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**Investigasi Desain Kompartemen Koagulasi-Flokulasi pada Prototipe Instalasi Pengolahan Limbah Sludge
Tambang Batubara melalui Pendekatan Reverse Engineering dan Validasi Eksperimental**
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INTISARI

Air limpasan tambang batubara mengandung padatan tersuspensi dan kekeruhan yang tinggi sehingga memerlukan pengolahan sebelum dibuang ke badan air, dan koagulasi–flokulasi hidraulik umum digunakan sebagai unit *pretreatment*. Kinerja unit ini tidak hanya ditentukan oleh dosis koagulan, tetapi juga oleh kesesuaian desain geometrik dan karakteristik hidraulik reaktor. Penelitian ini bertujuan menginvestigasi desain kompartemen koagulasi–flokulasi pada prototipe eksisting instalasi pengolahan lumpur (IPL) air limpasan tambang batubara melalui pendekatan reverse engineering dan validasi eksperimental.

Inventarisasi dimensi reaktor dilakukan untuk memperoleh parameter geometri, kemudian dianalisis karakteristik hidrauliknya yang meliputi *hydraulic retention time* (HRT), kecepatan aliran, *surface loading rate*, *headloss*, daya hidraulik, gradien kecepatan (G), dan bilangan Camp (G·t). Nilai G dan G.t dievaluasi terhadap kriteria desain koagulasi–flokulasi hidraulik menurut Smet (2002). Potensi pengendapan partikel dinilai dari hubungan antara *settling velocity*, *surface loading rate*, dan *scouring velocity* dengan mengasumsikan partikel *sludge* air limpasan tambang sebagai *medium silt*. Hasil analisis diverifikasi melalui pengujian laboratorium pada HRT 30 menit menggunakan koagulan *Poly Aluminium Chloride* (PAC).

Hasil penelitian menunjukkan reaktor memiliki satu sekat efektif yang membentuk dua *flow pass* sehingga memperpanjang lintasan aliran menjadi $3{,}05 \times 10^{-1}$ m dari panjang geometrik 0,10 m. Pada kondisi operasi diperoleh debit $1{,}3 \times 10^{-3}$ L/s, kecepatan aliran horizontal $2{,}3 \times 10^{-4}$ m/s, *surface loading rate* $7{,}0 \times 10^{-5}$ m/s, *headloss* $2{,}5 \times 10^{-3}$ m, daya hidraulik $3{,}0 \times 10^{-5}$ W, gradien kecepatan (G) 3,766 s^{-1}, dan bilangan Camp (G.t) 6.778,82. Nilai G dan G.t tersebut berada di bawah kriteria desain Smet (2002); meskipun demikian, *settling velocity* lebih besar daripada *surface loading rate* dan kecepatan aliran horizontal lebih kecil daripada *scouring velocity* sehingga partikel *medium silt* tetap cenderung mengendap tanpa tergerus. Verifikasi laboratorium menunjukkan penurunan kekeruhan dari 540 NTU menjadi 80,33 NTU (efisiensi 85,12%) sebagai unit *pretreatment* dan mencapai 96,52% ketika dikombinasikan dengan filtrasi.

Berdasarkan hasil tersebut disimpulkan bahwa reaktor eksisting tetap efektif difungsikan sebagai unit *pretreatment* meskipun nilai G dan G.t belum memenuhi kriteria desain, karena kombinasi HRT, konfigurasi baffle, pola aliran, dan karakteristik partikel *medium silt* mengompensasi rendahnya energi pencampuran. Untuk meningkatkan nilai G agar memenuhi kriteria desain, direkomendasikan penambahan jumlah sekat (*baffle*) guna memperbesar kehilangan energi aliran, atau penambahan *blower* sebagai sumber energi pencampuran tambahan pada kompartemen koagulasi–flokulasi.

Kata kunci: air limpasan tambang, koagulasi–flokulasi, karakteristik hidraulik, reaktor skala pilot, *reverse engineering*

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ABSTRACT

Coal mine runoff contains high suspended solids and turbidity and thus requires treatment before being discharged into water bodies, for which hydraulic coagulation–flocculation is commonly used as a pretreatment unit. The performance of this unit is governed not only by the coagulant dosage but also by the suitability of the reactor's geometric design and hydraulic characteristics, which are often left unevaluated in empirically built pilot-scale reactors. This research investigated the design of the coagulation–flocculation compartment of a coal mine runoff sludge treatment plant (IPL) prototype through a reverse engineering approach and experimental validation.

An inventory of the reactor dimensions was carried out to obtain the geometric parameters, after which the hydraulic characteristics were analyzed, including the hydraulic retention time (HRT), flow velocity, surface loading rate, head loss, hydraulic power, velocity gradient (G), and Camp number (G.t). The G and G.t values were evaluated against the hydraulic coagulation–flocculation design criteria of Smet (2002). The settling potential of the particles was assessed from the relationship among settling velocity, surface loading rate, and critical scouring velocity, assuming the coal mine runoff sludge particles as medium silt. The analysis was then verified through laboratory testing at a 30-minute HRT using Poly Aluminium Chloride (PAC) as the coagulant.

The results show that the reactor has one effective baffle forming two flow passes, which extends the flow path to 3.05×10^{-1} m from the 0.10 m geometric length. At the operating condition, a discharge of 1.3×10^{-3} L/s, a horizontal flow velocity of 2.3×10^{-4} m/s, a surface loading rate of 7.0×10^{-5} m/s, a head loss of 2.5×10^{-3} m, a hydraulic power of 3.0×10^{-5} W, a velocity gradient (G) of 3.766 s^{-1}, and a Camp number (G.t) of 6,778.82 were obtained. These G and G.t values are below the Smet (2002) design criteria; nevertheless, the settling velocity was greater than the surface loading rate and the horizontal flow velocity was smaller than the critical scouring velocity, so the medium silt particles still tend to settle without being scoured. Laboratory verification showed a turbidity reduction from 540 NTU to 80.33 NTU (85.12% efficiency) as a pretreatment unit, reaching 96.52% when combined with filtration.

It is concluded that the existing reactor remains effective as a pretreatment unit despite the G and G.t values not meeting the design criteria, because the combination of HRT, baffle configuration, flow pattern, and medium silt particle characteristics compensates for the low mixing energy. To increase the G value so that it meets the design criteria, it is recommended to add baffles to increase the flow energy loss, or to add a blower as an additional mixing energy source in the coagulation–flocculation compartment.

Keywords: *coal mine runoff, coagulation–flocculation, hydraulic characteristics, pilot-scale reactor, reverse engineering*.