NaOH-ACTIVATED OIL PALM EMPTY FRUIT BUNCH BIOCHAR ADSORPTION FOR INTEGRATED ANAEROBIC-AEROBIC TREATMENT OF PALM OIL MILL EFFLUENT

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ABSTRACT

AZMYA PRASETYANINGTYAS. NaOH-Activated Oil Palm Empty Fruit Bunch Biochar Adsorption for Integrated Anaerobic–Aerobic Treatment of Palm Oil Mill Effluent. Supervised by ALLEN KURNIAWAN and ARIANI DWI ASTUTI.

Palm Oil Mill Effluent (POME) contains high concentrations of oil and grease (O&G) and organic matter that require effective treatment. This study evaluated NaOH-activated oil palm empty fruit bunch (OPEFB) biochar integrated with an Upflow Anaerobic Sludge Blanket (UASB) reactor and Rotating Biological Contactor (RBC), and developed a simplified first-order adsorption–Anaerobic Digestion Model No. 1 (ADM1) framework to predict soluble chemical oxygen demand (sCOD) removal. Biochar activated with 1 M NaOH achieved the highest O&G removal efficiency (75.93%). The integrated system removed over 97% of O&G, while the highest sCOD removal efficiency (80.91 ± 9.58%) was obtained at a hydraulic retention time of 3 days. The model yielded calibration and validation R^2 values of 0.9463, 0.8773, and 0.5663. Overall, the integrated adsorption–UASB–RBC system effectively enhanced POME treatment and provided a practical framework for predicting sCOD removal.

Keywords: Biochar Adsorption, Oil Palm Empty Fruit Bunch, Palm Oil Mill Effluent, Process Modeling, Upflow Anaerobic Sludge Blanket

ABSTRAK

AZMYA PRASETYANINGTYAS. NaOH-Activated Oil Palm Empty Fruit Bunch Biochar Adsorption for Integrated Anaerobic–Aerobic Treatment of Palm Oil Mill Effluent. Dibimbing oleh ALLEN KURNIAWAN dan ARIANI DWI ASTUTI.

Limbah cair pabrik kelapa sawit (POME) mengandung minyak dan lemak (O&G) serta bahan organik yang tinggi sehingga memerlukan pengolahan. Penelitian ini mengevaluasi biochar tandan kosong kelapa sawit (TKKS) teraktivasi NaOH yang diintegrasikan dengan reaktor *Upflow Anaerobic Sludge Blanket* (UASB) dan *Rotating Biological Contactor* (RBC), serta mengembangkan model adsorpsi orde satu–*Anaerobic Digestion Model* No. 1 (ADM1) sederhana untuk memprediksi penyisihan *soluble chemical oxygen demand* (sCOD). Biochar teraktivasi NaOH 1 M menghasilkan penyisihan O&G tertinggi sebesar 75,93%. Sistem terintegrasi menyisihkan O&G lebih dari 97%, sedangkan penyisihan sCOD tertinggi mencapai 80,91 ± 9,58% pada HRT 3 hari. Model menghasilkan nilai R^2 kalibrasi dan validasi berturut-turut sebesar 0,9463; 0,8773; dan 0,5663. Integrasi adsorpsi biochar–UASB–RBC efektif meningkatkan pengolahan POME sekaligus menyediakan kerangka pemodelan untuk memprediksi penyisihan sCOD.

Kata kunci: Adsorpsi Biochar, Limbah Cair Kelapa Sawit, Proses Modeling, Tandan Kosong Kelapa Sawit, *Upflow Anaerobic Sludge Blanket*

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PREFACE

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Azmya Prasetyaningtyas

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C_0, C_t, C_{eff}	=	O&G concentration at initial, time (t), and effective concentration after adsorption (mg/L)
C_{in}	=	Influent concentration before adsorption (mg/L)
$f_{ac,su}$	=	Acetate fraction produced from soluble substrate conversion (-)
I_{pH}	=	pH inhibition factor (-)
$k(T)$	=	Temperature-corrected kinetic constant (d^{-1})
k_{ads}	=	Adsorption rate constant (day^{-1})
$k_{dec,ac}$	=	Decay coefficient of acetoclastic biomass (day^{-1})

$k_{m,su}$	=	Maximum soluble substrate uptake rate (g COD g COD^{-1} d^{-1})
$k_{m,ac}$	=	Maximum acetate uptake rate (g COD g COD^{-1} d^{-1})
$K_{S,su}$	=	Half-saturation constant for soluble substrate (g COD/L)
$K_{S,ac}$	=	Half-saturation constant for acetate (g COD/L)
pH_{LL}	=	Lower pH inhibition threshold (-)
pH_{UL}	=	Upper pH inhibition threshold (-)
Q	=	Influent flow rate (L/day)
R^2	=	Coefficient of determination (-)
S_{ac}	=	Acetate concentration (g COD/L)
SI	=	Sensitivity Index (%)
S_{in}	=	Influent substrate concentration (g COD/L)
$S_{in,ADM1}$	=	Influent substrate concentration entering ADM1 (g COD/L)
S_{su}	=	Soluble substrate concentration (g COD/L)
T	=	Operating temperature (°C)
T_{ref}	=	Reference temperature (°C)
X_{ac}	=	Acetoclastic methanogenic biomass concentration (g COD/L)
Y_{ac}	=	Methanogenic biomass yield coefficient (g COD g COD^{-1})
Y_{su}	=	Acidogenic biomass yield coefficient (g COD g COD^{-1})
y_i	=	Observed value
ρ_{su}	=	Acidogenesis rate (g COD L^{-1} d^{-1})
ρ_{ac}	=	Methanogenesis rate (g COD L^{-1} d^{-1})
Θ	=	Temperature correction coefficient (-)
η	=	Adsorption efficiency (%)
X_{su}	=	Acidogenic biomass concentration (g COD/L)
$k_{dec,su}$	=	Decay coefficient of acidogenic biomass (day^{-1})
ρ_{su}	=	Soluble substrate utilization rate (g COD L^{-1} day^{-1})
ρ_{ac}	=	Acetate utilization rate (g COD L^{-1} day^{-1})
t	=	Time (day)
RMSE	=	Root Mean Square Error (mg/L)
MAPE	=	Mean Absolute Percentage Error (%)
ρ	=	Spearman correlation coefficient
p	=	Probability value
HRT	=	Hydraulic retention time (day)

GLOSSARY

Adsorbate	:	A substance that is retained on the surface of an adsorbent during the adsorption process.
Adsorbent	:	A material used to remove contaminants through adsorption.
Adsorption	:	The accumulation of molecules from a liquid or gas phase onto the surface of a solid material.
Anaerobic Digestion	:	A biological process in which microorganisms degrade organic matter in the absence of oxygen.
Anaerobic Digestion Model No. 1 (ADM1)	:	A mathematical model developed by the International Water Association (IWA) to simulate anaerobic digestion processes.
Biochar	:	A carbon-rich porous material produced from biomass through pyrolysis under oxygen-limited conditions.
Biochemical Oxygen Demand (BOD_5)	:	The amount of oxygen required by microorganisms to biologically degrade organic matter over a five-day period.
Chemical Oxygen Demand (COD)	:	The amount of oxygen required to chemically oxidize organic compounds in wastewater.
Chemical Activation	:	A process that modifies biochar properties using chemical agents to improve adsorption performance.
Contact Angle	:	The angle formed between a liquid droplet and a solid surface, used to evaluate surface wettability.
Energy Dispersive X-ray Spectroscopy (EDX)	:	An analytical technique used to determine the elemental composition of a material.
Fourier Transform Infrared Spectroscopy (FTIR)	:	An analytical technique used to identify surface functional groups based on infrared absorption spectra.
Hydraulic Retention Time (HRT)	:	The average time wastewater remains in a treatment reactor.
Hydrophobicity	:	The tendency of a material surface to repel water.
Mixed Liquor Suspended Solids (MLSS)	:	The concentration of suspended biomass and solids present in a biological reactor.
Methanogenesis	:	The final stage of anaerobic digestion in which methanogenic microorganisms convert substrates into methane.

Oil and Grease (O&G)	:	A group of hydrophobic organic compounds consisting primarily of fats, oils, waxes, and related substances.
Oil Palm Empty Fruit Bunch (OPEFB)	:	A lignocellulosic residue generated after the removal of fruits from oil palm fresh fruit bunches.
Palm Oil Mill Effluent (POME)	:	Wastewater generated during palm oil extraction and processing operations.
Pseudo-First-Order (PFO) Model	:	A kinetic model that assumes the adsorption rate is proportional to the number of available adsorption sites.
Pyrolysis	:	The thermal decomposition of biomass under limited or oxygen-free conditions.
Rotating Biological Contactor (RBC)	:	An attached-growth aerobic treatment system that uses rotating discs to support biofilm development.
Scanning Electron Microscopy (SEM)	:	A microscopy technique used to examine the surface morphology of materials at high magnification.
Sensitivity Analysis	:	A method used to evaluate the influence of model parameters on simulation outputs.
Soluble Chemical Oxygen Demand (sCOD)	:	The dissolved fraction of COD that passes through a standard filtration process.
Total Suspended Solids (TSS)	:	The concentration of suspended particulate matter present in wastewater.
Upflow Anaerobic Sludge Blanket (UASB)	:	An anaerobic reactor in which wastewater flows upward through a blanket of active sludge biomass.