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Investigation of bentonite–goethite mixture as a novel material for low-level landfill liners

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The safe containment of hazardous waste requires landfill liner materials with both effective radiation shielding and strong hydro-mechanical performance. This study investigates the potential of a bentonite-goethite mixture as a novel material for hazardous waste landfill liners. The study examines the radiation shielding of the mixtures, represented by the linear attenuation coefficient, through experimental (Na (Tl) spectrometer detector), numerical (MCNP code), and reference database (XCOM and PHY-X) approaches. Moreover, the hydraulic permeability and mechanical properties are evaluated experimentally. For this, the varying proportions of goethite from 10 to 50% were examined. The results show an increase of up to 20, 24, and 28 percent in the linear attenuation coefficient at gamma ray energies of Cs^{137} (661.6 keV) and Co^{60} (1173.2 and 1332.5 keV). Higher goethite percentages, correlating with density variations and enhancing radiation shielding effectiveness. Numerical and reference database results align closely with experimental findings, suggesting their utility for assessing other mixtures. The direct shear test reveals that with an increase of goethite proportion to 50 percent, the cohesion is reduced to half and the friction angle is inclined twice the pure bentonite values, attributed to bentonite reduction and goethite roughness. Unconfined compressive strength trends show 20% improvement at specific mixture composition with 30% goethite, while hydraulic conductivity inclines with goethite content to 8.8×10^{-10} m/s. In this study the bentonite-goethite mixture illustrates improving radiation shielding and maintaining hydro-mechanical properties for landfill liners. This may offer a sustainable alternative using waste materials from mineral processing, contributing to waste management and environmental sustainability.

Landfills are geo-environmental structures that play a vital role in the management of low-level radioactive waste. These systems pose two major environmental risks: potential gamma-ray radiation and the leaching of hazardous materials into surrounding soil and water sources[1–3]. To mitigate these risks, effective radiation shielding and hydraulic impermeability are essential, with landfill liners serving as the primary barrier. Clay soil is widely used as a base material for landfill liners due to its availability, durability, and relatively low permeability. Recent studies have focused on enhancing the radiation shielding and hydro-mechanical performance of clay soil liners[4–8].

According to radiation theory, density is the key factor influencing gamma-ray attenuation, as represented by the linear attenuation coefficient (μ)[4,9–14]. This principle is widely applied in geotechnical and geomechanical investigations[15,16]. Consequently, the incorporation of heavyweight additives—such as lead, steel slag, barite, zeolite, magnetite, and hematite—into clay liners has emerged as a promising strategy to improve radiation shielding[17–20]. Regarding sustainable development, it is desirable to use high-density industrial by-products as additives in bentonite-based liners to enhance the radiation shielding performance.

Isfahani and Azhari (2021) evaluated the effect of basalt fiber additions (0.5%, 1%, 2%, and 5%) on the radiation shielding performance of clay soil[21]. Their results demonstrated that basalt fiber enhanced shielding efficiency, with 2% addition yielding the highest linear attenuation coefficients of 12.3 m^{-1}, 10.14 m^{-1}, and 8.5

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