PROCESS SIMULATION-BASED LIFE CYCLE ASSESSMENT FOR FUEL-GRADE BIOETHANOL PRODUCTION FROM PADDY RICE STRAW

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Thesis/Dissertation submitted in partial fulfillment of the requirements for the degree

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DECLARATION

I declare that this is my own work, and this thesis does not incorporate without acknowledgment any material previously submitted for a degree or diploma in any other University or Institute of higher learning, and to the best of my knowledge and belief, it does not contain any material previously published or written by another person except where the acknowledgment is made in the text. I retain the right to use this content in whole or part in future works (such as articles or books).

Signature: U.W.P.M. Jayasundara Date: 28/12/2023

The above candidate has carried out research for the MSc thesis under my supervision. I confirm that the declaration made above by the student is true and correct.

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Signature of the Supervisors: Date: 28.12.2023

A. Signed by Dr. H.H.M.P. Rathnayake

B. Signed by Dr. G.S.M.D.P. Sethunga

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ABSTRACT

For the life cycle scenario of bioethanol production from unutilized rice straw, the life cycle stage of paddy rice cultivation can be excluded with a zero-inventory allocation rule, i.e., rice straw with no applied valorization in current practice. This study evaluates the life cycle net energy analysis, greenhouse gas (GHG) assessment, and comparative life cycle environmental impact assessment for nine (09) scenarios of scaled-up bioethanol production process routes using unutilized rice straw as the feedstock. Three different feedstock pretreatment technologies and three different bioethanol dehydration technologies are incorporated to develop the process route scenarios for scaled-up processing plant models. The process simulation technique is integrated to model the scaled-up production plants to produce bioethanol at 99.7 vol% purity from unutilized rice straw, and the simulation results are retrieved to calculate inventory data for life cycle assessment (LCA). This research aims to determine the most environmentally benign scenario of the process route to produce fuel-grade bioethanol at an industrial scale from unutilized rice straw. The simulated mass flow and energy flow results are comparable with those of real plants, reported in the published literature, which validates the process simulation results in this study. According to the overall results, fuel-grade bioethanol production using rice straw via adopting dilute acid pretreatment technology for feedstock pretreatment and extractive distillation technology for bioethanol dehydration showcases the most sustainable routine from environmental and energy perspectives. Inclusive of energy generation using the waste flows in the process (i.e., spent wash and solid residues), the life cycle net energy analysis results show a net energy gain of 7,804.0 MJ/m^3 of bioethanol with a net renewable energy gain of 38,230.9 MJ/m^3 of bioethanol that corresponds to a net energy ratio of 1.20 and renewability factor of 5.49 for the base-case scenario developed for Sri Lankan context with dilute acid pretreatment and extractive distillation. The life cycle GHG assessment exhibits a net global warming potential of 584.8 kg CO_2 eq/m^3 of bioethanol. The effect of system boundary expansion up to the end-of-life stage as gasohol (E10), the sensitivity of the key process parameters, and the economic benefit via valorization of unutilized rice straw are further analyzed and discussed.

Keywords: Bioethanol production, Unutilized rice straw, Simulation integrated LCA, Net energy analysis, GHG assessment

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LIST OF ABBREVIATIONS

Abbreviation	Description
AD	Anaerobic digestion
CHP	Combined Heat and Power
COD	Chemical Oxygen Demand
DS	Dehydration Scenario
GHG	Greenhouse Gas
GWP	Global Warming Potential
IPCC	Intergovernmental Panel for Climate Change
LCA	Life Cycle Assessment
LCIA	Life Cycle Inventory Analysis
MCF	Methane Correction Factor
NA	Not applicable
NEV	Net Energy Value
NER	Net Energy Ratio
NRnEV	Net Renewable Energy Value
NRTL	Non-Random Two Liquid
PS	Pretreatment Scenario
Rn	Renewability
SSF	Simultaneous Saccharification and Fermentation
UASB	Up-flow Anaerobic Sludge Blanket

LIST OF APPENDICES