

ABSTRAK

Penelitian ini mengevaluasi optimasi pengolahan limbah cair industri biodiesel berbasis minyak kelapa sawit di PT X Cilegon dengan kapasitas 360 m³/hari melalui perbandingan teknis dan analisis teknoekonomi pada tiga skema konfigurasi: koagulasi-flokulasi dan dissolved air flotation (CF + DAF), koagulasi-flokulasi dan membrane bioreactor (CF + MBR), serta integrasi hibrida CF + DAF + MBR menggunakan koagulan PAC dan tawas. Hasil penelitian menunjukkan bahwa skema terintegrasi CF + DAF + MBR dengan dosis optimum tawas 125.000 ppm (dan PAC 50.000 ppm) merupakan konfigurasi terbaik yang berhasil menurunkan beban pencemar limbah secara masif, mencapai efisiensi penyisihan COD 96,71% (menjadi 49 mg/L), BODs 98,50% (13 mg/L), TSS 99,59% (2 mg/L), serta minyak dan lemak 97,30% (4 mg/L) sehingga memenuhi baku mutu lingkungan Permen LHK No. 5 Tahun 2014. Dari perspektif teknoekonomi, meskipun membutuhkan belanja modal awal (CAPEX) lebih tinggi sebesar Rp 7,69 Miliar, penambahan unit DAF bertindak sebagai pelindung membran hilir dari fouling parah sehingga memperpanjang umur pakainya dari 2 tahun menjadi 7 tahun; hal ini memangkas biaya operasional (OPEX) tahunan secara signifikan hingga menghasilkan Levelized Cost of Treatment (LCOT) terendah yaitu Rp 21.259/m³ (dibandingkan Rp 27.016/m³ pada skema tanpa DAF), dengan Incremental Payback Period hanya 1,02 tahun dan Incremental IRR sebesar 98,17%, yang membuktikan kelayakan serta ketahanan finansial jangka panjang bagi industri biodiesel.

Kata Kunci: Limbah Cair Biodiesel, Koagulasi-Flokulasi, Dissolved Air Flotation (DAF), Membrane Bioreactor (MBR), Analisis Tekno-Ekonomi, LCOT, Membrane Fouling.

ABSTRACT

This research investigates the optimization and techno-economic feasibility of treating palm oil-based biodiesel wastewater at PT X Cilegon (design capacity of 360 m³/day) across three process configurations: coagulation-flocculation with dissolved air flotation (CF + DAF), coagulation-flocculation with a membrane bioreactor (CF + MBR), and an integrated CF + DAF + MBR system using alum and PAC coagulants. The experimental results demonstrated that the integrated CF + DAF + MBR system operated with an optimal alum dosage of 125,000 ppm achieved superior performance by drastically removing major pollutants yielding removal efficiencies of 96.71% for COD (49 mg/L), 98.50% for BOD₅ (13 mg/L), 99.59% for TSS (2 mg/L), and 97.30% for oil & grease (4 mg/L) thereby fully complying with the environmental standards of MoEF Regulation No. 5/2014. From a techno-economic perspective, although the integrated system requires a higher initial capital expenditure (CAPEX of IDR 7.69 billion), the upstream DAF unit effectively mitigates membrane fouling and extends MBR lifespan from 2 to 7 years, significantly reducing annual operational expenditures (OPEX) to achieve the lowest Levelized Cost of Treatment (LCOT) of IDR 21,259/m³ (compared to IDR 27,016/m³ without DAF), with an Incremental Payback Period of just 1.02 years and an Incremental IRR of 98.17%, confirming its exceptional technical efficiency and long-term financial sustainability for the biodiesel industry.

Keywords: Biodiesel Wastewater, Coagulation-Flocculation, Dissolved Air Flotation (DAF), Membrane Bioreactor (MBR), Techno-Economic Analysis, LCOT, Membrane Fouling.