

**A PLANT DESIGN ON PYROGALLOL DERIVATIVE
FOR BIODIESEL ANTIOXIDANT ADDITIVE PRODUCT**

By

Jessica Kurniawan
11604019

BACHELOR'S DEGREE
in

CHEMICAL ENGINEERING – SUSTAINABLE ENERGY AND ENVIRONMENT
FACULTY OF LIFE SCIENCES AND TECHNOLOGY



SWISS GERMAN UNIVERSITY
The Prominence Tower
Jalan Jalur Sutera Barat No. 15, Alam Sutera
Tangerang, Banten 15143 - Indonesia

July 2020

Revised after Thesis Defense on 7 July 2020

STATEMENT BY THE AUTHOR

I hereby declare that this submission is my own work and to the best of my knowledge, it contains no material previously published or written by another person, nor material which to a substantial extent has been accepted for the award of any other degree or diploma at any educational institution, except where due acknowledgement is made in the thesis.

Jessica Kurniawan

Student

Date

Approved by:

Dr. Hery Sutanto, M.Si.

Thesis Advisor

Date

Dr. Akhmad Darmawan, M.Si.

Thesis Co-Advisor

Date

Dr. Dipl. -Ing. Samuel P. Kusumocahyo

Dean

Date

Jessica Kurniawan

ABSTRACT

A PLANT DESIGN ON PYROGALLOL DERIVATIVE FOR BIODIESEL ANTIOXIDANT ADDITIVE

By

Jessica Kurniawan
Dr. Hery Sutanto, M.Si.
Dr. Akhmad Darmawan, M.Si.

SWISS GERMAN UNIVERSITY

Biodiesel is a rapidly growing renewable energy source in Indonesia. However, its instability during storage is still an issue that needs to be solved. The currently available antioxidant in the market are mostly insoluble in oil-based samples, thus it is not very applicable for biodiesel. In the previous research, the synthesis of a new antioxidant product resulted in pyrogallol derivative. It is a modified, soluble antioxidant in biodiesel that is formed from the reaction between pyrogallol and methyl linoleate using 2,2-diphenyl-1-picrylhydrazyl. Pyrogallol derivative, when applied to biodiesel, shows excellent results and has the potential to be widely used in the biodiesel industry in Indonesia. In this research, an upscaling of the pyrogallol derivative production was designed and calculated from the production, process equipment selection, marketing plan as well as financial plan. The designed plant, when running for 8 hours a day, 25 days in a month, have a capacity of 958 kg/month. This is enough to supply 60% of the biodiesel quota in Indonesia.

Keywords: pyrogallol, methyl linoleate, biodiesel, antioxidant, plant design

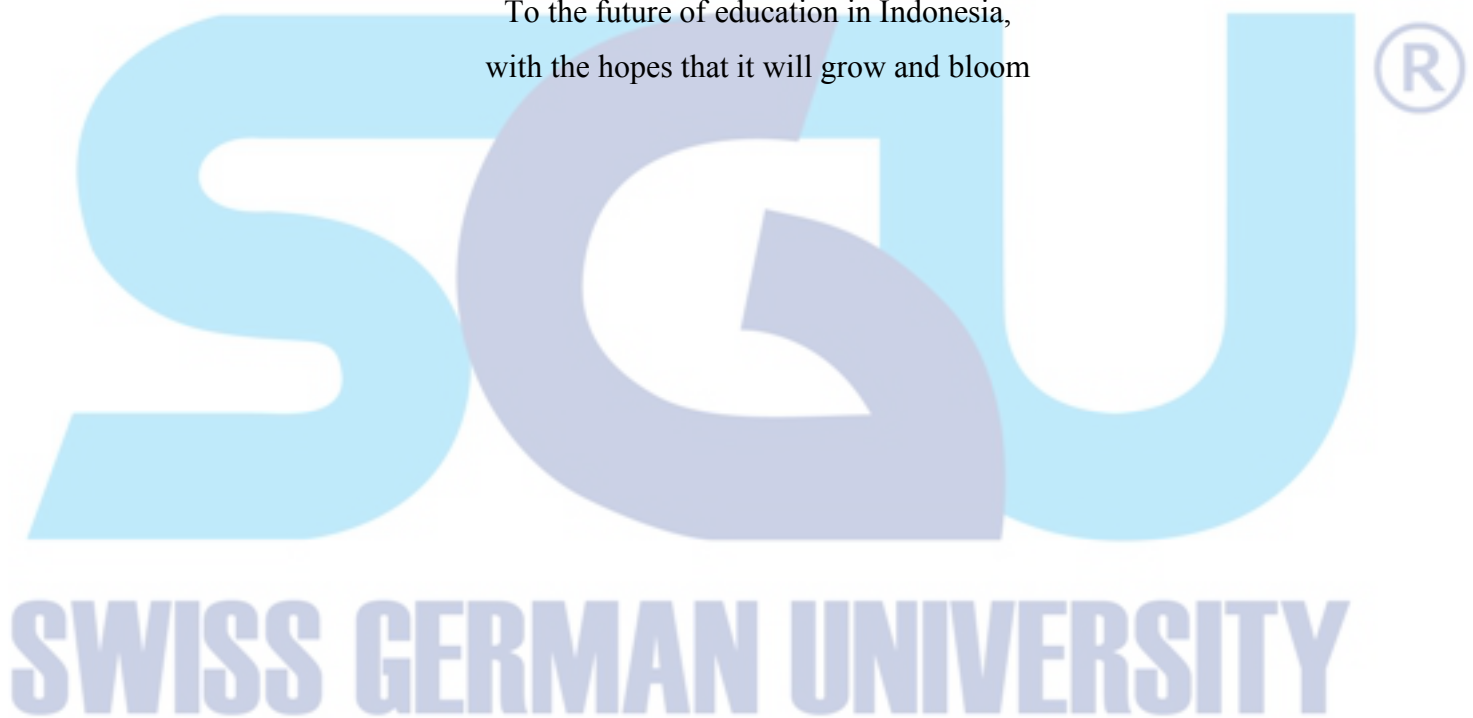


SWISS GERMAN UNIVERSITY

DEDICATION

To the ones that have been my support system,
no matter how small it may seem

To the future of education in Indonesia,
with the hopes that it will grow and bloom



ACKNOWLEDGEMENTS

First and foremost, I would like to thank God for only through his wonderful plan I can finish this thesis work in the midst of the pandemic.

I would like to thank Dr. Hery Sutanto as my advisor, and also Dr. Akhmad Darmawan, M.Si as my co-advisor. Thank you for the support and guidance every step of the way until this thesis is finally done. I would like to also thank Ms. Silvy Yusri, S.Si, MT and Dr. –Ing. Diah Indriani Widiputri, S.T, M.Sc for the help in significant parts of this thesis as well as all chemical engineering lecturers and lab assistants that have given me the foundation of knowledge throughout my university years.

I would like to thank my father and mother, Benjamin Budi Kurniawan and Juliwati Santoso, and also my brother Joshua Kurniawan. Your small encouragements every step of the way is what made me believe in myself, as much as you believed in me. To Johanssen Jonathan, thank you for always being there to cheer me up when my frustration kicks in.

To all of Sustainable Energy and Environment 2016 classmates, thank you. Each of you had been a memorable part of my journey from the start of university life, living together in a small town called Jena and finally finishing this journey together. Although we could not spend our last semester together, thank you for bringing colors this past four years.

And finally, to all of my friends and family whose names I could not mention one by one, thank you for the little encouragements and help on solving my problems along the way. Without your simple answers to my tiniest problems, I would not be able to stand in this moment.

TABLE OF CONTENTS

| | Page |
|---|-----------|
| DEDICATION..... | 5 |
| ACKNOWLEDGEMENTS..... | 6 |
| TABLE OF CONTENTS..... | 7 |
| LIST OF FIGURES..... | 9 |
| LIST OF TABLES..... | 11 |
| CHAPTER 1 - INTRODUCTION..... | 13 |
| 1.1 Background..... | 13 |
| 1.2 Research Problem..... | 14 |
| 1.3 Research Objectives..... | 14 |
| 1.4 Hypothesis..... | 15 |
| CHAPTER 2 - LITERATURE REVIEW..... | 16 |
| 2.1 Energy Situation..... | 16 |
| 2.1.1 World Energy..... | 16 |
| 2.1.2 Indonesia..... | 16 |
| 2.1.3 Renewable Energy..... | 17 |
| 2.2 Biodiesel..... | 17 |
| 2.2.1 Regulations and Standards..... | 18 |
| 2.2.2 Advantages..... | 20 |
| 2.2.3 Drawbacks..... | 20 |
| 2.3 Antioxidant..... | 22 |
| 2.3.1 Pyrogallol..... | 22 |
| 2.4 Modifications of Antioxidants..... | 23 |
| 2.4.1 Pyrogallol Derivative..... | 24 |
| 2.4.2 DPPH Method..... | 24 |
| 2.5 Synthesis of Pyrogallol Derivative..... | 25 |
| 2.6 State of the art..... | 28 |
| CHAPTER 3 – RESEARCH METHODS..... | 30 |
| 3.1 Methodology..... | 30 |
| 3.1.1 Literature Study..... | 31 |
| 3.1.2 Designing Process Flow Diagram (PFD)..... | 31 |
| 3.1.3 Materials and Energy Balances..... | 31 |
| 3.1.4 Process Equipment Selection..... | 32 |
| 3.1.5 Utilities..... | 32 |
| 3.1.6 Marketing Plan..... | 32 |

| | | |
|--|---|-----------|
| 3.1.7 | Financial Plan..... | 33 |
| CHAPTER 4 – RESULTS AND DISCUSSIONS..... | | 34 |
| 4.1 | Production Capacity | 34 |
| 4.2 | Process Flow Diagram..... | 34 |
| 4.2.1 | Synthesis of Pyrogallol Derivative..... | 35 |
| 4.2.3 | Separation of Product and Recycle Streams | 39 |
| 4.3 | Material Balance | 40 |
| 4.3.1 | Pyrogallol Radicalization Tank..... | 40 |
| 4.3.2 | Methyl Linoleate Radicalization Tank | 41 |
| 4.3.3 | Reactor Tank | 41 |
| 4.3.4 | Zeolite 13X Membrane..... | 42 |
| 4.3.5 | Zeolite SAPO-34 Membrane | 43 |
| 4.3.6 | Settling Tank | 44 |
| 4.4 | Energy Balance | 44 |
| 4.5 | Process Equipment Selection..... | 47 |
| 4.5.1 | Storage Tanks..... | 47 |
| 4.5.2 | Reactor vessels | 49 |
| 4.5.3 | Membranes..... | 51 |
| 4.5.4 | Settling Tank | 53 |
| 4.6 | Utilities | 55 |
| 4.6.1 | Water usage..... | 55 |
| 4.6.2 | Electricity usage | 56 |
| 4.6.3 | Wastewater Treatment..... | 59 |
| 4.6.4 | Plant Layout | 61 |
| 4.7 | Marketing plan..... | 63 |
| 4.7.1 | Product..... | 63 |
| 4.7.2 | Price..... | 64 |
| 4.7.3 | Place..... | 65 |
| 4.7.4 | Promotion..... | 65 |
| 4.8 | Financial Plan | 66 |
| 4.8.1 | Cost of Goods Manufactured | 66 |
| 4.8.2 | Project Implementation Cost and Equity Distribution | 67 |
| 4.8.3 | Income Statement | 69 |
| 4.8.4 | Cash Flow | 70 |
| 4.8.5 | Payback Period..... | 71 |
| 4.8.7 | Payback Period with Solar PV Investment | 72 |
| 4.8.7 | Break-Even Analysis | 73 |
| CHAPTER 5 – CONCLUSIONS AND RECOMMENDATIONS | | 74 |
| 5.1 | Conclusions..... | 74 |
| 5.2 | Recommendations | 74 |
| APPENDIX..... | | 75 |

LIST OF FIGURES

| Figures | Page |
|---|-------------|
| Figure 2. 1 Indonesia's renewable energy share in 2030 (REMap, 2017) | 17 |
| Figure 2. 2 Transesterification reaction..... | 18 |
| Figure 2. 3 Direct Esterification Reaction..... | 18 |
| Figure 2. 4 Methyl Linolenate (left) and Methyl Linoleate (right) Structure..... | 21 |
| Figure 2. 5 Chemical structure of Pyrogallol | 22 |
| Figure 2. 6 Primary reaction of DPPH..... | 25 |
| Figure 2. 7 Radicalization of methyl linoleate and its resonance (Sutanto, Susanto and Nasikin, 2019)..... | 26 |
| Figure 2. 8 Radicalization of pyrogallol and its resonance (Sutanto, Susanto and Nasikin, 2019)..... | 26 |
| Figure 2. 9 Formation of methyl (9E, 11E)-13-(2,6-dihydroxyphenoxy) octadeca-9,11-dienoate (Sutanto, Susanto and Nasikin, 2019) | 27 |
| Figure 2. 10 Formation of methyl (10E, 12E)-9-(2,6-dihydroxyphenoxy) octadeca-10,12-dienoate (Sutanto, Susanto and Nasikin, 2019) | 27 |
| Figure 3. 1 Methods Flowchart | 30 |
| Figure 4. 1 Block diagram of the whole process | 34 |
| Figure 4. 2 Process Flow Diagram..... | 35 |
| Figure 4. 3 Pyrogallol and methyl linoleate structures with its hydrogens that are susceptible to radicalization..... | 36 |
| Figure 4. 4 Autoxidation of methyl linoleate (Luna <i>et al.</i> , 2007)..... | 37 |
| Figure 4. 5 Pyrogallol concentration .vs Stoichiometric ratio of DPPH graph | 38 |
| Figure 4. 6 Zeolite 13-X in the form of resin | 39 |
| Figure 4. 7 Vertical cylindrical tank with ellipsoidal head | 47 |
| Figure 4. 8 Membrane structure for the separation of pyrogallol derivative (Mitsubishi Chemical Corporation, 2017) | 51 |
| Figure 4. 9 Single-channelled membrane..... | 52 |
| Figure 4. 10 Photocatalytic wastewater treatment (Pandey <i>et al.</i> , 2016)..... | 60 |
| Figure 4. 11 Cross section of reactor tube..... | 61 |
| Figure 4. 12 Plant layout | 62 |

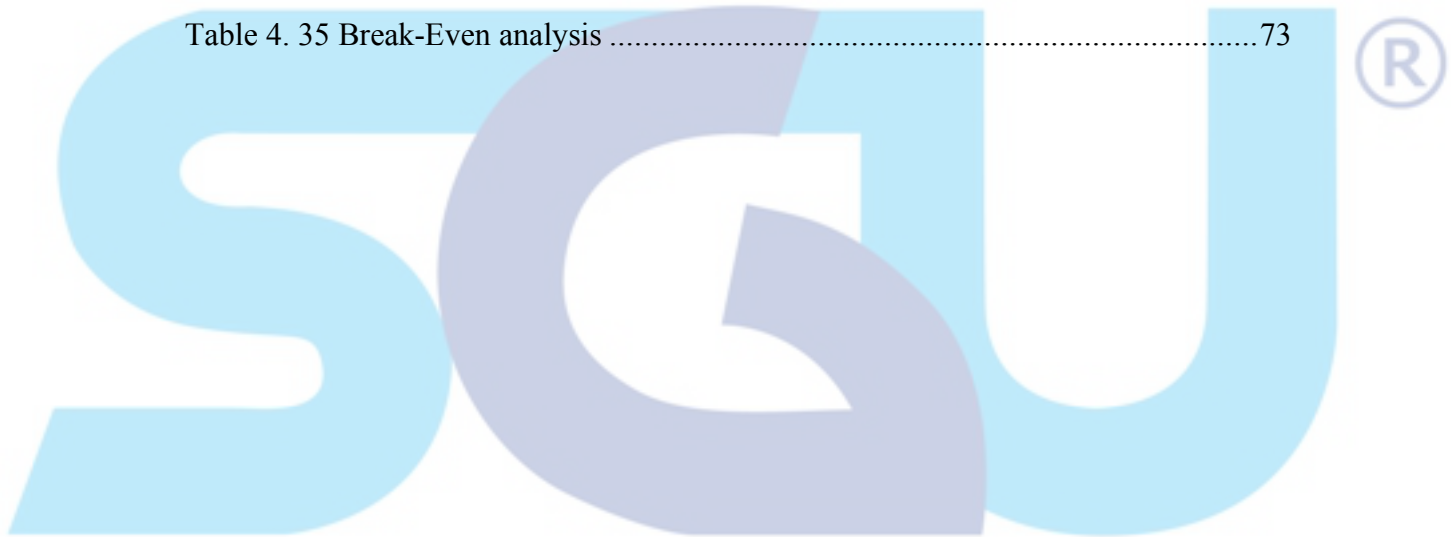
| | |
|--|----|
| Figure 4. 13 Packaging for Pyranox 25 kg (left) and 2 kg (right) | 64 |
| Figure 4. 14 Illustration of Pyranox exhibition booth..... | 66 |



LIST OF TABLES

| Table | Page |
|---|-------------|
| Table 2. 1 American, European (Knothe, 2006) and Indonesian Biodiesel Standards (Nasional, 2015)..... | 19 |
| Table 2. 4 State of the Art Table..... | 29 |
| Table 4. 1 Pyrogallol concentration and stoichiometric ratio of DPPH..... | 37 |
| Table 4. 2 Material balance on pyrogallol radicalization tank | 40 |
| Table 4. 3 Material balance on methyl linoleate radicalization tank | 41 |
| Table 4. 4 Material balance on reactor tank | 42 |
| Table 4. 5 Material balance on zeolite 13X membrane..... | 42 |
| Table 4. 6 Material balance on zeolite SAPO-34 membrane | 43 |
| Table 4. 7 Material balance on settling tank..... | 44 |
| Table 4. 8 Heat of formation in pyrogallol radicalization tank | 45 |
| Table 4. 9 Heat of formation in methyl linoleate radicalization tank | 46 |
| Table 4. 10 Heat of formation in reactor tank | 46 |
| Table 4. 11 Methyl linoleate storage tank specifications | 47 |
| Table 4. 12 Pyrogallol solution storage tank specifications | 48 |
| Table 4. 13 DPPH solution storage tank specifications | 48 |
| Table 4. 14 Pyrogallol derivative storage tank specifications | 49 |
| Table 4. 15 Pyrogallol radicalization tank specifications..... | 50 |
| Table 4. 16 Methyl linoleate radicalization tank specifications | 50 |
| Table 4. 17 Reactor tank specifications..... | 51 |
| Table 4. 18 Membrane specifications | 52 |
| Table 4. 19 Settling tank specifications..... | 53 |
| Table 4. 20 Amount of water needed..... | 56 |
| Table 4. 21 Electricity for process equipment and control..... | 56 |
| Table 4. 22 Illumination standard (Standar Nasional Indonesia, 2002)..... | 57 |
| Table 4. 23 Lighting power usage in the whole plant | 58 |
| Table 4. 24 Wastewater storage tank specifications | 60 |
| Table 4. 25 Legends | 63 |

| | |
|--|----|
| Table 4. 26 Division of area | 63 |
| Table 4. 27 Results of adding Pyranox (pyrogallol derivative product) into biodiesel | 63 |
| Table 4. 28 Pyranox price list | 65 |
| Table 4. 29 COGM..... | 66 |
| Table 4. 30 Project Implementation Cost..... | 68 |
| Table 4. 31 Equity distribution | 69 |
| Table 4. 32 Income Statement | 69 |
| Table 4. 33 Payback period | 71 |
| Table 4. 34 Payback Period with Solar PV Investment | 72 |
| Table 4. 35 Break-Even analysis | 73 |



SWISS GERMAN UNIVERSITY