settled-down sludge, which is then taken out and transferred to an anoxic tank or sludge thickening tank by a recycling pump. A flowchart of the biological wastewater treatment and operation conditions in ASIM can be seen in Figure 1 and Table 2.

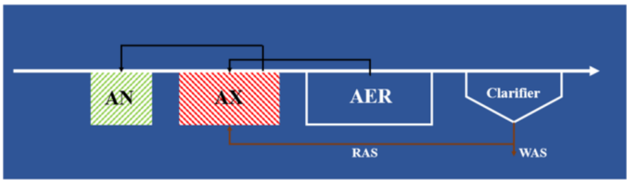

Figure 1. PFD POME Waste Water Treatment

Table 2. Basis Operation on ASIM

Basis Operation	Value
Debit	7000 m^3/day
Operating Temperature	27 ºC
Volume Clarifier	875 m^3
Return sludge flowrate	7000 m^3/day
Saturation Concentration for Oxygen	10 mg/L
Volume Anaerobic/Anoxic	875

Data analysis

Research using the full-factorial CCD method to improve COD removal is an essential component of experimental design. RSM is a crucial statistical method for planning experiments, creating models, assessing the impact of variables, and identifying the ideal operating conditions. (Kim & Rhee, 2018; Mishra et al., 2018). The RSM was utilized in this study to analyze the connection between the experimentally tested variables and the observed findings and to establish the ideal COD removal operating parameters. Three crucial processes are involved in RSM: (1) conducting statistically planned experiments; (2) evaluating the coefficients in a mathematical model; and (3) projecting the response and determining the suitability of the model. In this context, CCD is one of the experimental designs in RSM for fitting second-order models that is most frequently used. This design is equally predictable from its center in all directions. It can be used to research the interactions between the various factors affecting COD elimination.

The third or final stage involved performing an ANOVA for the response surface quadratic model to decide the significance or suitability of the models used to fit the experiments as well as the significance of the linear, interaction, and quadratic terms. A second-order polynomial regression model was built using the sequential ANOVA, lack of fit test, and other adequate measurements from CCD. The empirical model utilized to fit the experimental data obtained in the CCD is represented by the equation below. The independent variables used in this study are HRT, SRT and recirculation rate with COD removal as responses.

$$Y = a_o + \sum a_i X_i + \sum a_{ii} X_i^2 + \sum a_{ij} X_i X_j \ldots\ldots (1)$$

Where Y is the measured response, Xi and Xj are the independent variables, a_o represents the regression coefficient at the center point (intercept), and a_i, a_{ii} and a_{ij} are the regression coefficients of the mod (Bajpai & Katoch, 2020; Kadier et al., 2018).

The performance of the created model for three independent variables was represented mathematically as Eq. below:

$$Y = a_o + a_1X_1 + a_2X_2 + a_3X_3 + a_{11}X_1^2 + a_{22}X_2^2 + a_{33}X_3^3 + a_{12}X_1X_2 + a_{13}X_1X_3 + a_{23}X_2X_3 \ldots..(2)$$

Where X_1, X_2, and X_3 are the independent variables and a_1, a_2, a_3 denote linear coefficients, a_{11}, a_{22} and a_{33} are squared coefficients, and a_{12}, a_{13}, and a_{23} are interaction coefficients. The coefficient values were calculated using statistical tools. Experimental data from CCD were examined using multiple regressions. Utilizing the coefficient of determination R^2, which must be at least 0.8 to get a successful model fit, the quality of the fitted models was assessed. (Bajpai et al., 2020; Myers et al., 2016). The statistical significance of the regression coefficients was evaluated using ANOVA. A model was generally considered effective and practical if it had a high F-value and a good R^2 (correlation coefficient). Then, statistical calculations were done on the regression data to produce response surface diagrams (Prakash Maran et al., 2013). Model terms were assessed using the P-value (likelihood of error, P-value 0.05) and a 95% confidence interval. The model terms are assessed significant when the P-value (Prob > F) is less than 0.050. To create three-dimensional plots and their associated contour plots, the effects of three variables HRT, SRT, and recirculation rate were combined. The statistical data analysis, experimental design matrix, and optimization or response surface analysis were all carried out using the Minitab v.20 software program (Licence from Bandung Institut of Technology).

Results and Discussion

1. Fit summary and ANOVA

For various parameter combinations, statistically planned experiments were conducted to investigate the cumulative influence of the factors. Table 3 lists the experimental design matrix from CCD.

Tabel 3. Design matrix and Response of COD Removal

Run	SRT(hr)	HRT(hr)	IRR (Q)	COD Removal (%)
1	7	2	0.5	30.56488
2	10	2	0.5	99.7396
3	7	6	0.5	99.98272
4	10	6	0.5	99.99893
5	7	2	3	27.75819
6	10	2	3	99.32693
7	7	6	3	99.98549
8	10	6	3	99.99987
9	5.977311	4	1.75	99.68889
10	11.02269	4	1.75	99.99833
11	8.5	0.636414	1.75	1.643745
12	8.5	7.363586	1.75	99.99577
13	8.5	4	-0.35224	99.97467
14	8.5	4	3.852241	99.98052
15	8.5	4	1.75	99.97714
16	8.5	4	1.75	99.97714
17	8.5	4	1.75	99.97714
18	7	2	0.5	30.56488
19	10	2	0.5	99.7396
20	7	6	0.5	99.98272
21	10	6	0.5	99.99893
22	7	2	3	27.75819
23	10	2	3	99.32693
24	7	6	3	99.98549
25	10	6	3	99.99987
26	5.977311	4	1.75	99.68889
27	11.02269	4	1.75	99.99833
28	8.5	0.636414	1.75	1.643745
29	8.5	7.363586	1.75	99.99577
30	8.5	4	0.35224	99.97467
31	8.5	4	3.852241	99.98052
32	8.5	4	1.75	99.97714
33	8.5	4	1.75	99.97714
34	8.5	4	1.75	99.97714

Through ANOVA, the model's suitability was further supported. Figure 2 displays the outcomes of the ANOVA for COD removal. The P-value of 0.000 (P 0.05) for the regression model equation, in this case, shows that the second-order polynomial model adequately fitted the experimental results.

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	8	29673.5	3709.2	31.99	0.000
Linear	3	16816.4	5605.5	48.35	0.000
SRT	1	2923.7	2923.7	25.22	0.000
HRT	1	13891.2	13891.2	119.82	0.000
IRR	1	1.5	1.5	0.01	0.910
Square	2	7903.1	3951.6	34.08	0.000
SRT*SRT	1	0.3	0.3	0.00	0.961
HRT*HRT	1	7512.8	7512.8	64.80	0.000
2-Way Interaction	3	4954.1	1651.4	14.24	0.000
SRT*HRT	1	4950.0	4950.0	42.70	0.000
SRT*IRR	1	1.4	1.4	0.01	0.912
HRT*IRR	1	2.6	2.6	0.02	0.882
Error	25	2898.4	115.9		
Lack-of-Fit	6	2898.4	483.1	*	*
Pure Error	19	0.0	0.0		
Total	33	32571.9			

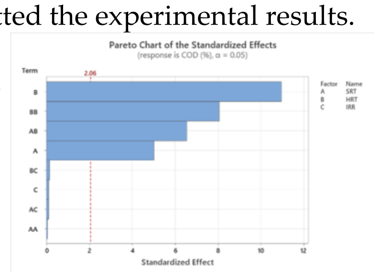

Figure 2. ANOVA and Pareto Chart COD Removal

Based on the ANOVA test in Fig.2, the coefficient of determination R-square is 91,10% and R-square(adj) is 88,25% which indicates that 91,10% of the COD removal variable is influenced by independent variables and only 0,89 % of all variables that cannot be defined by the model. The R-square value is large and feasible (>80%) with a small difference from the adjusted value, which is 2,75%. Thus, this model is feasible to be used to form equations that represent the experimental profile which can be seen in equation 1. Based on the Pareto diagram, it was discovered that the variables that had a significant impact were HRT, SRT, IRR, HRT^2, SRT^2, IRR^2 and 2-way interaction of SRT×HRT, SRT×IRR and HRT×IRR.

Regression Equation in Uncoded Units

CC Rei l (‘ = -272.5 + 30.9 SRT + 95.71 HRT - 2.2 IRR - 0.047 SRT*SRT - 4.360 HRT*HRT - 5.863 SRT*HRT + 0.16 SRT*IRR + 0.16 HRT*IRR……………………………..……….(3)

2. 3D plots and efficiency level

It is simpler to understand the direct and indirect effects of the variables when the response surface is plotted as a function of only two variables at a time while holding the other variables constant. Figure 3 display the reaction surface curves for COD removal. These graphs illustrate how SRT, HRT and IRR all have an impact on COD removal. When HRT and IRR were increased to values between 2 and 6 hours, the COD removal increased. The ideal conditions were SRT 8,63 hours, HRT 5,07 hours and IRR 1,75Q. Regarding the growth rate of microorganisms, the SRT is a crucial operational parameter in activated sludge treatment operations. According to field tests conducted in large-scale WWTPs, plants with a high SRT typically displayed high and steady elimination of both estrogens and estrogenic activity (Li et al., 2016).

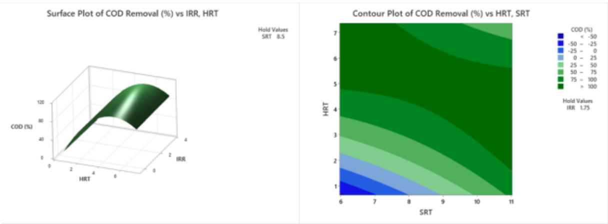

Figure 3. Surface Plot and Countour Plot of COD Removal

Conclusions

The use of statistical optimization methods CCD and RSM was utilized in conjunction with the statistical optimization approach to achieve the ideal process conditions while illuminating the relationships between the process variables. The outcomes made it very evident that the variable had a significant impact on COD removal. The outcomes clearly showed that HRT, SRT, and IRR had a significant impact on the COD elimination of POME. From the optimization, the maximum COD removal efficiency was derived at initial SRT 8,63 hours, HRT 5,07 hours and IRR 1,75Q. Due to the high R-square value of the regression model equation in ANOVA R-Square 91,10%, the experimental data were effectively adapted to the second-order regression model.

References

Audu, J. O., Dzulkarnain, E. L. N., Ibrahim, Z., Ibrahim, N., & Abdul-Wahab, M. F. (2020). *Dark Fermentation and Bioelectrochemical Systems for Enhanced Biohydrogen Production from Palm Oil Mill Effluent: Current Progress, Potentials, and Future Perspectives*. 1–35. https://doi.org/10.1007/978-3-030-39137-9_1

Bajpai, M., & Katoch, S. S. (2020). Techno-economical optimization using Box–Behnken (BB) design for chemical oxygen demand and chloride reduction from hospital wastewater by electrocoagulation. *Water Environment Research*, *92*(12), 2140–2154. https://doi.org/10.1002/WER.1387

Bajpai, M., Singh Katoch, S., & Singh, M. (2020). Optimization and economical study of electrocoagulation unit using CCD to treat real graywater and its reuse potential. *Environmental Science and Pollution Research*, *27*(33), 42040–42050. https://doi.org/10.1007/S11356-020-10171-X/TABLES/5

Iskandar, M. J., Baharum, A., Anuar, F. H., & Othaman, R. (2018). Palm oil industry in South East Asia and the effluent treatment technology—A review. *Environmental Technology & Innovation*, *9*, 169–185. https://doi.org/10.1016/J.ETI.2017.11.003

Kadier, A., Abdeshahian, P., Kalil, M. S., Hasan, H. A., & Hamid, A. A. (2018). Optimization of the Key Medium Components and Culture Conditions for Efficient Cultivation of G. sulfurreducens Strain PCA ATCC 51573 Using Response Surface Methodology. *Iranian Journal of Science and Technology, Transaction A: Science*, *42*(1), 237–244. https://doi.org/10.1007/S40995-018-0501-4/FIGURES/4

Kim, H. W., & Rhee, M. S. (2018). Response surface modeling of reductions in uropathogenic Escherichia coli biofilms on silicone by cranberry extract, caprylic acid, and thymol. *Https://Doi.Org/10.1080/08927014.2018.1488969*, *34*(6), 710–717. https://doi.org/10.1080/08927014.2018.1488969

Li, B., Qiu, Y., Zhang, C., Chen, L., & Shi, H. (2016). Understanding biofilm diffusion profiles and microbial activities to optimize integrated fixed-film activated sludge process. *Chemical Engineering Journal*, *302*, 269–277. https://doi.org/10.1016/J.CEJ.2016.05.048

Mishra, P., Singh, L., Ab Wahid, Z., Krishnan, S., Rana, S., Amirul Islam, M., Sakinah, M., Ameen, F., & Syed, A. (2018). Photohydrogen production from dark-fermented palm oil mill effluent (DPOME) and statistical optimization: Renewable substrate for hydrogen. *Journal of Cleaner Production*, *199*, 11–17. https://doi.org/10.1016/J.JCLEPRO.2018.07.028

Myers, R. H., Montgomery, D. C., & Anderson-Cook, C. M. (2016). Response surface methodology: process and product optimization using designed experiments. John Wiley & Sons.

Nabgan, W., Tuan Abdullah, T. A., Nabgan, B., Jalil, A. A., Nordin, A. H., Ul-Hamid, A., Hassan, N. S., Hussain, I., Coelho, A., Amin, A., & Ikram, M. (2021). Catalytic biohydrogen production from organic waste materials: A literature review and bibliometric analysis. *International Journal of Hydrogen Energy*, *46*(60), 30903–30925. https://doi.org/10.1016/J.IJHYDENE.2021.04.100

Nawaz, R., Kait, C. F., Chia, H. Y., Isa, M. H., Huei, L. W., Sahrin, N. T., & Khan, N. (2021). Countering major challenges confronting photocatalytic technology for the remediation of treated palm oil mill effluent: A review. *Environmental Technology & Innovation*, *23*, 101764. https://doi.org/10.1016/J.ETI.2021.101764

Prakash Maran, J., Sivakumar, V., Thirugnanasambandham, K., & Sridhar, R. (2013). Artificial neural network and response surface methodology modeling in mass transfer parameters predictions during osmotic dehydration of Carica papaya L. *Alexandria Engineering Journal*, *52*(3), 507–516. https://doi.org/10.1016/J.AEJ.2013.06.007

Saad, M. S., Wirzal, M. D. H., & Putra, Z. A. (2021). Review on current approach for treatment of palm oil mill effluent: Integrated system. *Journal of Environmental*

Management, *286*, 112209. https://doi.org/10.1016/J.JENVMAN.2021.112209

Salimin, Z., Susianto, M., Batara, B., & Chafidz, A. (2020). Utilization of Modified Zeolite Materials as Chromium Cation Exchanger for Treatment of Liquid Waste from Electroplating Industries. *Materials Science Forum*, *991*, 172–177. https://doi.org/10.4028/WWW.SCIENTIFIC.NET/MSF.991.172

Susanto, R., Rahmi, V. A., & Widyaningsih, D. (2022). Treatment Palm Oil Mill Effluent (POME) Using Continuous Column Plate Electric Reactor. *Al-Kimia*, *10*(2). https://doi.org/10.24252/AL-KIMIA.V10I2.25646

Wu, T. Y., Mohammad, A. W., Md. Jahim, J., & Anuar, N. (2007). Palm oil mill effluent (POME) treatment and bioresources recovery using ultrafiltration membrane: Effect of pressure on membrane fouling. *Biochemical Engineering Journal*, *35*(3), 309–317. https://doi.org/10.1016/J.BEJ.2007.01.029

Xu, L., Chen, N., & Chen, Z. (2017). Will China make a difference in its carbon intensity reduction targets by 2020 and 2030? *Applied Energy*, *203*, 874–882. https://doi.org/10.1016/J.APENERGY.2017.06.087

Yashni, G., Al-Gheethi, A., Radin Mohamed, R. M. S., Arifin, S. N. H., & Mohd Salleh, S. N. A. (2020). Conventional and advanced treatment technologies for palm oil mill effluents: a systematic literature review. *Https://Doi.Org/10.1080/01932691.2020.1788950*, 1–19. https://doi.org/10.1080/01932691.2020.1788950