Evaluating Lignin Proton Structural Evolution Following 25–200kGy Electron Beam Exposure

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Purpose: Lignin is the most abundant renewable source of aromatic carbon, but its highly crosslinked and heterogeneous structure hinders selective depolymerization into valuable monomers. Although thermochemical and catalytic strategies are well established, electron beam (EB) irradiation remains underexplored as a pretreatment method. EB provides rapid energy deposition, controlled radical generation, and potential solvent-free bond cleavage without harsh reagents, yet its mechanisms at moderate doses remain unclear. This study investigates EB irradiation (25–200 kGy) on alkaline and dealkaline lignin to assess structural modifications and possible β-O-4 bond cleavage. By comparing lignin types, the research evaluates composition-dependent degradation and explores EB irradiation as a green, scalable valorization strategy.

Methods: Lignin was irradiated under dry and wet conditions (25–200 kGy), with wet samples dissolved in deionized water to assess moisture effects. All samples were analyzed by ^{1}H NMR, and spectra were processed in Python for integration of key proton regions. Percent changes were calculated to evaluate dose-dependent structural modifications.

Results: The percent change in integrated aromatic proton intensity (6–8 ppm) was measured for alkaline and dealkaline lignin irradiated at 25 and 200 kGy under dry and wet conditions relative to unirradiated controls. At 25 kGy, alkaline lignin decreased moderately (dry ~−13%, wet ~−25%), while dry dealkaline lignin decreased (~−14%) and wet dealkaline lignin slightly increased (~+2–3%). At 200 kGy, alkaline lignin showed major reductions (dry ~−30%, wet ~−50%), whereas dealkaline lignin exhibited significant increases (dry ~+24%, wet ~+30%). Uncertainties include integration, sensitivity and baseline effects. Overall, irradiation induces dose-dependent structural changes influenced by moisture and lignin chemistry, impacting depolymerization strategies.

Conclusions: Electron beam irradiation (25–200 kGy) induces dose-dependent structural changes in alkaline and dealkaline lignin. Low doses initiate bond cleavage, while high doses cause aromatic loss or condensation depending on lignin type. Moisture and chemistry govern these pathways, highlighting EB irradiation as a green pretreatment method.

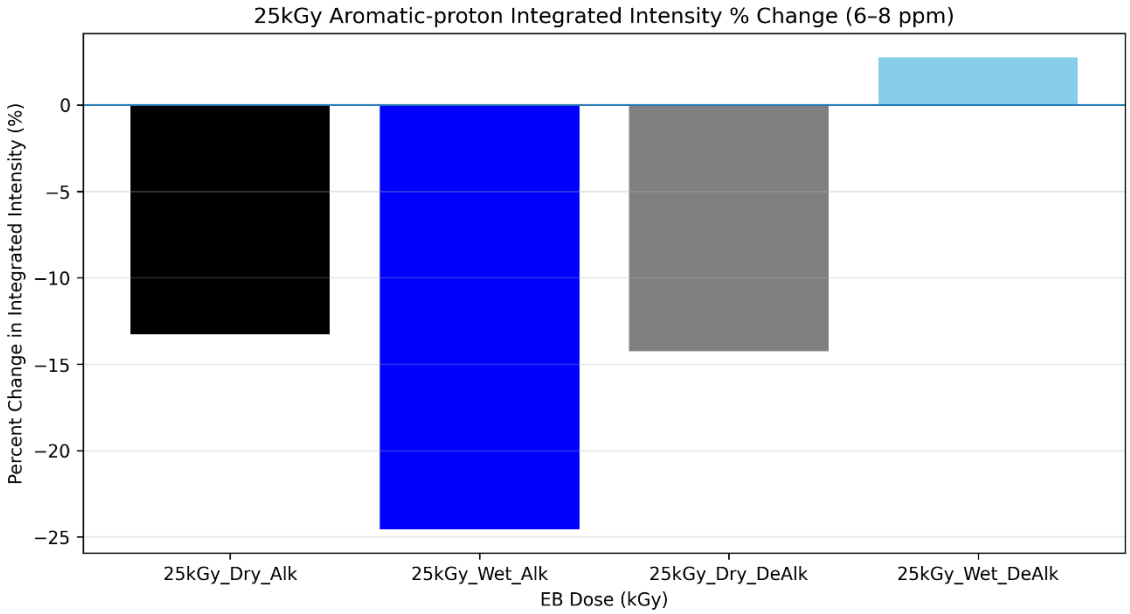

Figure 1: Percent change in aromatic proton intensity (6–8 ppm) at 25 kGy under dry and wet conditions.

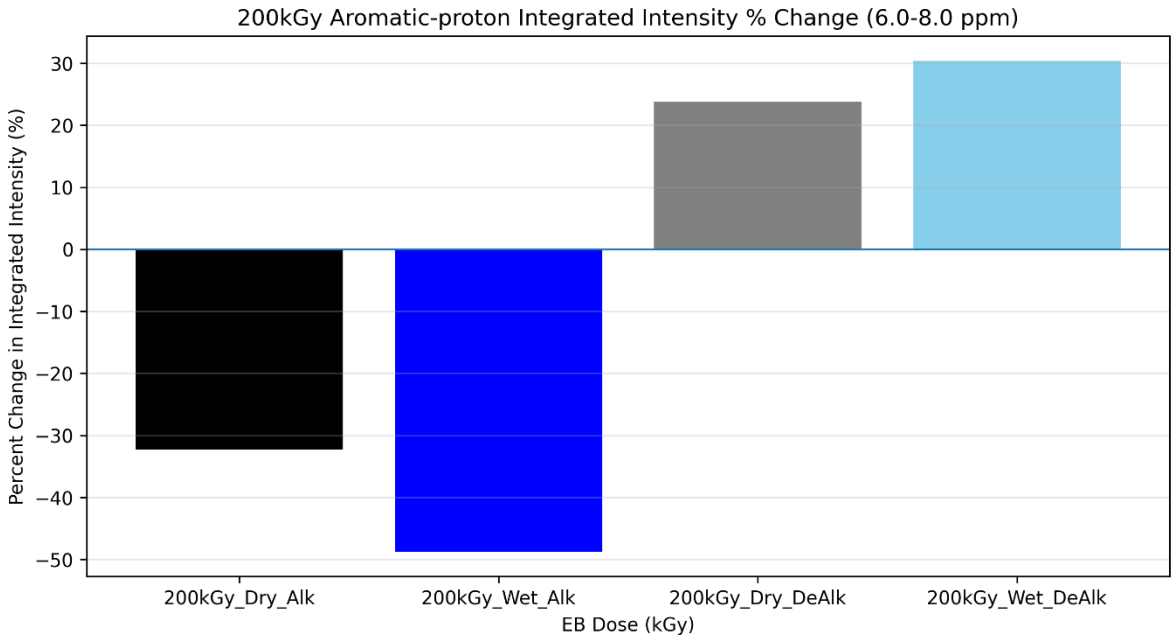

Figure 2: Percent change in aromatic proton intensity (6–8 ppm) at 200 kGy under dry and wet conditions.