



Hak Cipta Dilindungi Undang-undang

1. Dilarang mengutip sebagian atau seluruh karya tulis ini tanpa mencantumkan dan menyebutkan sumber :
 - a. Pengutipan hanya untuk kepentingan pendidikan, penelitian, penulisan karya ilmiah, penyusunan laporan, penulisan kritik atau tinjauan suatu masalah
 - b. Pengutipan tidak merugikan kepentingan yang wajar IPB University.
2. Dilarang mengumumkan dan memperbanyak sebagian atau seluruh karya tulis ini dalam bentuk apapun tanpa izin IPB University.

THERMAL EVALUATION AND MULTI-OBJECTIVE OPTIMIZATION OF MOVING BED BIOFILM REACTOR POST-TREATMENT FOR PALM OIL MILL EFFLUENT BASED ON ACTIVATED SLUDGE MODEL NO. 1

MIKAEL FEBRIAN ARITONANG



**CIVIL AND ENVIRONMENTAL ENGINEERING STUDY PROGRAM
FACULTY OF ENGINEERING AND TECHNOLOGY
IPB UNIVERSITY
BOGOR
2026**



@Hak cipta milik IPB University

IPB University



IPB University
— Bogor Indonesia —

Hak Cipta Dilindungi Undang-undang

1. Dilarang mengutip sebagian atau seluruh karya tulis ini tanpa mencantumkan dan menyebutkan sumber :
 - a. Pengutipan hanya untuk kepentingan pendidikan, penelitian, penulisan karya ilmiah, penyusunan laporan, penulisan kritik atau tinjauan suatu masalah
 - b. Pengutipan tidak merugikan kepentingan yang wajar IPB University.
2. Dilarang mengumumkan dan memperbanyak sebagian atau seluruh karya tulis ini dalam bentuk apapun tanpa izin IPB University.

Perpustakaan IPB University



DECLARATION OF THE UNDERGRADUATE THESIS INFORMATION SOURCES AND COPYRIGHT TRANSFER

I hereby declare that the undergraduate student thesis titled “Thermal Evaluation and Multi-Objective Optimization of Moving Bed Biofilm Reactor Post-Treatment for Palm Oil Mill Effluent Based on Activated Sludge Model No. 1” is my work under the guidance of my supervisors and has not been published or submitted to any university in any form. The source of information derived or quoted from unpublished or published documents by other authors has been mentioned in the text and included in the bibliography at the end of this thesis.

Hereby, I assign the copyright of this undergraduate thesis to the IPB University.

Bogor, June 2026

Mikael Febrian Aritonang
F4401221042

Hak Cipta Dilindungi Undang-undang

1. Dilarang mengutip sebagian atau seluruh karya tulis ini tanpa mencantumkan dan menyebutkan sumber :
 - a. Pengutipan hanya untuk kepentingan pendidikan, penelitian, penulisan karya ilmiah, penyusunan laporan, penulisan kritik atau tinjauan suatu masalah
 - b. Pengutipan tidak merugikan kepentingan yang wajar IPB University.
2. Dilarang mengumumkan dan memperbanyak sebagian atau seluruh karya tulis ini dalam bentuk apapun tanpa izin IPB University.



ABSTRACT

MIKAEL FEBRIAN ARITONANG. Thermal Evaluation and Multi-Objective Optimization of Moving Bed Biofilm Reactor Post-Treatment for Palm Oil Mill Effluent Based on Activated Sludge Model No. 1. Supervised by ALLEN KURNIAWAN and KANIA AMELIA SAFITRI.

The modified AnRBC system was previously unable to sufficiently reduce soluble organic compounds in POME, indicating the need for an aerobic post-treatment unit to improve final effluent quality. This research evaluated a MBBR as a post-treatment unit for POME treatment using Activated Sludge Model No. 1 (ASM1). The HRT in the AnRBC and MBBR units was varied under three operational conditions of 1, 2, and 3 d. The highest TCOD removal efficiency reached 91.76% at HRT of 3 d, reducing TCOD from 3052.90 mg/L to 251.63 mg/L. The ASM1 model showed good predictive with observed data, with $R^2 = 0.997$, MAPE = 3.07%. The TCOD-based thermal evaluation also described good predictive with MAPE = 4.40%. Multi-objective optimization identified the best condition at HRT of 3.25 days, temperature of 33 °C, pH 7.5, and carrier-specific surface area of 1200 m²/m³, producing predicted effluent COD of 322.6 mg/L, OUR of 31.19 mg O₂/(L.d), and SEC of 60.57 kWh/kgCOD_{removed}.

Keywords: activated sludge model no. 1 (ASM1), hydraulic retention time (HRT), moving bed biofilm reactor (MBBR), palm oil mill effluent (POME)

ABSTRAK

MIKAEL FEBRIAN ARITONANG. Thermal Evaluation and Multi-Objective Optimization of Moving Bed Biofilm Reactor Post-Treatment for Palm Oil Mill Effluent Based on Activated Sludge Model No. 1. Supervised by ALLEN KURNIAWAN dan KANIA AMELIA SAFITRI.

Sistem AnRBC termodifikasi sebelumnya belum mampu menurunkan senyawa organik terlarut pada POME secara memadai, sehingga diperlukan unit pasca-pengolahan aerobik untuk meningkatkan kualitas efluen akhir. Penelitian ini mengevaluasi MBBR sebagai unit pasca-pengolahan POME menggunakan Activated Sludge Model No. 1 (ASM1). HRT pada unit AnRBC dan MBBR divariasikan dalam tiga kondisi operasional, yaitu 1, 2, dan 3 hari. Efisiensi penyisihan TCOD tertinggi mencapai 91,76% pada HRT 3 hari, dengan penurunan TCOD dari 3052,90 mg/L menjadi 251,63 mg/L. Model ASM1 menunjukkan kemampuan prediksi yang baik dengan data pengamatan, dengan $R^2 = 0,997$ dan MAPE = 3,07%. Evaluasi termal berbasis TCOD juga menunjukkan kemampuan prediksi baik dengan MAPE = 4,40%. Optimasi multi-objektif mengidentifikasi kondisi terbaik pada HRT 3,25 hari, suhu 33 °C, pH 7,5, dan luas permukaan spesifik media 1200 m²/m³, menghasilkan prediksi COD efluen sebesar 322,6 mg/L, OUR sebesar 31,19 mg O₂/(L.d), dan SEC sebesar 60,57 kWh/kgCOD_{tersisihkan}.

Kata kunci: activated sludge model no. 1 (ASM1), hydraulic retention time (HRT), moving bed biofilm reactor (MBBR), palm oil mill effluent (POME)



@Hak cipta milik IPB University

IPB University



- Hak Cipta Dilindungi Undang-undang
1. Dilarang mengutip sebagian atau seluruh karya tulis ini tanpa mencantumkan dan menyebutkan sumber :
 - a. Pengutipan hanya untuk kepentingan pendidikan, penelitian, penulisan karya ilmiah, penyusunan laporan, penulisan kritik atau tinjauan suatu masalah
 - b. Pengutipan tidak merugikan kepentingan yang wajar IPB University.
 2. Dilarang mengumumkan dan memperbanyak sebagian atau seluruh karya tulis ini dalam bentuk apapun tanpa izin IPB University.

© Copyrighted by IPB University, 2026
Copyright is protected by Law

It is prohibited to quote parts or all of this paper without acknowledging or citing the source. Citation is only for the purposes of education, research, writing scientific papers, compiling reports, writing criticism, or reviewing a problem, and the citation is not detrimental to IPB University interests.

It is prohibited to publish and reproduce parts or all of this paper without IPB University's permission.



THERMAL EVALUATION AND MULTI-OBJECTIVE OPTIMIZATION OF MOVING BED BIOFILM REACTOR POST-TREATMENT FOR PALM OIL MILL EFFLUENT BASED ON ACTIVATED SLUDGE MODEL NO. 1

MIKAEL FEBRIAN ARITONANG

Undergraduate thesis
as one of the requirements to obtain a Bachelor's Degree in
Civil and Environmental Engineering Study Program

**CIVIL AND ENVIRONMENTAL ENGINEERING STUDY PROGRAM
FACULTY OF ENGINEERING AND TECHNOLOGY
IPB UNIVERSITY
BOGOR
2026**



@Hak cipta milik IPB University

Hak Cipta Dilindungi Undang-undang

1. Dilarang mengutip sebagian atau seluruh karya tulis ini tanpa mencantumkan dan menyebutkan sumber :
 - a. Pengutipan hanya untuk kepentingan pendidikan, penelitian, penulisan karya ilmiah, penyusunan laporan, penulisan kritik atau tinjauan suatu masalah
 - b. Pengutipan tidak merugikan kepentingan yang wajar IPB University.
2. Dilarang mengumunkan dan memperbanyak sebagian atau seluruh karya tulis ini dalam bentuk apapun tanpa izin IPB University.



@Hak cipta milik IPB University

IPB University



IPB University
— Bogor Indonesia —

Hak Cipta Dilindungi Undang-undang

1. Dilarang mengutip sebagian atau seluruh karya tulis ini tanpa mencantumkan dan menyebutkan sumber :
 - a. Pengutipan hanya untuk kepentingan pendidikan, penelitian, penulisan karya ilmiah, penyusunan laporan, penulisan kritik atau tinjauan suatu masalah
 - b. Pengutipan tidak merugikan kepentingan yang wajar IPB University.
2. Dilarang mengumumkan dan memperbanyak sebagian atau seluruh karya tulis ini dalam bentuk apapun tanpa izin IPB University.



Hak Cipta Dilindungi Undang-undang
1. Dilarang mengutip sebagian atau seluruh karya tulis ini tanpa mencantumkan dan menyebutkan sumber :
a. Pengutipan hanya untuk kepentingan pendidikan, penelitian, penulisan karya ilmiah, penyusunan laporan, penulisan kritik atau tinjauan suatu masalah
b. Pengutipan tidak merugikan kepentingan yang wajar IPB University.
2. Dilarang mengumumkan dan memperbanyak sebagian atau seluruh karya tulis ini dalam bentuk apapun tanpa izin IPB University.

Title : Thermal Evaluation and Multi-Objective Optimization of Moving Bed Biofilm Reactor Post-Treatment for Palm Oil Mill Effluent Based on Activated Sludge Model No. 1
Name : Mikael Febrian Aritonang
Student ID : F4401221042

Approved by

Supervisor:
Dr. Eng. Ir. Allen Kurniawan, S.T., M.T.
NIP. 19820729 201012 1 005
Co-supervisor:
Kania Amelia Safitri, S.T., M.T.
NIP. 19960301 202406 2 001



Known by

Head of the Civil and Environmental Engineering Program Research:
Ir. Tri Sudiby, S.T., M.Sc., Ph.D., IPM
NIP. 19840530 201404 1 001



Exam Date: 24 June 2026

Graduate Date: 07 JUL 2026



PREFACE

All praise and gratitude are due to God for His blessings, which allowed the author to complete this undergraduate thesis entitled “Thermal Evaluation and Multi-Objective Optimization of Moving Bed Biofilm Reactor Post-Treatment for Palm Oil Mill Effluent Based on Activated Sludge Model No. 1” in a timely fashion. This research was carried out from October 2025 to March 2026 and submitted to fulfill the requirements for a bachelor’s degree in the Department of Civil and Environmental Engineering, IPB University. The author would also like to express sincere appreciation to the following:

1. The Lord Jesus Christ for His blessings and guidance throughout my life, which have enabled me to navigate all these stages. Truly, I would not have been able to do so without His help.
2. The author would like to express sincere gratitude to his beloved parents and family for their endless love, prayers, and unwavering support throughout his academic journey.
3. Dr. Eng. Allen Kurniawan, S.T., M.T. and Kania Amelia Safitri, S.T., M.T. are deeply appreciated for their invaluable guidance, patience, constructive feedback, and expertise from the initial stages of this research until the completion of this undergraduate thesis.
4. Arif Nuryadin, as laboratory staff, is sincerely acknowledged for his significant assistance in discussions and in conducting the experimental work throughout the research process.
5. Cecilia Ruth Stefany Pasaribu, the author’s partner, who has prayed for, accompanied, and supported the author throughout this research.
6. Frans Edvan Sanjaya and Zidand Anand Hidayat, as teammates, are gratefully thanked for their companionship, collaboration, and insightful advice during this research journey.
7. Adi Arianto P, Satrio, Zidan, Ryu, Azmya, and Nathasia, fellow peers under Dr. Allen’s supervision, are warmly appreciated for their support, encouragement, and camaraderie throughout this academic endeavor.
8. The Ministry of Research, Technology, and Higher Education and the National Achievement Center of the Republic of Indonesia are gratefully acknowledged for funding and supporting this innovation and research.
9. Finally, all friends and associates whose names cannot be mentioned individually are sincerely appreciated for their continuous support, assistance, and encouragement.

Hopefully, this scientific work will be helpful for those who need it and for the advancement of science.

Bogor, June 2026

Mikael Febrian Aritonang

CONTENTS

LIST OF TABLES	xiii
LIST OF FIGURES	xiii
LIST OF APPENDIX	xiv
LIST OF NOTATIONS	xiv
GLOSSARY	xv
I INTRODUCTION	1
1.1 Background	1
1.2 Problem Formulation	4
1.3 Main Objectives	4
1.4 Research Significance	4
1.5 Scope of Research	5
II LITERATURE REVIEW	6
III METHODOLOGY	9
3.1 Research Site and Timeline	9
3.2 Instruments and Materials	9
3.3 Research Operation Procedure	10
3.3.1 POME Characteristic Test	10
3.3.2 Design Reactor of the Integrated OPEFB Adsorption-AnRBC-MBBR-Sedimentation System	11
3.3.3 Seeding and Acclimatization	17
3.3.4 Processing Unit Performance Analysis	17
3.3.5 Performance Analysis	19
3.3.6 Biofilm Thickness	19
3.4 Kinetic Modelling	20
3.4.1 Activated Sludge Model No.1 (ASM1)	20
3.4.2 Outlier Identification for Model Calibration	22
3.4.3 Parameter Estimation and Validation	23
3.5 Statistical Test	23
3.5.1 Coefficient of Determination R^2	23
3.5.2 Mean Absolute Percentage Error (MAPE)	24
3.6 Oxygen Transfer and Specific Energy	24
3.6.1 Oxygen Uptake Rate (OUR)	24
3.6.2 Oxygen Transfer Rate (OTR)	25
3.6.3 Specific Energy Consumption (SEC)	25
3.7 TCOD-Based Continuous Biological Heat Production Analysis	26
3.8 Sensitivity Analysis	28
3.9 Operational Variable and Kinetic Parameter Scenarios in ASM1 Modeling	28
3.9.1 Scenario 1: Effect of HRT	29
3.9.2 Scenario 2: Effect of Temperature	29
3.9.3 Scenario 3: Effect of pH	29
3.9.4 Scenario 4: Effect of Surface Area	29
3.10 Optimization of Operational Variables and Kinetic Parameters on MBBR Unit Performance using A Multi-Objective Optimization	29
IV RESULT AND DISCUSSION	31



4.1 POME Characteristic Analysis	31
4.2 The MBBR Unit Performance Evaluation	31
4.3 Biokinetic Coefficient Parameter on The MBBR Reactor	37
4.4 Evaluation of Oxygen Transfer and Energy Efficiency	39
4.5 Thermodynamic Evaluation of the MBBR Unit	41
4.6 Sensitivity Analysis	44
4.7 Operational Scenarios in ASM1 Modeling	45
4.8 Optimization of Operational Variables and Kinetic Parameters on MBBR Unit Performance	51
V CONCLUSIONS AND RECOMMENDATIONS	54
5.1 Conclusions	54
5.2 Recommendations	55
REFERENCES	56
APPENDIX	61
AUTOBIOGRAPHY	90

Hak Cipta Dilindungi Undang-undang

1. Dilarang mengutip sebagian atau seluruh karya tulis ini tanpa mencantumkan dan menyebutkan sumber :
 - a. Pengutipan hanya untuk kepentingan pendidikan, penelitian, penulisan karya ilmiah, penyusunan laporan, penulisan kritik atau tinjauan suatu masalah
 - b. Pengutipan tidak merugikan kepentingan yang wajar IPB University.
2. Dilarang mengumunkan dan memperbanyak sebagian atau seluruh karya tulis ini dalam bentuk apapun tanpa izin IPB University.

LIST OF TABLES

3.1 The standard for palm oil industry wastewater quality	10
3.2 Component of adsorption OPEFB	12
3.3 Component of AnRBC unit	14
3.4 Component of MBBR unit	15
3.5 Component of sedimentation unit	16
3.6 Operational variations in the combination reactor	19
3.7 Initial bounds used for parameter estimation	23
3.8 Baseline operational and kinetic parameters used in scenario simulation	28
4.1 PTPN VII's POME characteristic value	31
4.2 Temperature condition in MBBR unit	36
4.3 The estimation kinetics parameter in MBBR unit	38
4.4 Combination variations using multi objective simulation	53

LIST OF FIGURES

2.1 The identified research gaps within the research group	7
3.1 Design of configuration unit	9
3.2 Test procedure flow diagram	10
3.3 Reactor working mechanism	11
3.4 Design of adsorption OPEFB (in mm)	12
3.5 Design of AnRBC unit (in mm)	13
3.6 Design of electric motor unit	13
3.7 Design of MBBR unit (in mm)	15
3.8 Design of sedimentation unit (in mm)	16
3.9 Sample point on combination reactor	19
3.10 Model implementation in MBBR	22
3.11 The research framework of the multi objective optimization	30
4.1 TCOD concentration in MBBR unit	32
4.2 MLSS concentration in MBBR unit	33
4.3 Biofilm thickness of Kaldnes Helix No. 1 media	34
4.4 OG concentration in MBBR unit	35
4.5 pH concentration in MBBR unit	36
4.6 Boxplot of Influent TCOD and Effluent TCOD across HRT	37
4.7 Comparison of observed and ASM1 (K_i) over a 90-day period	39
4.8 Comparison of observed and ASM1 over a 90-day period	39
4.9 Comparison of OTR and OUR over a 90-day period	40
4.10 Comparison of SEC and TCOD removal over a 90-day period	41
4.11 TCOD allocation during MBBR operation over a 90-day period	42
4.12 Volumetric heat production and biological heat over a 90-day period	43
4.13 Comparison of T observed and T bio over a 90-day period	44
4.14 Significance of variable operational and performance to S_s estimation	45
4.15 Scenario S1 (HRT variation): effect of HRT on S_s (left axis) and SEC with removal efficiency (right axis)	47



Hak cipta milik IPB University

IPB University

Perpustakaan IPB University

4.16 Scenario S2 (<i>T</i> variation): effect of <i>T</i> on <i>S_s</i> (left axis) and SEC with removal efficiency (right axis)	48
4.17 Scenario S3 (pH variation): effect of pH on <i>S_s</i> (left axis) and SEC with removal efficiency (right axis)	49
4.18 Scenario S4 (<i>a_s</i> variation): effect of <i>a_s</i> on <i>S_s</i> (left axis) and SEC with removal efficiency (right axis)	50
4.19 Pareto plot of predicted <i>S_s</i> and SEC	52

LIST OF APPENDIX

Appendix 1 TCOD concentration measurement data	62
Appendix 2 TSS and MLSS concentration measurement data	63
Appendix 3 OG concentration measurement data	64
Appendix 4 pH concentration measurement data	65
Appendix 5 Temperature concentration measurement data	66
Appendix 6 Comparison of actual and predicted <i>S_s</i> values	67
Appendix 7 Effect of HRT mass on effluent concentration	68
Appendix 8 Effect of Temperature on effluent concentration	69
Appendix 9 Effect of pH on effluent concentration	70
Appendix 10 Effect of surface area on effluent concentration	71
Appendix 11 The MATLAB coding for the ASM1	72
Appendix 12 The MATLAB coding for the ASM1 (<i>K_i</i>)	75
Appendix 13 The MATLAB coding for the Monte Carlo	78
Appendix 14 The Python coding for the Multi-Objective Optimization	81

LIST OF NOTATIONS

S_s	= Readily biodegradable substrate or effluent COD concentration (mg/L)
$S_{s,in}$	= Volume of the POME (L)
Y_H	= Heterotrophic yield coefficient (mg TSS/mg COD)
K_s	= Half-saturation constant for substrate utilization (mg/L)
$\mu_{H,max}$	= Maximum specific growth rate of heterotrophic biomass (d^{-1})
θ	= Hydraulic retention time (d)
T	= Operating temperature ($^{\circ}C$)
K_i	= Inhibition constant for oil and grease inhibition (mg/L)
C_{OG}	= Oil and grease concentration (mg/L)
$X_{B,H}$	= Active heterotrophic biomass concentration (mg/L)
$\rho_{biofilm}$	= Biofilm density on carrier media (mg/L)
L	= Biofilm thickness
a_s	= Carrier-specific surface area (m^2/m^3)
Y_i	= Actual observed value at the <i>i</i> -th data point
\hat{Y}_i	= Model-predicted value at the <i>i</i> -th data point
\bar{Y}	= Mean of the observed values
Q_{air}	= Air flow rate supplied by the aeration system (L/h or m^3/h)

Hak Cipta Dilindungi Undang-undang
1. Dilarang mengutip sebagian atau seluruh karya tulis ini tanpa mencantumkan dan menyebutkan sumber :

- a. Pengutipan hanya untuk kepentingan pendidikan, penelitian, penulisan karya ilmiah, penyusunan laporan, penulisan kritik atau tinjauan suatu masalah
- b. Pengutipan tidak merugikan kepentingan yang wajar IPB University.

2. Dilarang mengumumkan dan memperbanyak sebagian atau seluruh karya tulis ini dalam bentuk apapun tanpa izin IPB University.

ρ_{air}	= Air density (kg/m ³)
f_{O_2}	= Oxygen mass fraction in air
n	= Total number of observations
R^2	= Coefficient of determination
MAPE	= Mean absolute percentage error (%)
C_{out}	= Effluent concentration
C_{in}	= Influent concentration
$\dot{m}_{\text{TCOD,removed}}$	= Mass removal rate of total chemical oxygen demand
$\dot{m}_{\text{TCOD,biomass}}$	= Mass conversion rate of total chemical oxygen demand into biomass
$\dot{m}_{\text{TCOD,ox}}$	= Mass oxidation rate of total chemical oxygen demand
$r_{\text{TCOD,ox}}$	= Volumetric oxidation rate of total chemical oxygen demand
\dot{q}_{bio}	= Volumetric biological heat generation rate
\dot{Q}_{bio}	= Total biological heat generation rate

GLOSSARY

Seeding	: The process of introducing and growing microorganisms that will be used as biological cultures for wastewater treatment.
Acclimatization	: The adaptation of microorganisms to POME characteristics allows the biomass to survive and perform biological degradation under reactor operating conditions.
Biomass	: Total living and active microorganisms involved in the degradation of organic matter during biological wastewater treatment.
Palm Oil Mill Effluent (POME)	: Organic wastewater generated from palm oil processing, characterized by high concentrations of organic matter, suspended solids, oil and grease, nutrients, and acidic pH.
Anaerobic Biological Contractor (AnRBC)	: An anaerobic biological treatment unit using rotating media as an attachment surface for microbial biofilms to degrade organic matter without oxygen
Moving Bed Biofilm Reactor (MBBR)	: An aerobic biological treatment unit using suspended carrier media as biofilm attachment surfaces to degrade residual organic compounds in wastewater.
Hydraulic Retention Time (HRT)	: The average time that a fluid remains in a reactor or treatment unit is a critical parameter to ensure effective degradation or purification of wastewater.
Kaldnes K1 Plus Media	: Plastic carrier media used as an attached-growth surface for biofilm development in the AnRBC and MBBR units.
Activated sludge model no. 1 (ASM1)	: A mathematical model used to describe biological wastewater treatment processes, including substrate degradation, biomass growth, and oxygen utilization.