OPTIMIZING SURFACE AREA OF MOVING BED BIOFILM REACTOR MEDIA COUPLED WITH ELECTROCOAGULATION FOR TREATING PALM OIL MILL EFFLUENT

SYLVIA WARDANI

MASTER STUDY PROGRAM OF CIVIL AND ENVIRONMENTAL ENGINEERING
FACULTY OF ENGINEERING AND TECHNOLOGY
IPB UNIVERSITY
BOGOR
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Bogor, July 2026

Sylvia Wardani
F0507251028

SUMMARY

WARDANI, SYLVIA. Optimizing Surface Area of Moving Bed Biofilm Reactor Media Coupled with Electrocoagulation for Treating Palm Oil Mill Effluent. Supervised by ALLEN KURNIAWAN and CHUSNUL ARIF.

Palm Oil Mill Effluent (POME) contains high organic matter, suspended solids, oil and grease, and nitrogen concentrations that often exceed discharge standards. This study evaluated a Moving Bed Biofilm Reactor coupled with electrocoagulation and kapok fiber pretreatment (KF–EC–MBBR), compared three Kaldnes media (K1, K3, K5), estimated biokinetic parameters using Activated Sludge Model No. 3 (ASM3), and optimized operational parameters under unsteady-state conditions. The system achieved removal efficiencies of 91–97% TSS, 91–94% O&G, 49–71% sCOD, 42–76% BOD, and 72–82% TN. Although the integrated system achieved high percentage removals, the final sCOD and BOD concentrations remained above the applicable discharge limits because of the very high influent strength. The calibrated ASM3 model predicted the best operating region within the evaluated parameter ranges at a biofilm thickness of 900 µm, an HRT of 52-62 h, and pH 7.5. K1 showed the best observed performance during its operating phase; however, the result may also reflect temporal changes in influent quality and biomass maturity because the carrier phases were operated sequentially. The calibrated ASM3 showed varying goodness of fit across the carrier operational phases, with R^2 values ranging from 0.77 to 0.94 for sCOD and from 0.33 to 0.94 for NH_3. Optimization identified a 900 µm biofilm thickness, 56–62 h HRT, and pH 7.5 as optimal, indicating these parameters must be managed jointly to maximize performance. These findings provide a basis for further optimization and pilot scale evaluation of the integrated KF–EC–MBBR system for POME treatment.

Keywords: Activated Sludge Model. 3, Biofilm Thickness, Electrocoagulation, Kaldnes Media, Palm Oil Mill Effluent.

RINGKASAN

WARDANI, SYLVIA. Optimasi Luas Permukaan Media *Moving Bed Biofilm Reactor* yang Dipadukan dengan Elektrokoagulasi untuk Pengolahan Limbah Cair Pabrik Kelapa Sawit. Dibimbing oleh ALLEN KURNIAWAN dan CHUSNUL ARIF.

Limbah cair pabrik kelapa sawit (POME) mengandung bahan organik, padatan tersuspensi, minyak dan lemak, serta nitrogen dalam konsentrasi tinggi yang seringkali melampaui baku mutu lingkungan. Penelitian ini mengevaluasi kinerja *Moving Bed Biofilm Reactor* yang dipadukan dengan elektrokoagulasi dan pretreatment serat kapuk (KF–EC–MBBR), membandingkan tiga jenis media Kaldnes (K1, K3, K5), mengestimasi parameter biokinetik menggunakan *Activated Sludge* Model No. 3 (ASM3), serta mengoptimasi parameter operasional pada kondisi unsteady-state. Sistem yang dikembangkan mencapai efisiensi penyisihan sebesar 91–97% TSS, 91–94% O&G, 49–71% sCOD, 42–76% BOD, dan 72–82% TN. Meskipun sistem terintegrasi mencapai persentase penyisihan yang tinggi, konsentrasi akhir sCOD dan BOD masih berada di atas baku mutu pembuangan yang berlaku karena konsentrasi influen awal yang sangat tinggi. K1 menunjukkan kinerja terbaik selama tahap operasinya. Namun, hasil tersebut juga mungkin dipengaruhi oleh perubahan kualitas influen dari waktu ke waktu dan tingkat kematangan biomassa, karena setiap fase media pembawa dioperasikan secara berurutan. Model ASM3 yang telah dikalibrasi menunjukkan goodness of fit yang bervariasi pada setiap fase operasional media, dengan nilai R^2 berkisar antara 0,77–0,94 untuk sCOD dan 0,33–0,94 untuk NH_3. Kondisi operasi optimum dicapai pada ketebalan *biofilm* 900 µm, HRT 58,87 jam, dan pH 7,5, menunjukkan bahwa ketiga parameter perlu dikelola secara simultan untuk memaksimalkan kinerja pengolahan. Temuan ini mendukung penerapan teknologi EC-MBBR yang diintegrasikan dengan pemodelan ASM3 untuk pengolahan POME yang efektif.

Kata kunci: Activated Sludge Model. 3, Ketebalan Biofilm, Elektrokoagulasi, MBBR, Media Kaldnes, Limbah cair pabrik kelapa sawit.

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SYLVIA WARDANI

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Examiner on Thesis Exam:
Prof. Dr. Ir. Suprihatin

Thesis Title : Optimizing Surface Area of Moving Bed Biofilm Reactor Media Coupled with Electrocoagulation for Treating Palm Oil Mill Effluent
Name : Sylvia Wardani
NIM : F0507251028

Approved by

Supervisor:
Dr. Eng. Ir. Allen Kurniawan, S.T., M.T.
NIP. 19820729 201012 1 005

Co-supervisor:
Prof. Dr. Ir. Chusnul Arif, S.TP., M.Si., IPM.
NIP. 19801206 200501 1 004

Known by

Head of Master Program of Civil and Environmental Engineering:
Prof. Dr. Ir. Satyanto K. Saptomo, S. T. P., M. Si.
NIP. 19730411 200501 1 002

Dean of the Faculty of Engineering and Technology:
Prof. Dr. Ir. Slamet Budijanto, M.Agr.
NIP. 19610502 198603 1002

Exam Date: 11 August 2026 Date of Approval: 13 AUG 2026

PREFACE

The author extends praise and gratitude to God Almighty, Allah SWT, who has given health and blessings to the author, thus she can complete her thesis entitled "Optimizing Surface Area of Moving Bed Biofilm Reactor Media Coupled with Electrocoagulation for Treating Palm Oil Mill Effluent" correctly and on time. This thesis was submitted in partial fulfillment of the requirements for the Master's Degree in Civil and Environmental Engineering at IPB University.

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The author has compiled this thesis as well as possible, but the author also realizes that there are many imperfections both in content and grammar. Therefore, the author welcomes any constructive suggestions and corrections to improve it. The author hopes that this thesis can help enrich the knowledge of the readers.

Bogor, August 2026

Sylvia Wardani

CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF NOTATION

Q	= Influent flow rate ($L.h^{-1}$ or $m^3.d^{-1}$)
V	= Effective liquid volume of the reactor ($m^3.d^{-1}$)
HRT	= Hydraulic Retention Time – average time the wastewater remains in the reactor (h or d)
HRT_{min}	= Minimum hydraulic retention time required to achieve effluent quality target (h)
S	= Soluble substrate concentration within the reactor (COD or BOD) ($mg.L^{-1}$ (as COD or BOD))
S(t)	= Substrate concentration in the reactor as a function of time (dynamic condition) ($mg.L^{-1}$)
S_{in}	= Influent soluble substrate concentration entering the reactor (after pretreatment, EC, and sedimentation) ($mg.L^{-1}$)
S_{eff}	= Effluent substrate concentration or target effluent concentration ($mg.L^{-1}$)
X(t)	= Active biomass concentration as a function of time (dynamic condition) ($mg.L^{-1}$)
X_{in}	= Particulate or biomass concentration entering the reactor (from EC effluent) ($mg.L^{-1}$)
r_s(S,X)	= Rate of substrate consumption (substrate degradation rate) ($mgCOD.L^{-1}.h^{-1}$ or $mgCOD.L^{-1}.d^{-1}$)
r_x(S,X)	= Rate of biomass growth (cell production rate) ($mgCOD.L^{-1}.h^{-1}$)
k_h	= Hydrolysis rate constant for particulate substrate (d^{-1})
k_{stor}	= Maximum storage rate constant for soluble substrate (d^{-1})
K_s	= Half-saturation constant for soluble substrate ($mgCOD.L^{-1}$.)
K_o	= Half-saturation constant for dissolved oxygen ($mgO_2.L^{-1}$)
$\mu_{h,max}$	= Maximum specific growth rate for heterotrophic bacteria (d^{-1})
$\mu_{a,max}$	= Maximum specific growth rate for autotrophic bacteria (d^{-1})
K_{nh}	= Half-saturation constant for ammonium (nitrogen source) ($mgN.L^{-1}$)
$K_{i,o}$	= Oxygen inhibition constant (for anoxic reactions) ($mgO_2.L^{-1}$)
X_h	= Concentration of heterotrophic biomass (microorganisms degrading organics) ($mgCOD.L^{-1}$)
X_a	= Concentration of autotrophic biomass (nitrifying bacteria) ($mgCOD.L^{-1}$)
X_s	= Concentration of particulate biodegradable substrate ($mgCOD.L^{-1}$)
X_{sto}	= Stored intracellular polymer or energy reserve in biomass ($mgCOD.L^{-1}$)
S_o	= Dissolved oxygen concentration ($mgO_2.L^{-1}$)
S_{nh}	= Ammonium nitrogen concentration (NH3–N) ($mgN.L^{-1}$)
S_i	= Soluble inert organic matter (non-biodegradable COD) ($mgCOD.L^{-1}$)
R^2	= Coefficient of determination

APPENDIX LIST