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Evaluasi Desain IPAL Bulaksumur Residence
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INTISARI

Air limbah domestik dari kawasan hunian komunal memiliki debit dan karakteristik yang berubah mengikuti aktivitas penghuni. Fluktuasi tersebut dapat memengaruhi waktu tinggal hidrolik, kestabilan proses biologis, konsumsi energi, dan keandalan peralatan pengolahan. Oleh karena itu, evaluasi instalasi pengolahan air limbah (IPAL) tidak cukup dilakukan dengan membandingkan kapasitas hidrolik desain dengan debit aktual, tetapi juga perlu mempertimbangkan kesesuaian volume tangki ekualisasi terhadap fluktuasi debit, penggunaan energi, serta gangguan operasional.

IPAL Gedung Merapi Bulaksumur Residence melayani 84 penghuni dan dirancang untuk mengolah greywater dengan kapasitas 8,06 m^3/hari. Sistem pengolahan terdiri atas tangki ekualisasi, dua tangki aerasi, clarifier, dan tangki penyimpanan. Proses biologis menggunakan sistem lumpur aktif dengan aerasi intermiten melalui *Microbubble Generator* (MBG). Evaluasi dilakukan melalui observasi lapangan, analisis volume air limbah terpompa, perhitungan statistik debit dan *Hydraulic Retention Time* (HRT), analisis mass diagram, serta pengukuran konsumsi dan intensitas energi. Keandalan operasional dianalisis menggunakan *Failure Mode and Effects Analysis* (FMEA), *Fishbone Diagram*, dan *Fault Tree Analysis* (FTA) untuk mengidentifikasi kegagalan kritis, akar penyebab, dan hubungan antarpenyebab kegagalan.

Hasil penelitian menunjukkan bahwa debit rata-rata selama 81 hari pengamatan sebesar 4,10 m^3/hari, setara dengan sekitar 50,85% dari kapasitas desain, sehingga secara rata-rata kapasitas hidraulik IPAL masih mencukupi. Meskipun demikian, analisis debit jam-jaman menunjukkan adanya fluktuasi debit temporal yang berkaitan dengan aktivitas penghuni, yang mengindikasikan bahwa beban hidraulik tidak terdistribusi secara merata sepanjang hari. Berdasarkan *mass diagram*, kebutuhan volume ekualisasi mencapai 1,124 m^3, lebih besar daripada volume nominal tangki sebesar 1,05 m^3. Pada debit desain sebesar 8,06 m^3/hari, volume hasil evaluasi tersebut menghasilkan HRT teoritis sebesar 3,35 jam, sedikit lebih panjang dibandingkan HRT desain awal sebesar 3,13 jam dan lebih tinggi daripada kriteria waktu detensi maksimum 0,5 jam yang tercantum dalam Panduan PUPR. Evaluasi energi menunjukkan bahwa intensitas energi berfluktuasi mengikuti volume air limbah yang diolah, dengan konsumsi energi didominasi oleh sistem aerasi dan resirkulasi. Hasil FMEA menunjukkan bahwa gangguan aerasi merupakan mode kegagalan dengan prioritas penanganan tertinggi. *Fishbone Diagram* mengidentifikasi faktor material, peralatan, metode, dan manusia sebagai kelompok utama penyebab gangguan operasional, sedangkan FTA menunjukkan hubungan logis antara gangguan aliran, aerasi, kelistrikan, dan kegiatan pemeliharaan yang dapat menyebabkan kegagalan operasional IPAL.

Kata kunci: Greywater, IPAL Domestik, Tangki Ekualisasi, Intensitas Energi, Keandalan Operasional.

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ABSTRACT

Domestic wastewater from communal residential areas has flow rates and characteristics that vary according to occupants' activities. These fluctuations may affect hydraulic retention time, biological process stability, energy consumption, and the reliability of treatment equipment. Therefore, the evaluation of a wastewater treatment plant (WWTP) should not be limited to comparing the design hydraulic capacity with the actual flow rate, but should also consider the adequacy of the equalization tank volume in accommodating flow fluctuations, energy use, and operational disturbances.

The WWTP at Merapi Building, Bulaksumur Residence, serves 84 occupants and was designed to treat greywater with a capacity of 8.06 m³/day. The treatment system consists of an equalization tank, two aeration tanks, a clarifier, and a storage tank. The biological treatment process employs an activated sludge system with intermittent aeration using a Microbubble Generator *(MBG). The evaluation was conducted through field observations, analysis of pumped wastewater volume, statistical analysis of flow rates and* Hydraulic Retention Time *(HRT), mass diagram analysis, and measurements of energy consumption and energy intensity. Operational reliability was analyzed using* Failure Mode and Effects Analysis *(FMEA), a* Fishbone Diagram*, and* Fault Tree Analysis *(FTA) to identify critical failures, root causes, and causal relationships among failure events.*

The results showed that the average flow rate during the 81-day observation period was 4.10 m³/day, equivalent to approximately 50.85% of the design capacity, indicating that the WWTP had sufficient hydraulic capacity on an average-flow basis. Nevertheless, the hourly flow analysis revealed temporal flow fluctuations associated with occupants' activities, indicating that the hydraulic load was not uniformly distributed throughout the day. Based on the mass diagram, the required equalization volume was 1.124 m³, exceeding the nominal tank volume of 1.05 m³. At the design flow rate of 8.06 m³/day, the revised volume resulted in a theoretical HRT of 3.35 hours, slightly longer than the initial design HRT of 3.13 hours and higher than the maximum detention time criterion of 0.5 hours specified in the PUPR Guidelines. The energy evaluation showed that energy intensity fluctuated with the volume of wastewater treated, with energy consumption dominated by the aeration and recirculation systems. The FMEA results identified aeration failure as the failure mode with the highest priority for corrective action. The Fishbone Diagram identified material, equipment, method, and human factors as the main categories contributing to operational disturbances, while the FTA demonstrated the logical relationships among flow, aeration, electrical, and maintenance-related disturbances that could lead to operational failure of the WWTP.

Keywords: Greywater, Domestic Wastewater Treatment Plant, Equalization Tank, Energy Intensity, Operational Reliability.