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ENHANCING METHANOGENESIS IN ANAEROBIC BIOREACTORS USING *PHRAGMITES AUSTRALIS* AND ADDITIVES – A REVIEW

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Abstract – Anaerobic digestion of lignocellulosic biomass, particularly *Phragmites australis* (common reed), presents potential for sustainable biogas production. However, its rigid structure and high lignocellulose content hinder microbial accessibility and methanogenesis efficiency. To overcome these limitations, various additives including iron-based nanomaterials, trace metal additives, enzymatic pretreatments, and cosubstrates have been investigated to optimize biogas yield, methane content, and process stability. This review presents a comprehensive analysis of the role of supplements in improving anaerobic digestion of *Phragmites australis*. It has been demonstrated that iron-based nanomaterials, including iron oxide (FeO₄), micro zero-valent iron (ZVI), iron (II, III) oxide, and zero-valent iron nanoparticles (nZVI), reduce process inhibition and improve redox balance. Additionally, micronutrient supplementation (e.g., nickel, cobalt) promotes microbial enzymatic activity by enhancing methanogenic pathways. Enzymatic pretreatment methods including cellulase and hemicellulase enhance hydrolysis efficiency, resulting in increased volatile fatty acid production and higher methane yield. Co-digestion with nitrogen-rich substrates such as food waste or manure has also been found to optimize the carbon to nitrogen ratio, reducing ammonia inhibition and promoting stable microbial activity. Additionally, by strengthening methanogenic pathways, micronutrient supplementation increases microbial enzymatic activity. Cellulase and hemicellulase are two examples of enzymatic pre-treatment techniques that improve hydrolysis efficiency, resulting in increased volatile fatty acid production and a higher methane output. This review addresses important issues with feedstock recalcitrance, process inhibition, and biogas quality while highlighting the additives' synergistic benefits in maximizing anaerobic digestion performance.

Keywords – *Anaerobic digestion; biogas production; iron-based nanomaterials; methanogenesis; Phragmites australis*