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**Transformasi Limbah Sludge IPAL Sewon menjadi Paving Block : Studi Dampak Lingkungan dengan Uji
TCLP, Life Cycle Assessment (LCA) Berbasis SimaPro, dan Valuasi Moneter Eco-cost**
Intan Larashatiku, Ir. Intan Supraba, S.T., MSc., Ph.D., IPM., ASEAN. Eng.
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INTISARI

Pengolahan air limbah IPAL Sewon Yogyakarta yang semakin meningkat berdampak pada peningkatan *sludge* yang dihasilkan sebagai produk akhir. Saat ini, limbah *sludge* hanya dibuang dan ditimbun di TPA Wukirsari Klaten tanpa adanya pengolahan lanjutan, sehingga berpotensi menghasilkan emisi gas rumah kaca akibat pelepasan gas metana dari dekomposisi limbah serta potensi pencemaran lindi. Pengolahan alternatif limbah *sludge* diperlukan untuk mengurangi timbulan dampak lingkungan dari aktivitas penimbunan, penelitian ini mengolah *sludge* menjadi material substitusi agregat halus dalam pembuatan *paving block*.

Penggunaan metode eksperimental skala laboratorium pada penelitian ini untuk menguji kelayakan mutu fisik mekanik melalui uji kuat tekan SNI 03-0691-1996 serta keamanan lingkungan dengan uji TCLP (*Toxicity Characteristic Leaching Procedure*) PP No. 22 Tahun 2021 akibat dari penggunaan material limbah dalam komposisi penyusun *paving block*. Selain itu, analisis LCA (*Life Cycle Assessment*) skenario pengolahan *sludge* konvensional yang eksisting di IPAL Sewon dibandingkan dengan skenario alternatif menjadi *paving block* menggunakan pendekatan *Midpoint* di SimaPro. Interpretasi lanjutan hasil LCA menjadi valuasi moneter menggunakan metode *eco-cost* dengan *database* Idemat.

Temuan penelitian ini menunjukkan komposisi optimal ≤ 10,5% substitusi *sludge* memenuhi klasifikasi mutu D dengan kuat tekan 14,157 MPa dan konsentrasi pelindian logam berat memenuhi baku mutu TCLP. Hasil analisis LCA dalam pengolahan 7.884 kg *sludge* (setara sekali pengangkutan IPAL Sewon per semester) menunjukkan dominasi emisi *Global Warming* sebesar 6.180 kg CO_2 eq pada skenario konvensional akibat dekomposisi, sedangkan dominasi emisi skenario alternatif *paving block* berasal dari produksi semen portland sebesar 36.700 kg CO_2 eq. Analisis *Eco-cost* memvalidasi hasil tersebut dengan biaya investasi pemulihan lingkungan skenario alternatif mencapai Rp254.844.946,56 sedangkan skenario konvensional lebih rendah sebesar Rp22.185.902,43. Dengan demikian, terdapat fenomena *trade-off* dengan pemanfaatan *sludge* yang terbukti memenuhi baku mutu *paving block* dan TCLP sehingga mewujudkan *zero waste to sanitary landfill*. Akan tetapi, substitusi semen portland melepaskan emisi lingkungan yang signifikan sehingga memerlukan alternatif material pengikat ramah lingkungan.

Kata kunci: *Sludge, Paving Block,* IPAL Sewon, *Life Cycle Assessment, Eco-cost.*

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ABSTRACT

The increasing wastewater treatment activities at Sewon Yogyakarta Wastewater Treatment Plant (WWTP) result in an increased volume of sludge generated as a final product. Currently, the sludge is disposed at the Wukirsari Landfill, Klaten without any further treatment which potentially generates greenhouse gas emissions due to methane release from waste decomposition as well as potential leachate pollution. Alternative sludge treatment is required to reduce the environmental impacts of landfilling activities. Therefore, this study utilizes sludge as a fine aggregate substitution material in paving block manufacturing.

A laboratory scale experimental method was employed in this study to evaluate the physical-mechanical quality feasibility through compressive strength testing conforming to SNI 03-0691-1996 and environmental safety through the Toxicity Characteristic Leaching Procedure (TCLP) test in accordance with Government Regulation (PP) No. 22 of 2021 resulting from the incorporation of waste material in the paving block composition. Furthermore, a Life Cycle Assessment (LCA) analysis was conducted to compare the existing conventional sludge treatment scenario at Sewon WWTP with the alternative paving block scenario using the Midpoint approach in SimaPro software. Further interpretation of the LCA results was standardized into monetary valuation using the Eco-cost method based on the Idemat database.

The findings indicate that an optimal composition of ≤ 10,5% sludge substitution meets the Class D quality standard with a compressive strength of 14,157 MPa and the heavy metal leaching concentrations comply with the TCLP regulatory thresholds. The LCA results for the treatment of 7.884 kg of sludge (equivalent to a half-yearly haulage from IPAL Sewon) indicated a dominance of Global Warming emissions of 6.180 kg CO_2 eq due to waste decomposition, whereas emissions in the alternative paving block scenario were dominated by portland cement production at 36.700 kg CO_2 eq. Eco-cost analysis validated these findings, revealing that environmental prevention costs for the alternative scenario were considerably higher, reaching IDR 254.844.946,56, whereas the conventional scenario exhibits a lower cost of IDR 22.185.902,43. Consequently, an environmental trade-off phenomenon occurs, whereby sludge utilization is proven to satisfy paving block and TCLP quality standards, thereby achieving zero waste to sanitary landfill. However, Portland cement substitution releases significant environmental emissions thus requiring alternative eco-friendly binder materials to reduce the resulting emission burden.

Keywords: *Sludge, Paving Block,* Sewon WWTP, *Life Cycle Assessment, Eco-cost*