

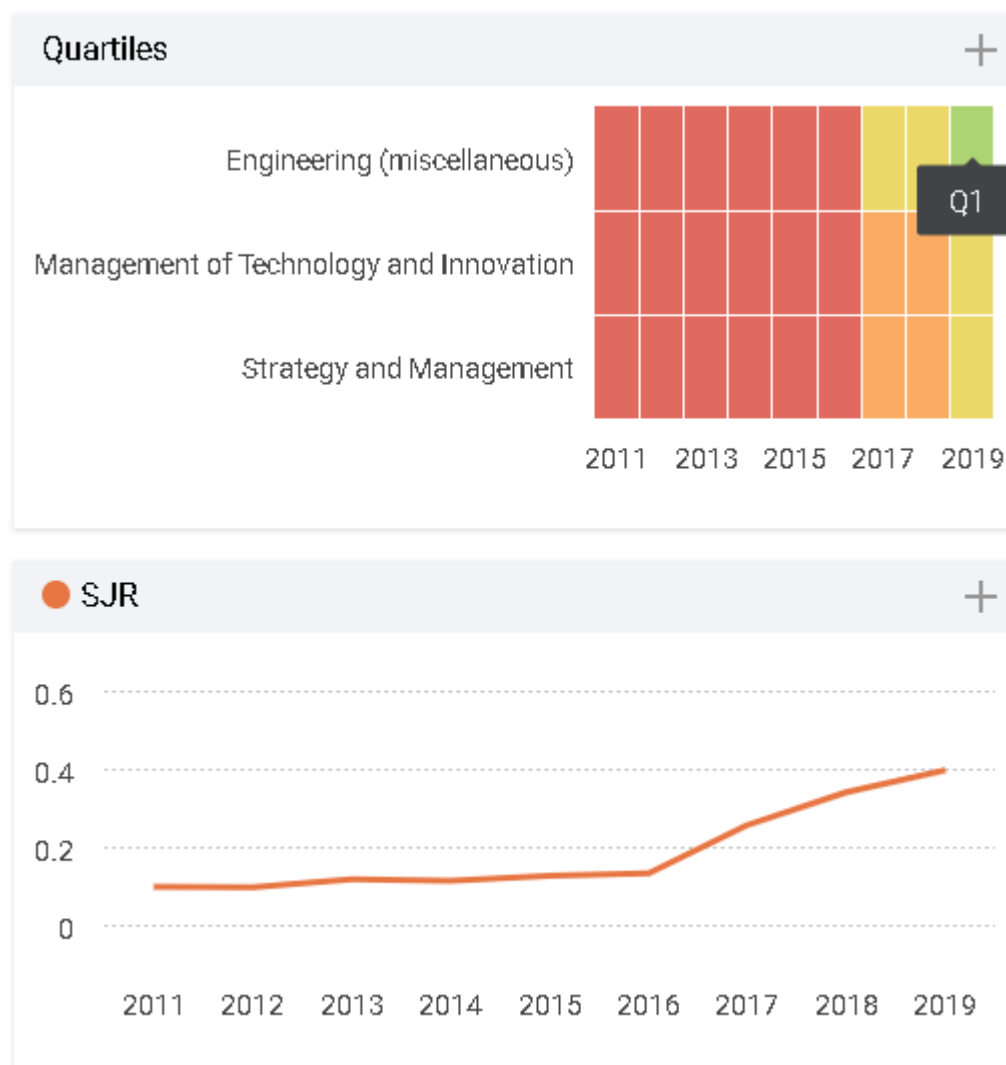
# About the Journal

International Journal of Technology (IJTech) is quarterly international referred journal with the objectives to explore, develop, and elucidate the knowledge of engineering design and technology, to keep practitioners and researchers informed on current issues and best practices, as well as serving as a platform for the exchange of ideas, knowledge, and expertise among technology researchers and practitioners.

IJTech is published by Universitas Indonesia. Published papers in IJTech strongly represent the use of sustainable technology in product and service designs for tropical environment. Sustainable technology has been developed in various Asian countries that comply with the principles of social, economic, and ecological sustainability and is categorized into the following themes: conventional and renewable energy, sustainable architecture, construction and environment, advanced material and manufacturing technology, efficiency and productivity improvement. Technology application and development for tropical environment that encourage innovation, improve economic benefits, stimulate business growth, and increasing the quality of human life while still trying to maintain the balance between the technology itself and the environment indicates the character and the unique features of IJTech.

IJTech is currently indexed in Google Scholar, DOAJ, EBSCO, GISI, Index Copernicus, SCOPUS, SCImago, Emerging Sources Citation Index (ESCI) Thomson Reuters, Directory of Research Journal Indexing (DRJI), has been accepted for coverage in selected Elsevier product(s), and a member of CrossRef.

In 2019, IJTech journal rank raised with h-index 12 and classified into Q1 journal (1st quartile) for the Engineering field in Scimago Journal & Country Rank database.



More info about this rank can be found here (<https://www.scimagojr.com/journalsearch.php?q=21100235612&tip=sid&clean=0>).

- Editorial Board (<https://ijtech.eng.ui.ac.id/people>)
- Focus and Scope (<https://ijtech.eng.ui.ac.id/about/5/focus-and-scope>)
- Online Submissions (<https://ijtech.eng.ui.ac.id/about/3/online-submission>)
- Publication Policy (<https://ijtech.eng.ui.ac.id/about/11/publication-policy>)
- Publication Ethics and Policy (<https://ijtech.eng.ui.ac.id/about/10/policy>)
- Author Guidelines (<https://ijtech.eng.ui.ac.id/about/4/author-guidelines>)
- List of Reviewers (<https://ijtech.eng.ui.ac.id/about/12>)

- Most downloaded papers (<https://ijtech.eng.ui.ac.id/home/mostdownloadedpapers>)
- Most cited papers (<https://ijtech.eng.ui.ac.id/about/14>)

## 🔒 Login

### Username

### Password

Not as user?

Register (<https://ijtech.eng.ui.ac.id/register>)

**LOGIN**

## 📖 IJTech

p-ISSN : 2086-9614 (<https://portal.issn.org/resource/ISSN/2086-9614>)

e-ISSN : 2087-2100 (<https://portal.issn.org/resource/ISSN/2087-2100>)

## 📈 Journal Metrics



(<https://www.scimagojr.com/journalsearch.php?q=21100235612&tip=sid&exact=no>)

(<https://www.scimagojr.com/journalsearch.php?q=21100235612&tip=sid&exact=no>)

Metrics by SCOPUS 2019

CiteScore 2019: **1.8**

CiteScoreTracker 2019: **1.18**

Source Normalized Impact per Paper (SNIP): **1.395**

Acceptance rate: **17 %**

Average time to publish: **133 days**.

## 📈 IJTech is indexed in



(<https://www.scopus.com/sourceid/21100235612>)



(<http://www.ebsco.com/index.asp>)



(<https://doaj.org/toc/2086-9614>)



([https://www.scimagojr.com/journalsearch.php?](https://www.scimagojr.com/journalsearch.php?q=21100235612&tip=sid)

[q=21100235612&tip=sid](https://www.scimagojr.com/journalsearch.php?q=21100235612&tip=sid))



([https://journals.indexcopernicus.com/search/details?](https://journals.indexcopernicus.com/search/details?id=31340)

[id=31340](https://journals.indexcopernicus.com/search/details?id=31340))



(<http://www.crossref.org>)



([https://scholar.google.co.id/scholar?](https://scholar.google.co.id/scholar?q=site%3Ahttp%3A%2F%2Fijtech.eng.ui.ac.id)

[q=site%3Ahttp%3A%2F%2Fijtech.eng.ui.ac.id](https://scholar.google.co.id/scholar?q=site%3Ahttp%3A%2F%2Fijtech.eng.ui.ac.id))



(<https://mjl.clarivate.com/search-results?issn=2086-9614>)



(<http://info.flagcounter.com/AoS7>)



## EDITORIAL TEAM

---

### Editor in Chief

1. Prof. Dr. Mohammed Ali Berawi, Universitas Indonesia, Indonesia

### Managing Editor

1. Dr. Eny Kusriani, Universitas Indonesia, Indonesia

### Members

1. Prof. Dr. Akhmad Herman Yuwono , Universitas Indonesia, Indonesia
2. Prof. Dr. Anwar Usman, Universiti Brunei Darussalam, Brunei Darussalam
3. Prof. Dr. Bambang Sugiarto, Universitas Indonesia, Indonesia
4. Dr. Cecilia Vale, University of Porto, Portugal
5. Prof. Dr. Dedi Priadi, Universitas Indonesia, Indonesia
6. Dr. Eko Adhi Setiawan, Universitas Indonesia, Indonesia
7. Prof. Dr. Esah Hamzah, Universiti Teknologi Malaysia, Malaysia
8. Dr. Giuseppe Lo Papa, Teagasc Rural Economy Research Centre, Ireland
9. Prof. Dr. Hamzah Abdul Rahman, Universiti Malaya, Malaysia
10. Dr. Hendri Dwi Saptioratri, Universitas Indonesia, Indonesia
11. Prof. Dr. Heri Hermansyah, S.T., M.Eng., IPU, Universitas Indonesia, Indonesia
12. Dr. Hng Huey Hoon, Nanyang Technological University, Singapore , Singapore
13. Dr. Imam Jauhari Makhnun, Universitas Indonesia, Indonesia, Indonesia
14. Prof. Dr. Isti Surjandari, Universitas Indonesia, Indonesia
15. Dr. Johannes Widodo, National University of Singapore, Singapore
16. Prof. Dr. Jong-Taek Oh, Chonnam National University, Korea, Republic of
17. Dr. Lee Wilson, University of Saskatchewan, Canada
18. Dr. Muhamad Asvial, Universitas Indonesia, Indonesia
19. Dr. Muhammad Arif Budiyananto, Universitas Indonesia, Indonesia
20. Prof. Dr. Muhammad Idris Saleh, Universiti Sains Malaysia, Malaysia
21. Dr. Muhammad Suryanegara, Universitas Indonesia, Indonesia
22. Prof. Dr. Nandy Putra, Universitas Indonesia, Indonesia
23. Dr. Nofrijon Sofyan, Universitas Indonesia, Indonesia
24. Dr. Nyoman Suwartha, Universitas Indonesia, Indonesia
25. Prof. Paramita Atmodiwiryo, Universitas Indonesia, Indonesia
26. Prof. Dr. Prof. Dr. Hideaki Ohgaki, Kyoto University, Japan
27. Prof. Dr. Raimundo Delgado, University of Porto, Portugal
28. Dr. Reza Kia, Sharif University of Technology, Iran (Islamic Republic of)
29. Dr. Roy Woodhead, Sheffield Hallam University, United Kingdom
30. Prof. Rui Calcada, University of Porto, Portugal
31. Dr. Ruki Harwahu, Universitas Indonesia, Indonesia
32. Dr. Sam P. Sinha, Scientific Research & Development, United States
33. Prof. Dr. Simon P. Ringer, University of Sydney, Australia
34. Prof. Sri Harjanto, Universitas Indonesia, Indonesia
35. Prof. Dr. Sutrasno Kartohardjono, Universitas Indonesia, Indonesia
36. Prof. Dr. T. Yuri M. Zagloel, Universitas Indonesia, Indonesia
37. Prof. Dr. Toshio Shudo, Tokyo Metropolitan University, Japan
38. Prof. Dr. Yandi Andri Yatmo, Universitas Indonesia, Indonesia
39. Dr. Yudan Whulanza, Universitas Indonesia, Indonesia
40. Prof. Dr. Yung- Hui Lee, National Taiwan University, Taiwan
41. Dr. Yung-Jung Hsu, National Chiao Tung University, Taiwan

### About the Journal

- Editorial Board (<https://ijtech.eng.ui.ac.id/people>)
- Focus and Scope (<https://ijtech.eng.ui.ac.id/about/5/focus-and-scope>)
- Online Submissions (<https://ijtech.eng.ui.ac.id/about/3/online-submission>)
- Publication Policy (<https://ijtech.eng.ui.ac.id/about/11/publication-policy>)

- Publication Ethics and Policy (<https://ijtech.eng.ui.ac.id/about/10/policy>)
- Author Guidelines (<https://ijtech.eng.ui.ac.id/about/4/author-guidelines>)
- List of Reviewers (<https://ijtech.eng.ui.ac.id/about/12>)

- Most downloaded papers (<https://ijtech.eng.ui.ac.id/home/mostdownloadedpapers>)
- Most cited papers (<https://ijtech.eng.ui.ac.id/about/14>)

### 🔒 Login

#### Username

ariefbudiman7

#### Password

.....

Not as user?

Register (<https://ijtech.eng.ui.ac.id/register>)

**LOGIN**

### 📖 IJTech

p-ISSN : 2086-9614 (<https://portal.issn.org/resource/ISSN/2086-9614>)

e-ISSN : 2087-2100 (<https://portal.issn.org/resource/ISSN/2087-2100>)

### 📈 Journal Metrics



(<https://www.scimagojr.com/journalsearch.php?q=21100235612&tip=sid&exact=no>)

(<https://www.scimagojr.com/journalsearch.php?q=21100235612&tip=sid&exact=no>)

Metrics by SCOPUS 2019

CiteScore 2019: **1.8**

CiteScoreTracker 2019: **1.18**

Source Normalized Impact per Paper (SNIP): **1.395**

Acceptance rate: **17 %**

Average time to publish: **133 days.**

### 📈 IJTech is indexed in



(<https://www.scopus.com/sourceid/21100235612>)



(<http://www.ebsco.com/index.asp>)



(<https://doaj.org/toc/2086-9614>)



([https://www.scimagojr.com/journalsearch.php?](https://www.scimagojr.com/journalsearch.php?q=21100235612&tip=sid)

[q=21100235612&tip=sid](https://www.scimagojr.com/journalsearch.php?q=21100235612&tip=sid))



([https://journals.indexcopernicus.com/search/details?](https://journals.indexcopernicus.com/search/details?id=31340)

[id=31340](https://journals.indexcopernicus.com/search/details?id=31340))



(<http://www.crossref.org>)

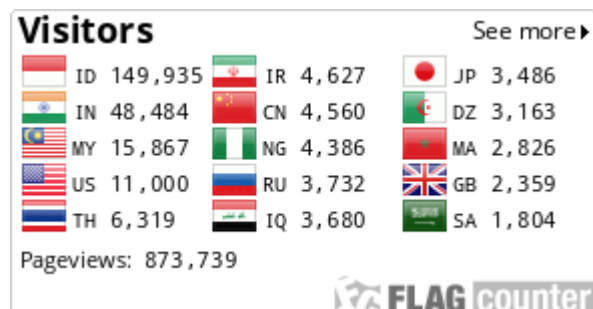


([https://scholar.google.co.id/scholar?](https://scholar.google.co.id/scholar?q=site%3Ahttp%3A%2F%2Fijtech.eng.ui.ac.id)

[q=site%3Ahttp%3A%2F%2Fijtech.eng.ui.ac.id](https://scholar.google.co.id/scholar?q=site%3Ahttp%3A%2F%2Fijtech.eng.ui.ac.id))



(<https://mjl.clarivate.com/search-results?issn=2086-9614>)



(<http://info.flagcounter.com/AoS7>)





## JOURNAL ISSUE

---



21 Jul 2020

Volume 11, Number 3

---



Empowering Healthcare, Economic, and Social Resilience during Global Pandemic Covid-19 (<https://ijtech.eng.ui.ac.id/article/view/4200>)

Mohammed Ali Berawi

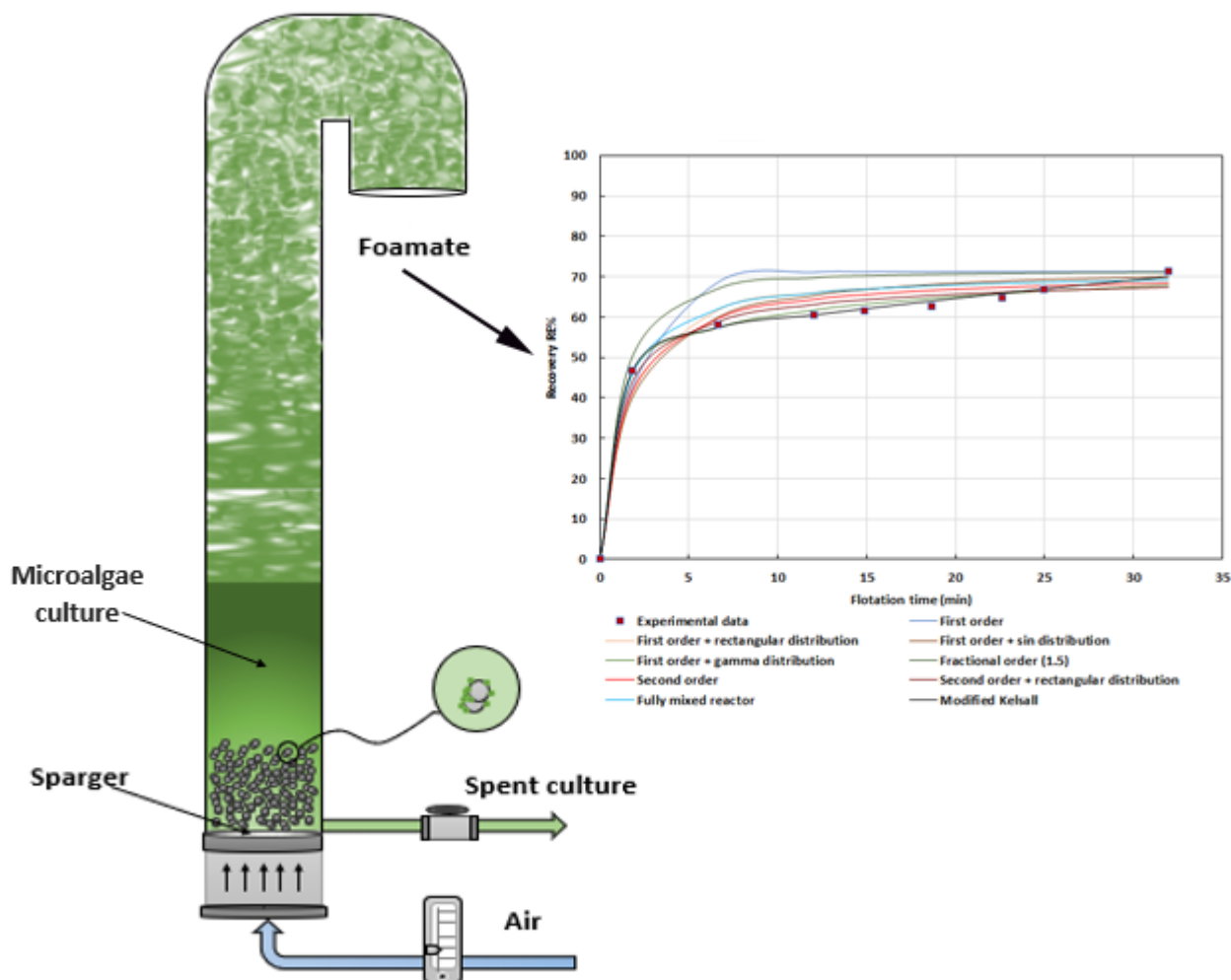
Publication Date (Online):

Jul 21, 2020

DOI: <https://doi.org/10.14716/ijtech.v11i3.4200> (<https://doi.org/10.14716/ijtech.v11i3.4200>)

Pages : 436-439

---



Kinetic Study of Air Bubbles-Cetyltrimethylammonium Bromide (CTAB) Surfactant for Recovering Microalgae Biomass in a Foam Flotation Column (<https://ijtech.eng.ui.ac.id/article/view/3983>)

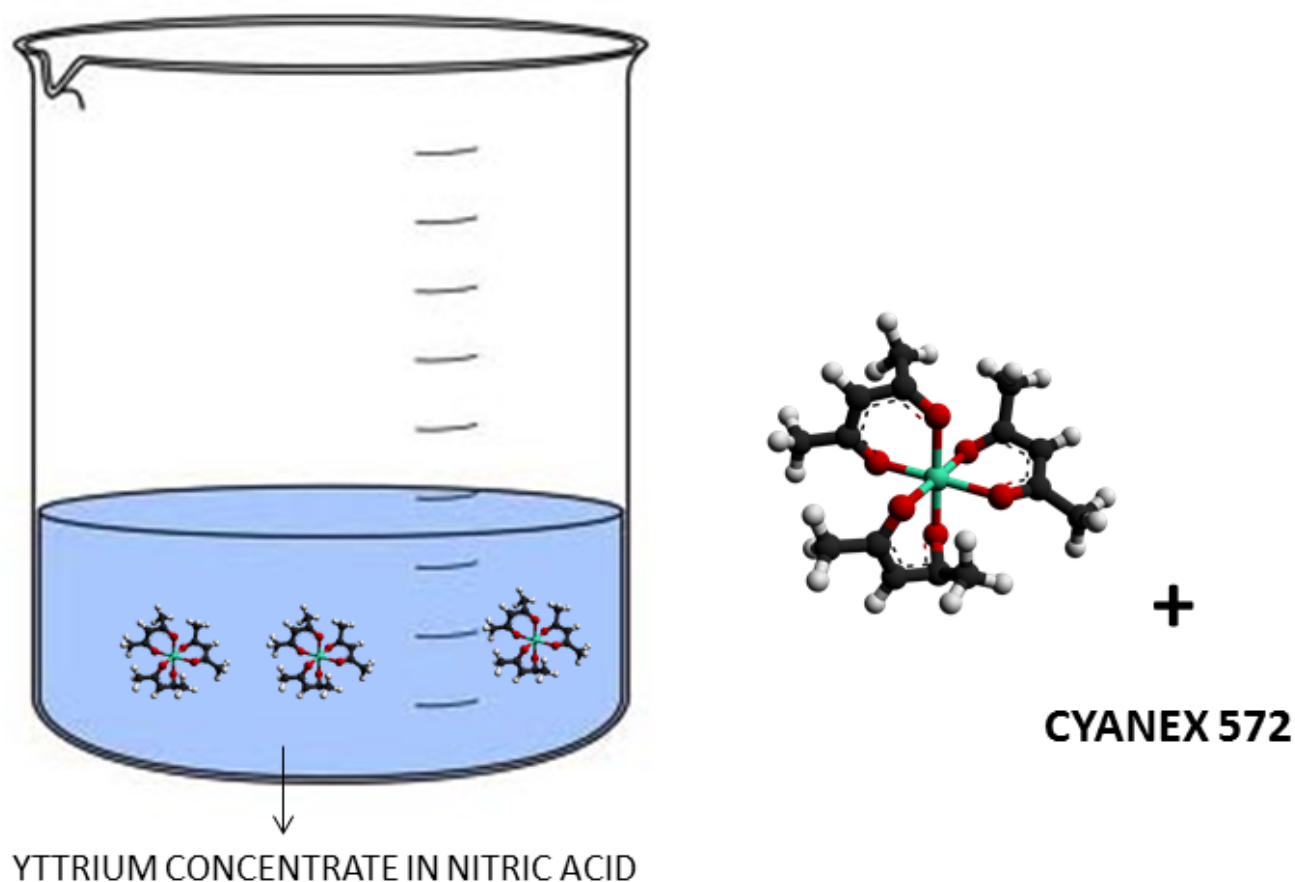
Muayad A. Shihab, Mohammed A. Dhahir, Hamad K. Mohammed

Publication Date (Online):

Jul 21, 2020

DOI: <https://doi.org/10.14716/ijtech.v11i3.3983> (<https://doi.org/10.14716/ijtech.v11i3.3983>)

Pages : 440-449



## Extraction Development for the Separation of Gadolinium from Yttrium and Dysprosium Concentrate in Nitric Acid using Cyanex 572 (<https://ijtech.eng.ui.ac.id/article/view/2581>)

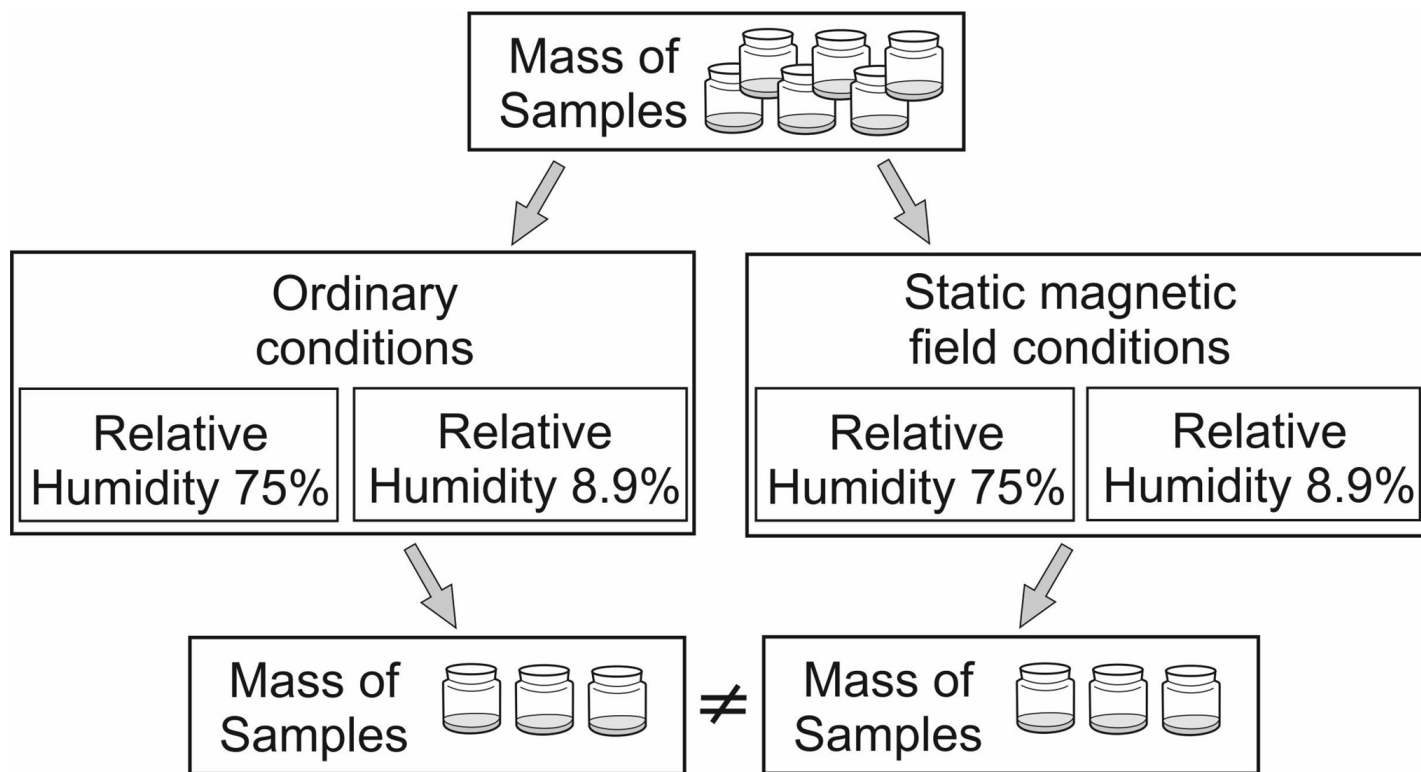
Kris Tri Basuki, Alfiyatur Rohmaniyyah, Wahyu Rachmi Pusparini, Andri Saputra

Publication Date (Online):

Jul 21, 2020

DOI: <https://doi.org/10.14716/ijtech.v11i3.2581> (<https://doi.org/10.14716/ijtech.v11i3.2581>)

Pages : 450-460



## Water Vapor Sorption on the Surface of Selected Organic Samples in an Artificial Static Magnetic Field of 10 mT (<https://ijtech.eng.ui.ac.id/article/view/3831>)

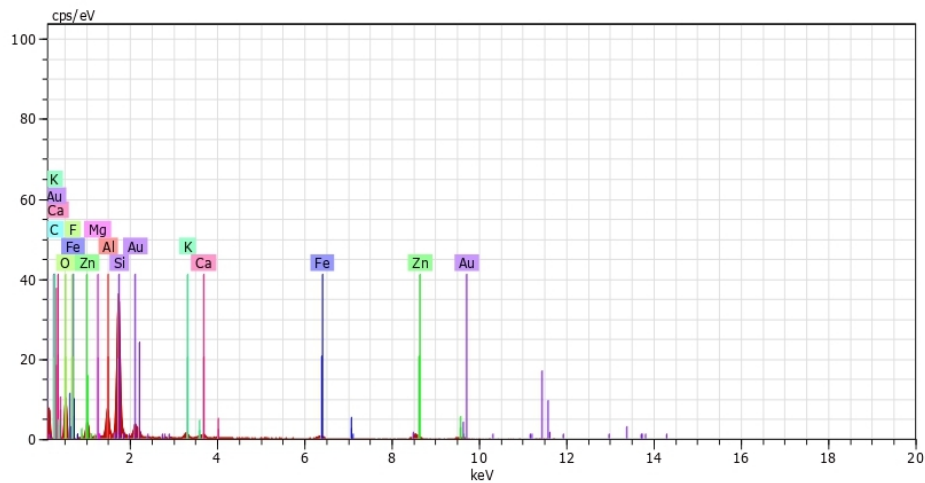
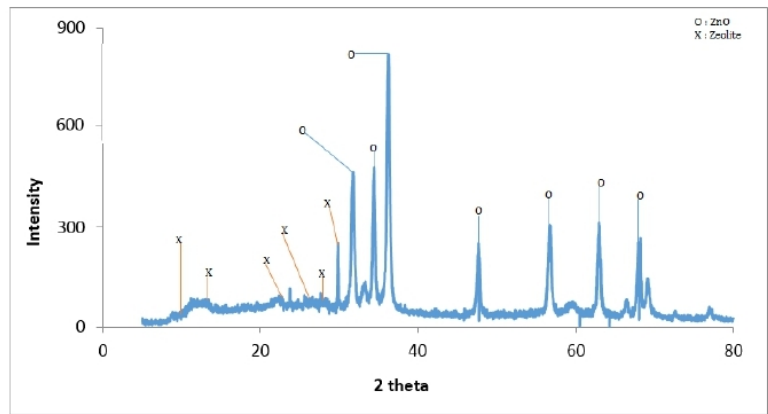
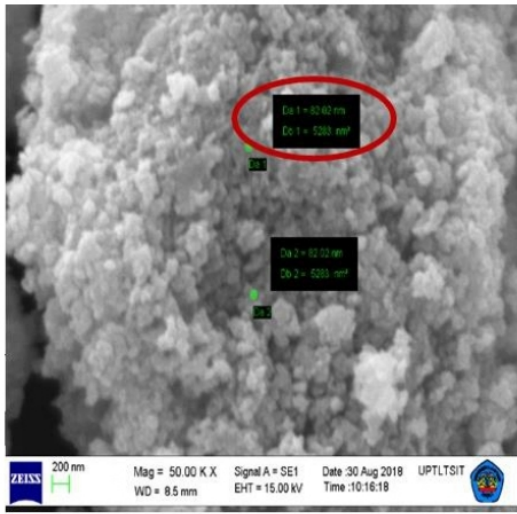
Aneta Ocieczek, Zbigniew Otremba

Publication Date (Online):

Jul 21, 2020

DOI: <https://doi.org/10.14716/ijtech.v11i3.3831> (<https://doi.org/10.14716/ijtech.v11i3.3831>)

Pages : 461-471



## Synthesis of Nano-Photocatalyst ZnO-Natural Zeolite to Degrade Procion Red (<https://ijtech.eng.ui.ac.id/article/view/3800>)

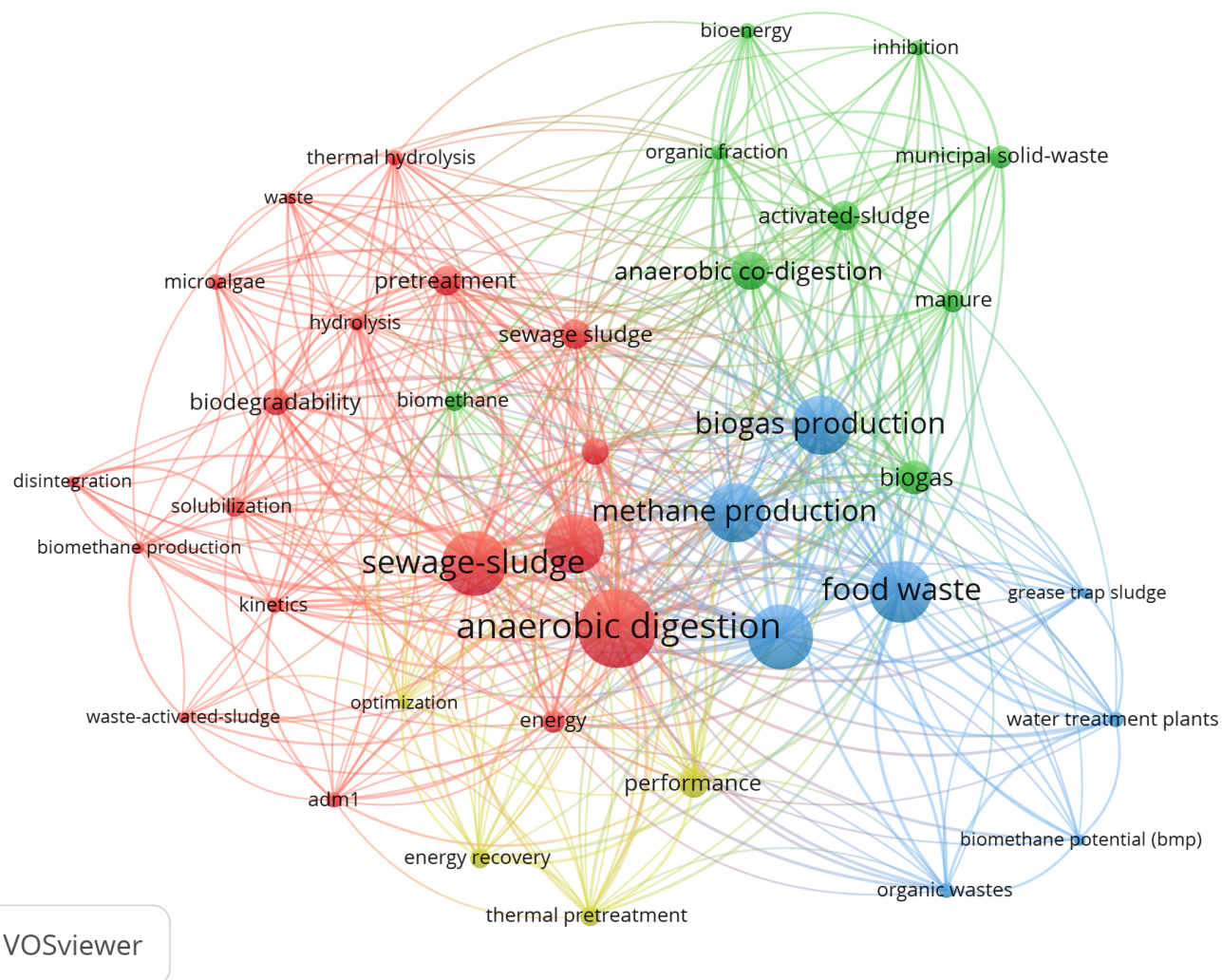
Tuty Emilia Agustina, Elda Melwita, David Bahrin, Rianzya Gayatri, Indah Fitriany Purwaningtyas

Publication Date (Online):

Jul 21, 2020

DOI: <https://doi.org/10.14716/ijtech.v11i3.3800> (<https://doi.org/10.14716/ijtech.v11i3.3800>)

Pages : 472-481



## Improvement of Biomethane Potential by Anaerobic Co-Digestion of Sewage Sludge and Cocoa Pod Husks (<https://ijtech.eng.ui.ac.id/article/view/4079>)

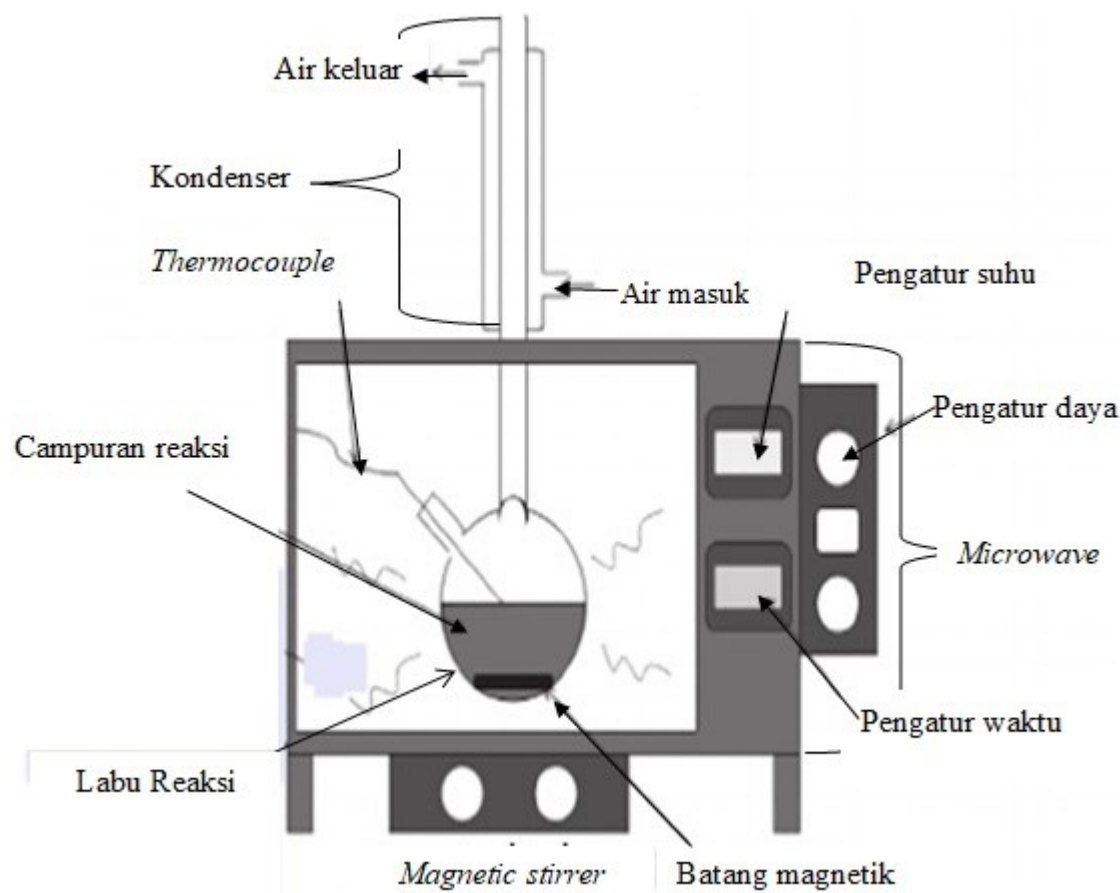
Daniela Mora-Cortés, Yeison Alberto Garcés-Gómez, Sebastian I. Pacheco

Publication Date (Online):

Jul 21, 2020

DOI: <https://doi.org/10.14716/ijtech.v11i3.4079> (<https://doi.org/10.14716/ijtech.v11i3.4079>)

Pages : 482-491



# Intensification of Synthesis of Fatty Acid Isopropyl Ester using Microwave (<https://ijtech.eng.ui.ac.id/article/view/3513>)

Amrina Maulida, Zahrati Zahrati, Hilyati Kamila, Teuku Mukhriza, Asri Gani, Muhammad Dani Supardan

Publication Date (Online):

Jul 21, 2020

DOI: <https://doi.org/10.14716/ijtech.v11i3.3513> (<https://doi.org/10.14716/ijtech.v11i3.3513>)

Pages : 492-500

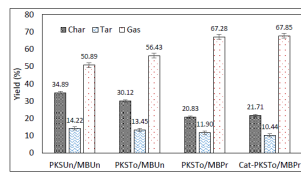


Figure 2 Effect of co-gasification of PKS<sub>Un</sub>/MB<sub>Un</sub>, PKS<sub>to</sub>/MB<sub>Un</sub>, PKS<sub>to</sub>/MB<sub>Pr</sub>, and Cat-PKS<sub>to</sub>/MB<sub>Pr</sub> on product yield

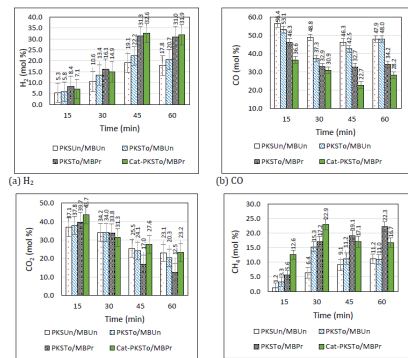


Figure 3 Effect of co-gasification of PKS<sub>Un</sub>/MB<sub>Un</sub>, PKS<sub>to</sub>/MB<sub>Un</sub>, PKS<sub>to</sub>/MB<sub>Pr</sub>, and Cat-PKS<sub>to</sub>/MB<sub>Pr</sub> on gases composition

# The Effect of Pretreated Palm Kernel Shell and Mukah Balingian Coal Co-gasification on Product Yield and Gaseous Composition (<https://ijtech.eng.ui.ac.id/article/view/2916>)

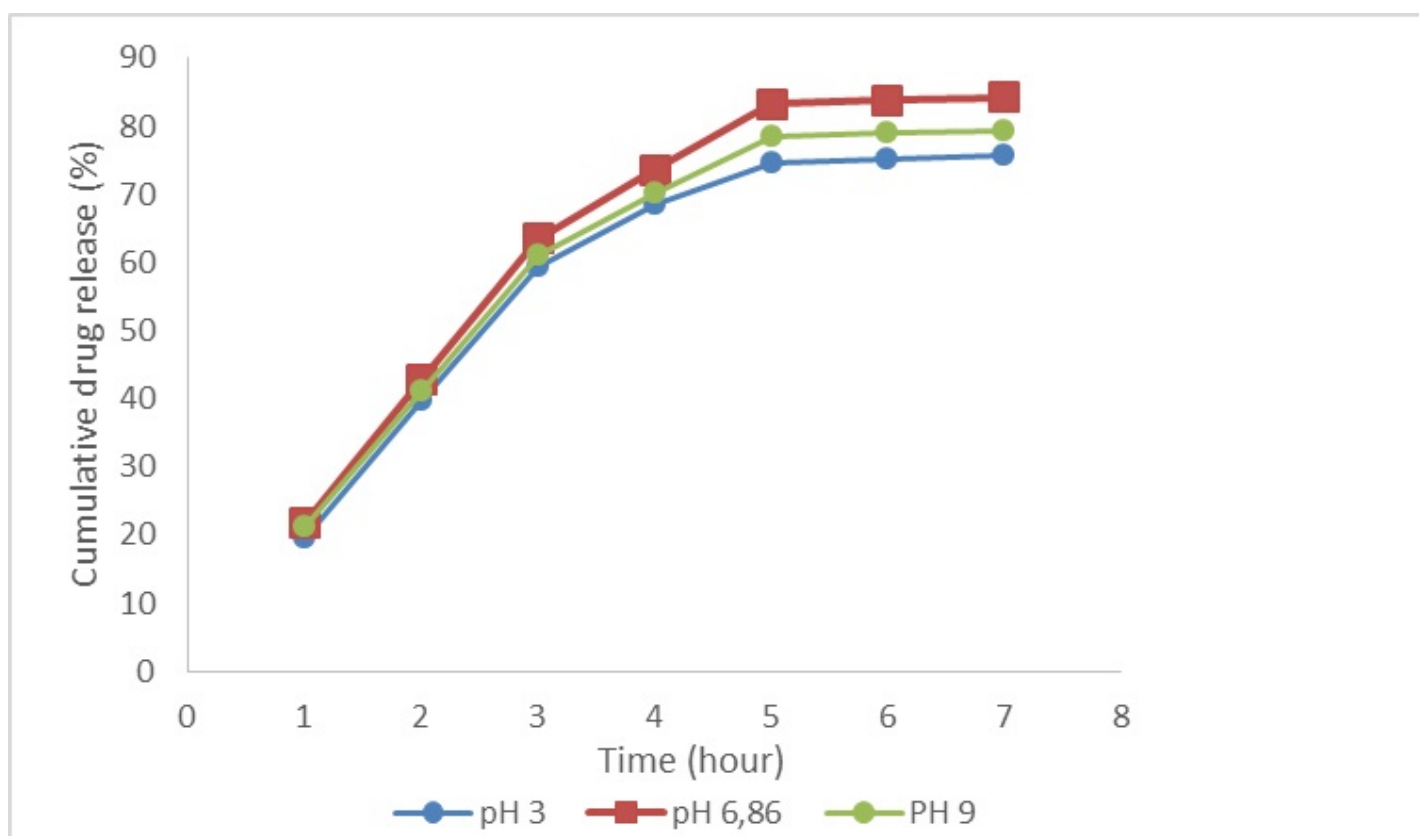
Razi Ahmad, Mohd Azlan Mohd Ishak, Khudzir Ismail, Nur Nasulhah Kasim, Alina Rahayu Mohamed, Asnida Yanti Ani, Raja Razuan Raja Deris, Khairul Adzfa Radzun

Publication Date (Online):

Jul 21, 2020

DOI: <https://doi.org/10.14716/ijtech.v11i3.2916> (<https://doi.org/10.14716/ijtech.v11i3.2916>)

Pages : 501-510



## Controlled Release of Metformin Hydrogen Chloride from Stimuli-responsive Hydrogel based on Poly(N- Isopropylacrylamide)/Chitosan/Polyvinyl Alcohol Composite (<https://ijtech.eng.ui.ac.id/article/view/2330>)

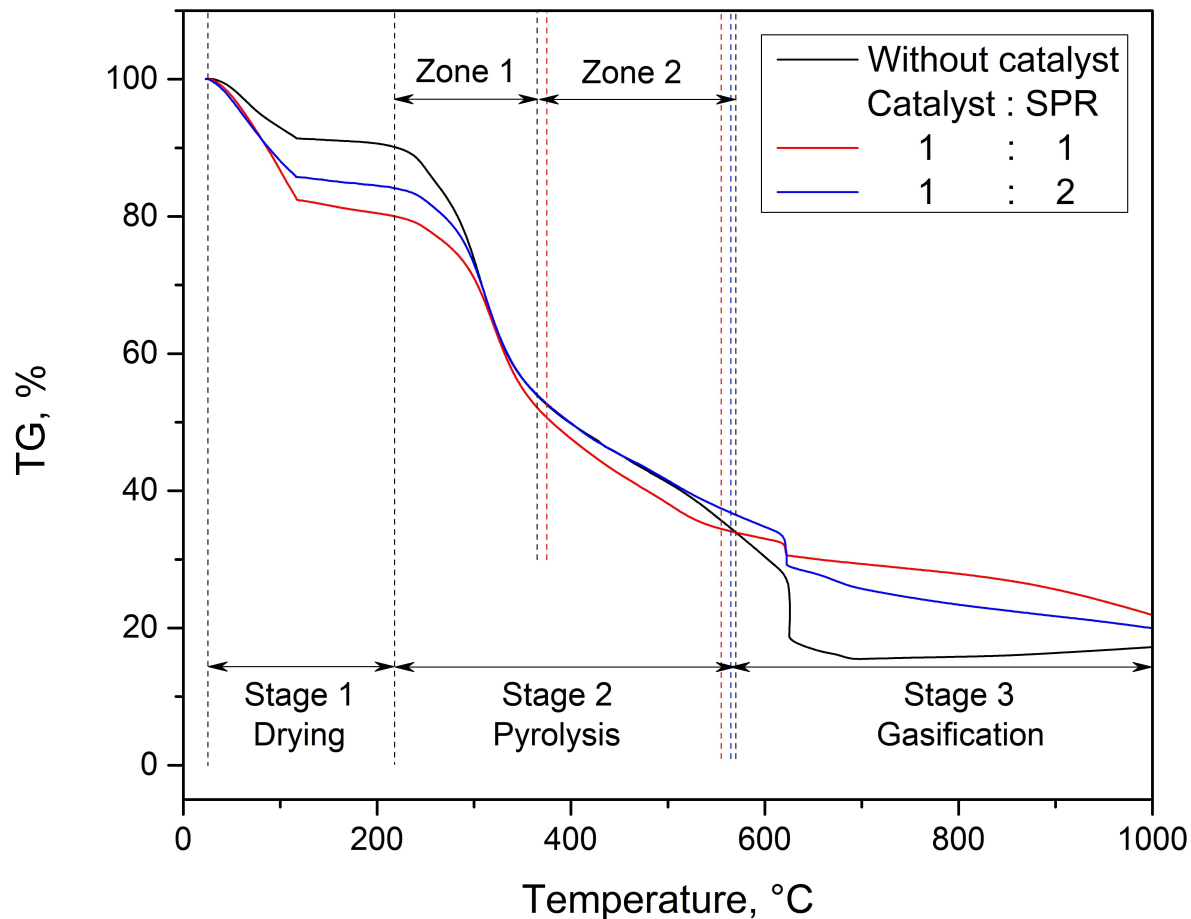
Dhena Ria Barleany, Claudia Vivi Ananta, Fistia Maulina, Agus Rochmat, Hafid Alwan, Erizal

Publication Date (Online):

Jul 21, 2020

DOI: <https://doi.org/10.14716/ijtech.v11i3.2330> (<https://doi.org/10.14716/ijtech.v11i3.2330>)

Pages : 511-521



## Catalytic Pyrolysis of Spirulina platensis Residue (SPR): Thermochemical Behavior and Kinetics (<https://ijtech.eng.ui.ac.id/article/view/2967>)

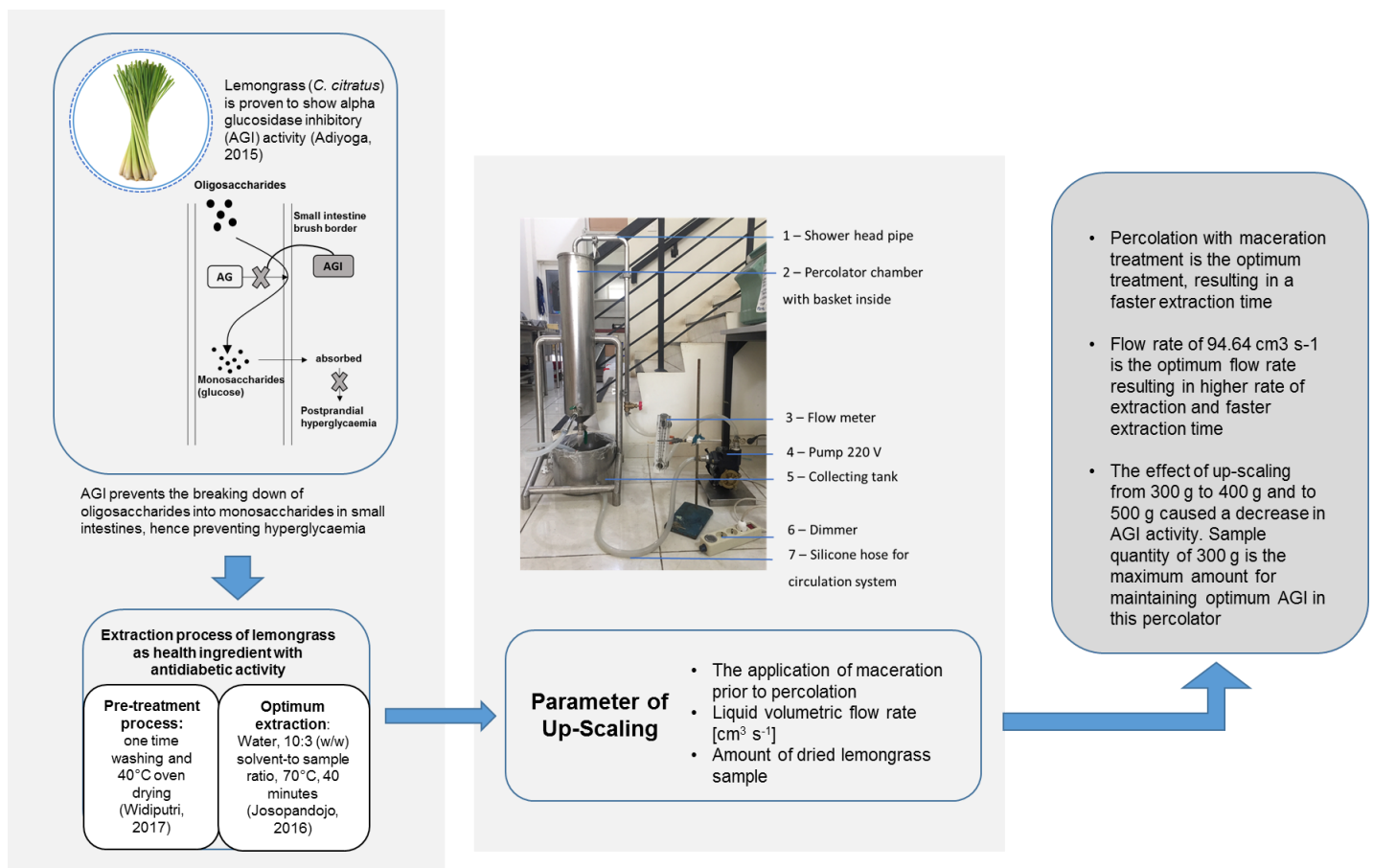
Siti Jamilatun, Budhijanto, Rochmadi, Avido Yuliestyan, Muhammad Aziz, Jun-ichiro Hayashi, Arief Budiman

Publication Date (Online):

Jul 21, 2020

DOI: <https://doi.org/10.14716/ijtech.v11i3.2967> (<https://doi.org/10.14716/ijtech.v11i3.2967>)

Pages : 522-531



## Upscaling the *Cymbopogon citratus* (lemongrass) Extraction Process to Obtain Optimum Alpha-glucosidase Inhibitor (AGI) Levels (<https://ijtech.eng.ui.ac.id/article/view/3688>)

Diah Indriani Widiputri, Ivana Julisantika, Irvan Setiadi Kartawiria, Maria DPT Gunawan-Puteri, Florence Ignatia

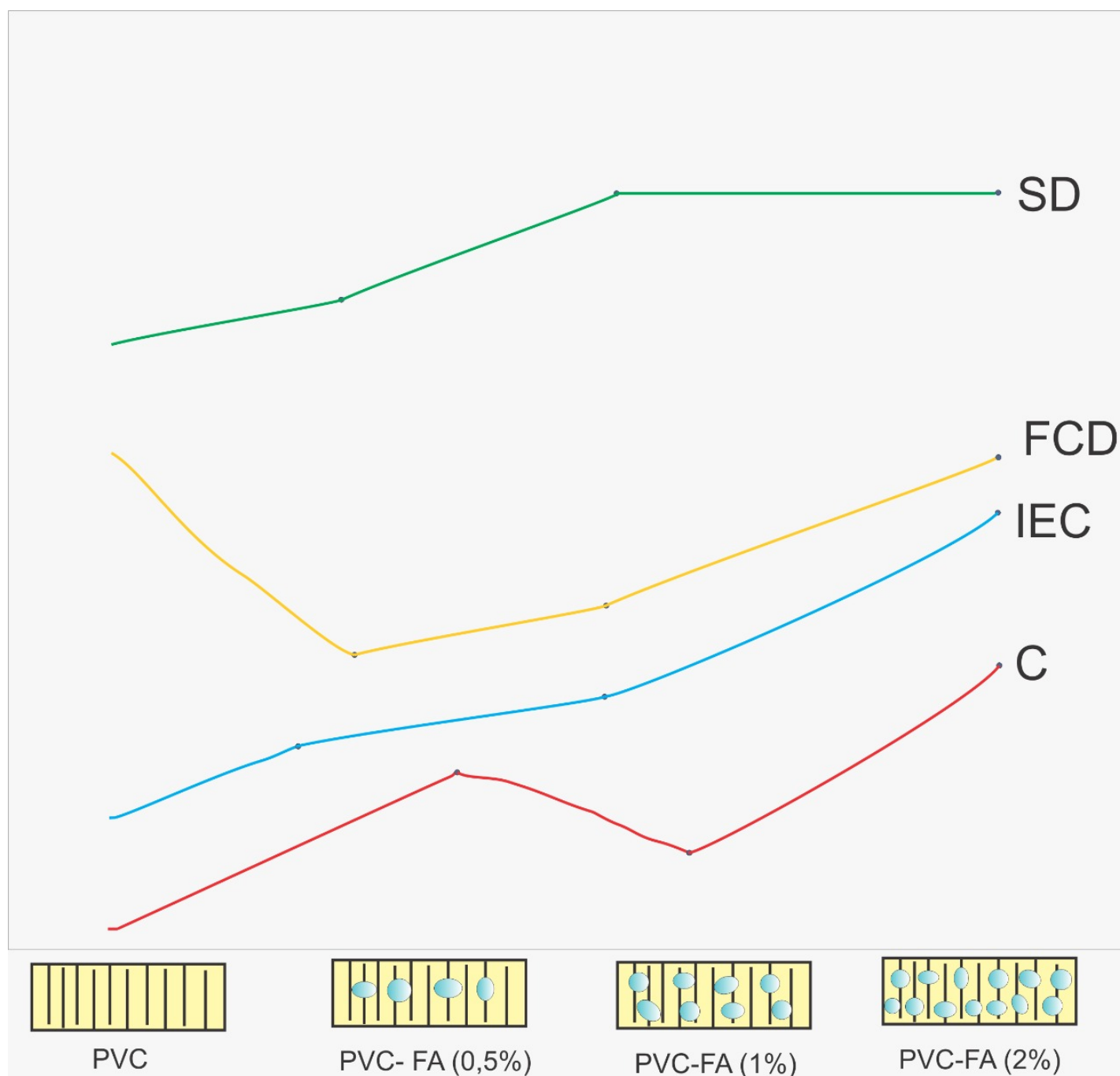
Publication Date (Online):

Jul 21, 2020

DOI: <https://doi.org/10.14716/ijtech.v11i3.3688> (<https://doi.org/10.14716/ijtech.v11i3.3688>)

Pages : 532-543





### Effects of Fly Ash Loading on the Characteristics of PVC-based Cation Exchange Membranes for Reverse Electrodialysis (<https://ijtech.eng.ui.ac.id/article/view/3773>)

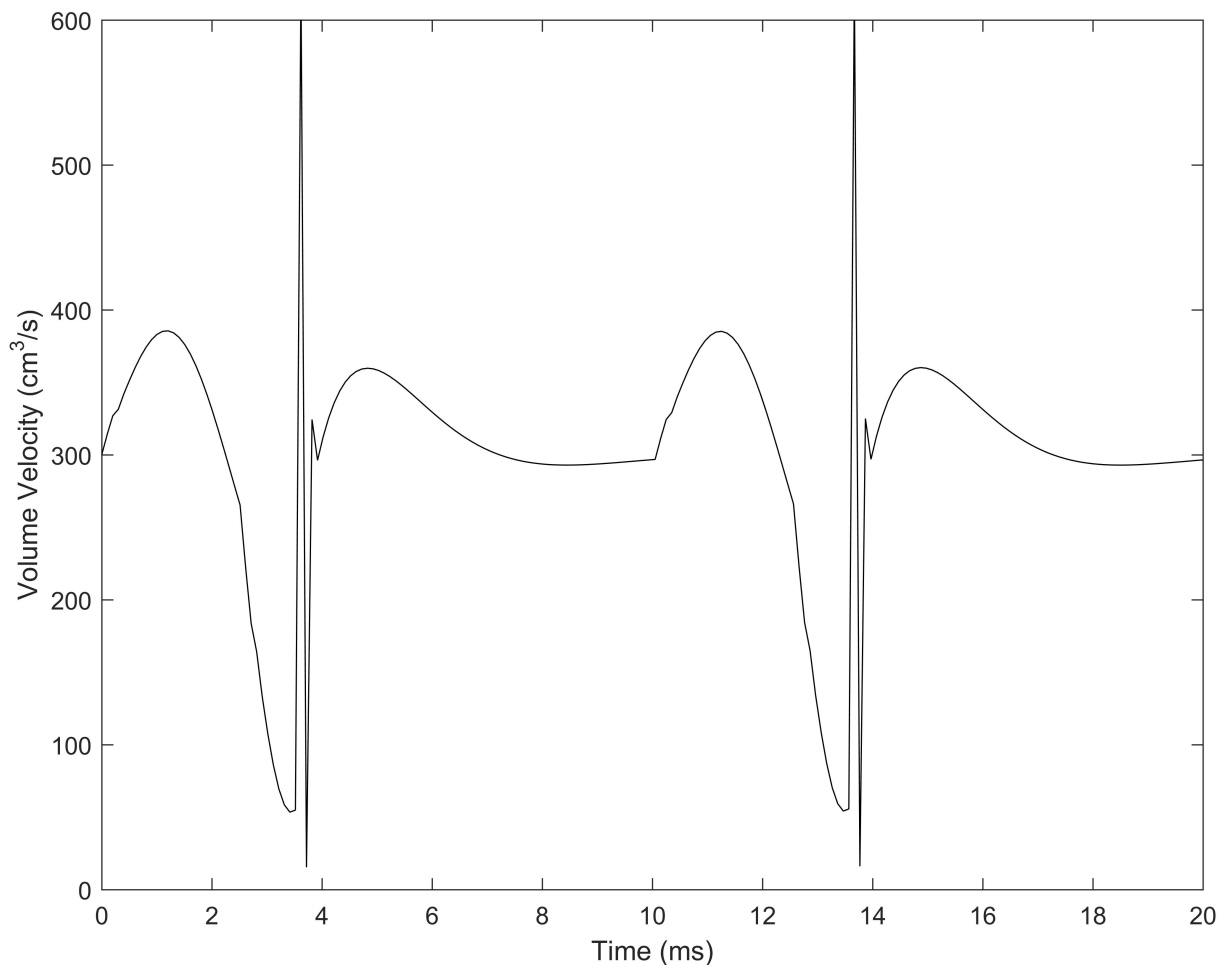
Heru Susanto, Yunita Fahmi, Anisa Tri Hutami, Yuliyanto Triyono Hadi

Publication Date (Online):

Jul 21, 2020

DOI: <https://doi.org/10.14716/ijtech.v11i3.3773> (<https://doi.org/10.14716/ijtech.v11i3.3773>)

Pages : 544-553



## Design of Electrolarynx to Increase Energy Efficiency by Varying the Driving Source (<https://ijtech.eng.ui.ac.id/article/view/2152>)

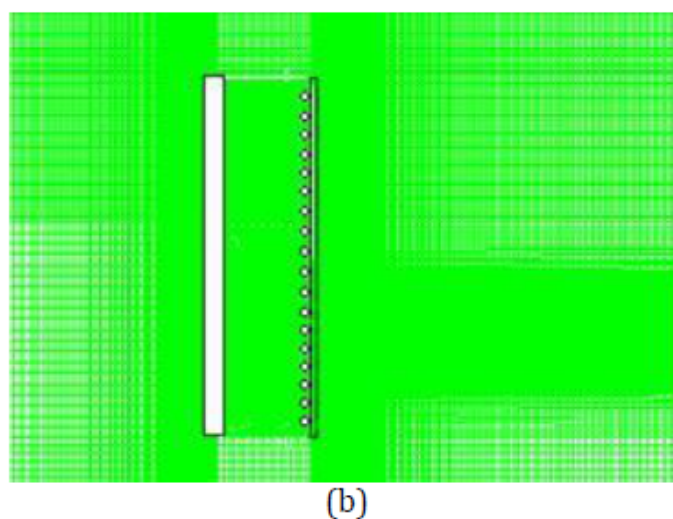
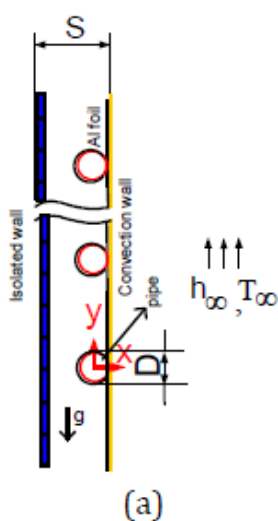
Madhushankara Maila, Somashekara Bhat, Keerthana Prasad

Publication Date (Online):

Jul 21, 2020

DOI: <https://doi.org/10.14716/ijtech.v11i3.2152> (<https://doi.org/10.14716/ijtech.v11i3.2152>)

Pages : 554-563



## Characteristics of Air Flow and Heat Transfer in Serpentine Condenser Pipes with Attached Convection Plates in Open Channel (<https://ijtech.eng.ui.ac.id/article/view/2583>)

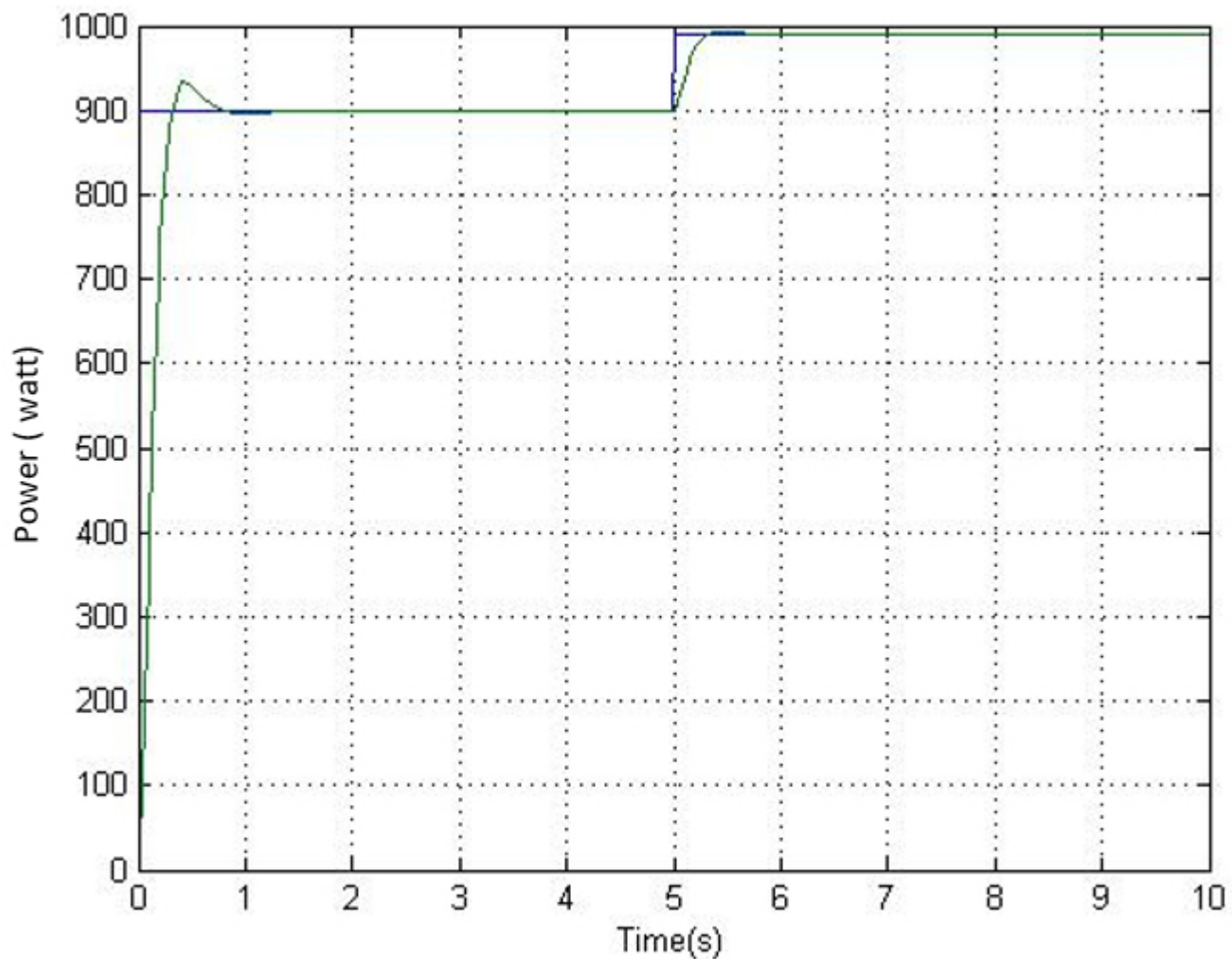
Edy Susanto, M. Idrus Alhamid, Nasruddin, Budihardjo, Prabowo, Sentot Novianto

Publication Date (Online):

Jul 21, 2020

DOI: <https://doi.org/10.14716/ijtech.v11i3.2583> (<https://doi.org/10.14716/ijtech.v11i3.2583>)

Pages : 564-573



Design of Output Power Control System Based on Mass Flow Rate Comparison of Air-Fuel Ratio (AFR) on Dual Fuel Generator Set by Using PID Control Method  
(<https://ijtech.eng.ui.ac.id/article/view/2710>)

Arief Abdurrahman, Totok Soehartanto, Herry Sufyan Hadi, Mohammad Berel Toriki, Bambang Lelono Widjiantoro, Bambang Sampurno

Publication Date (Online):

Jul 21, 2020

DOI: <https://doi.org/10.14716/ijtech.v11i3.2710> (<https://doi.org/10.14716/ijtech.v11i3.2710>)

Pages : 574-586

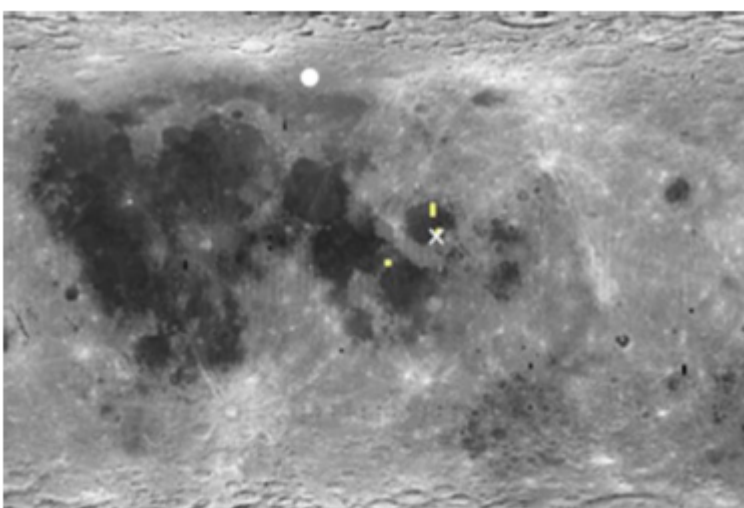


Figure 1 The appearance of regolith and breccia from Luna 24 mission (Diaz et al., 2015)

Sociotechnological Perspective on the Development of Lunar and Martian Infrastructures Made of Concrete Materials (<https://ijtech.eng.ui.ac.id/article/view/2174>)

Dicky Rezady Munaf, Yasraf Amir Piliang

Publication Date (Online):

Jul 21, 2020

DOI: <https://doi.org/10.14716/ijtech.v11i3.2174> (<https://doi.org/10.14716/ijtech.v11i3.2174>)

Pages : 587-598

Mushrooms	2014-15	2015-16	2016-17	2017-18	2018-19
Area	Na	170	183	198	230
Production	51	436	459	487	503

Noted: The area is in thousand ha; production is in thousand mt  
 Source: [National Horticulture Board, 2018-2019](#)

**Value Chain Analysis of Indian Edible Mushroom**  
 (<https://ijtech.eng.ui.ac.id/article/view/3979>)

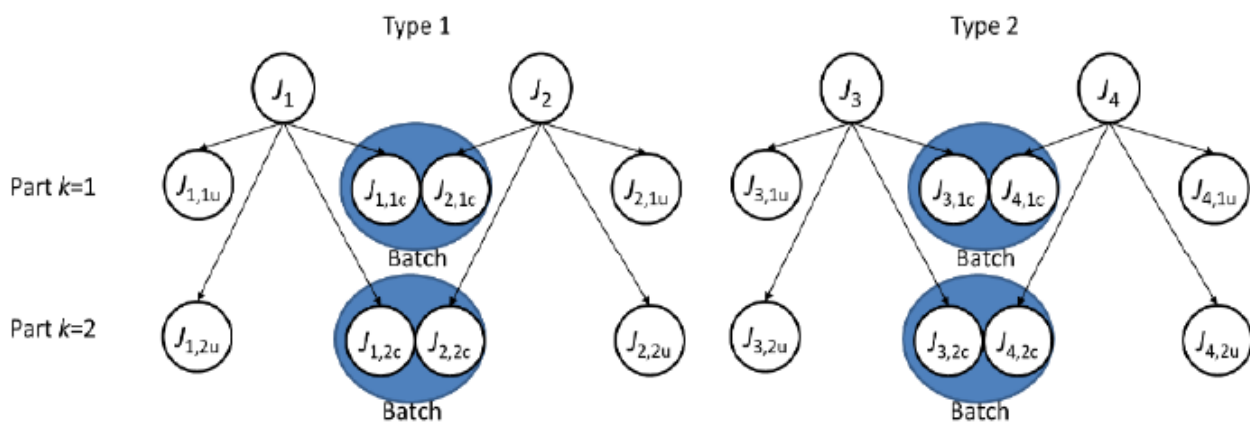
C Ganeshkumar, M Prabhu, Sai Prahlada Reddy, Arokiaraj David

Publication Date (Online):

Jul 21, 2020

DOI: <https://doi.org/10.14716/ijtech.v11i3.3979> (<https://doi.org/10.14716/ijtech.v11i3.3979>)

Pages : 599-607



**A Batch Scheduling Model for a Three-stage Hybrid Flowshop Producing Products with Hierarchical Assembly Structures**  
 (<https://ijtech.eng.ui.ac.id/article/view/3555>)

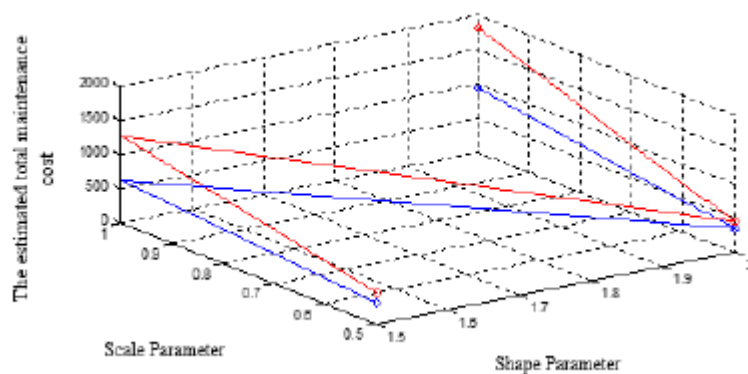
Rahmi Maulidya, Suprayogi, Rachmawati Wangsaputra, Abdul Hakim Halim

Publication Date (Online):

Jul 21, 2020

DOI: <https://doi.org/10.14716/ijtech.v11i3.3555> (<https://doi.org/10.14716/ijtech.v11i3.3555>)

Pages : 608-618

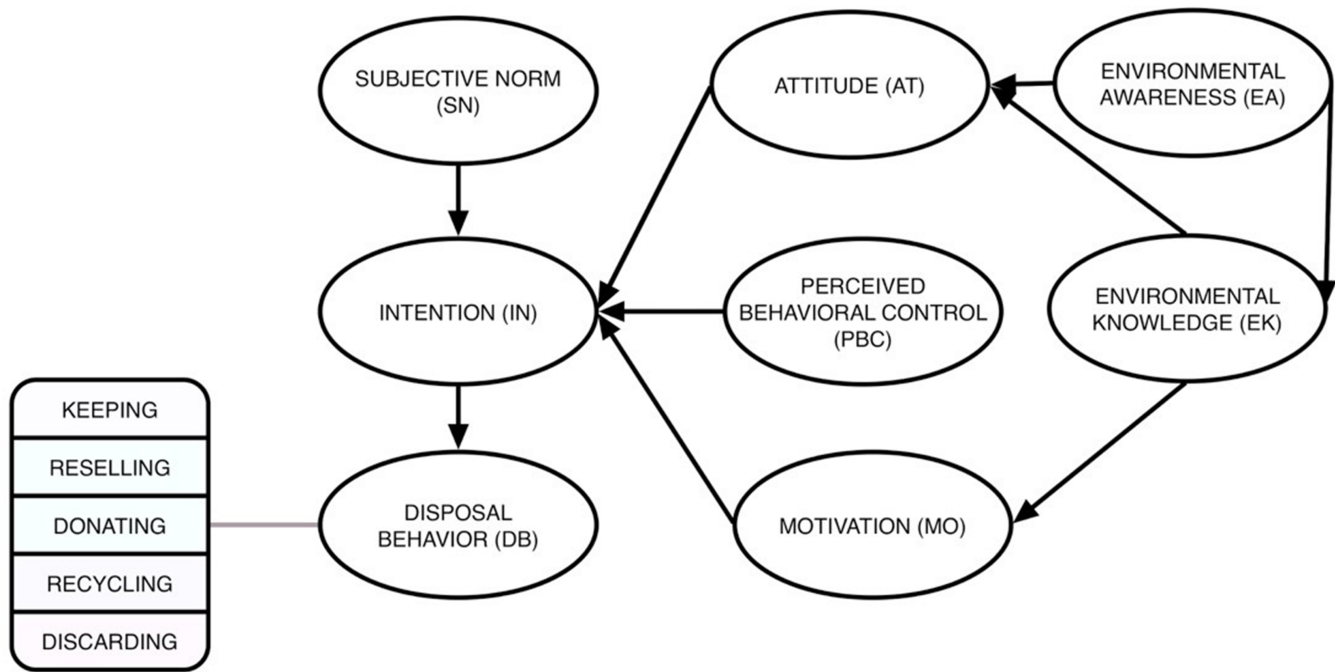


**Overall Equipment Effectiveness Evaluation of Maintenance Strategies for Rented Equipment**  
 (<https://ijtech.eng.ui.ac.id/article/view/3579>)

Ade Supriatna, Moses Laksono Singgih, Erwin Widodo, Nani Kurniati

Publication Date (Online):

Jul 21, 2020



**What Drives Individuals to Dispose of Waste Mobile Phones? A Case Study in Indonesia** (<https://ijtech.eng.ui.ac.id/article/view/3855>)

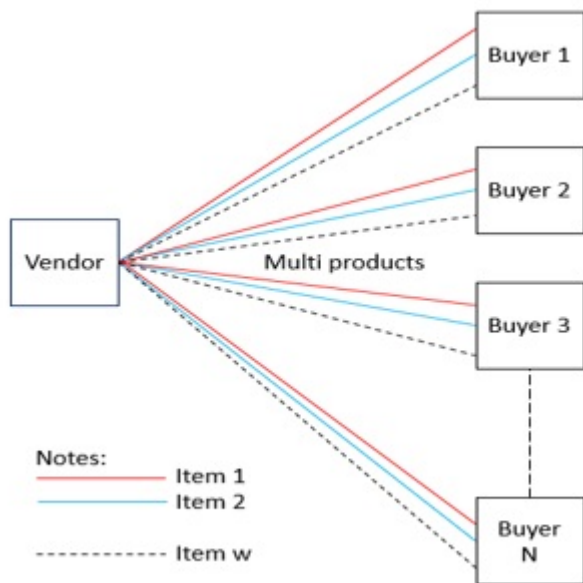
Romadhani Ardi, Billy Muhamad Iqbal, Sekarsyifa Sesarea, Komarudin Komarudin

Publication Date (Online):

Jul 21, 2020

DOI: <https://doi.org/10.14716/ijtech.v11i3.3855> (<https://doi.org/10.14716/ijtech.v11i3.3855>)

Pages : 631-641



**Integrated Supply Chain for a Single Vendor and Multiple Buyers and Products with Crashing Lead Time** (<https://ijtech.eng.ui.ac.id/article/view/3750>)

Kinley Aritonang, Marihot Nainggolan, Adrianus Vincent Djunaidi

Publication Date (Online):

Jul 21, 2020

DOI: <https://doi.org/10.14716/ijtech.v11i3.3750> (<https://doi.org/10.14716/ijtech.v11i3.3750>)

Pages : 642-651

## About the Journal

- Editorial Board (<https://ijtech.eng.ui.ac.id/people>)
- Focus and Scope (<https://ijtech.eng.ui.ac.id/about/5/focus-and-scope>)
- Online Submissions (<https://ijtech.eng.ui.ac.id/about/3/online-submission>)
- Publication Policy (<https://ijtech.eng.ui.ac.id/about/11/publication-policy>)
- Publication Ethics and Policy (<https://ijtech.eng.ui.ac.id/about/10/policy>)
- Author Guidelines (<https://ijtech.eng.ui.ac.id/about/4/author-guidelines>)
- List of Reviewers (<https://ijtech.eng.ui.ac.id/about/12>)

- Most downloaded papers (<https://ijtech.eng.ui.ac.id/home/mostdownloadedpapers>)
- Most cited papers (<https://ijtech.eng.ui.ac.id/about/14>)

## Login

### Username

### Password

Not as user?

Register (<https://ijtech.eng.ui.ac.id/register>)

**LOGIN**

## IJTech

p-ISSN : 2086-9614 (<https://portal.issn.org/resource/ISSN/2086-9614>)

e-ISSN : 2087-2100 (<https://portal.issn.org/resource/ISSN/2087-2100>)

## Journal Metrics



(<https://www.scimagojr.com/journalsearch.php?q=21100235612&tip=sid&exact=no>)

Metrics by SCOPUS 2019

CiteScore 2019: **1.8**

CiteScoreTracker 2019: **1.18**

Source Normalized Impact per Paper (SNIP): **1.395**

Acceptance rate: **17 %**

Average time to publish: **133 days.**

## IJTech is indexed in



(<https://www.scopus.com/sourceid/21100235612>)



(<http://www.ebsco.com/index.asp>)



(<https://doaj.org/toc/2086-9614>)



(<https://www.scimagojr.com/journalsearch.php?>

q=21100235612&tip=sid)



(<https://journals.indexcopernicus.com/search/details?>

id=31340)



(<http://www.crossref.org>)



(<https://scholar.google.co.id/scholar?>

q=site%3Ahttp%3A%2F%2Fijtech.eng.ui.ac.id)



(<https://mjl.clarivate.com:/search-results?issn=2086-9614>)



(<http://info.flagcounter.com/AoS7>)

Copyright © 2017 Faculty of Engineering  
International Journal of Technology

IJTech secretariat, Engineering Center Bld., 2<sup>nd</sup> Fl.  
Faculty of Engineering, Universitas Indonesia  
Depok 16424, Indonesia.





## Catalytic Pyrolysis of *Spirulina platensis* Residue (SPR): Thermochemical Behavior and Kinetics

Siti Jamilatun<sup>1</sup>, Budhijanto<sup>2</sup>, Rochmadi<sup>2</sup>, Avido Yuliestyan<sup>3</sup>, Muhammad Aziz<sup>4,6</sup>, Jun-ichiro Hayashi<sup>5</sup>, Arief Budiman<sup>2\*</sup>

<sup>1</sup>Department of Chemical Engineering, Faculty of Industrial Technology, Universitas Ahmad Dahlan, Jalan Kapas 9, Yogyakarta 55166, Indonesia

<sup>2</sup>Department of Chemical Engineering, Faculty of Engineering, Universitas Gadjah Mada, Jalan Grafika 2, Yogyakarta 55284, Indonesia

<sup>3</sup>Department of Chemical Engineering, Faculty of Industrial Technology, Universitas Pembangunan Nasional "Veteran" Yogyakarta, Jalan SWK 104, Yogyakarta 55283, Indonesia

<sup>4</sup>Institute of Innovative Research, Tokyo Institute of Technology, i6-25, 2-12-1 Ookayama, Meguro-ku, Tokyo 152-8550 Japan

<sup>5</sup>Institute for Material Chemistry and Engineering, Kyushu University, Kasuga 816-8580 Japan

<sup>6</sup>Institute of Industrial Science, The University of Tokyo, 4-6-1 Komaba, Meguro-ku, Tokyo 153-8505, Japan

**Abstract.** The pyrolysis characteristics of *Spirulina platensis* residue (SPR) with silica–alumina catalysts were investigated using thermogravimetric analysis (TGA). The effects of differing amounts of catalysts on thermochemical behavior and kinetics parameters (pre-exponential factor in Arrhenius equation [A] and activation energy [Ea]) were studied. The experiment was carried out from 30 to 1000°C at a heating rate of 20°C/min for the case of non-catalytic and catalytic pyrolysis (silica–alumina). For the catalytic pyrolysis, also of interest were the catalyst-to-SPR weight ratios of 1:1 and 1:2. The TGA curve and differential thermogravimetric peak analysis results suggest that the use of catalysts in pyrolysis (particularly at a catalyst-to-SPR weight ratio of 1:1) reduces both pyrolysis time and temperature range to 14.68 min and 230–555°C, respectively. The kinetic parameters were then calculated in a one-step global non-isothermal model and solved using a least squares method in MATLAB. The presence of catalyst was able to reduce Ea to the lowest value from 41.10 kJ/mol (without catalyst) to 40.77 kJ/mol (weight ratio of 1:2) and 39.46 kJ/mol (weight ratio of 1:1) in Zone 1. However, the increase of catalyst quantity was not in line with the increase of reaction rate constant (k) and resulted in reasonably low A of, respectively, 593.30, 406.31, and 266.37.

**Keywords:** Activation energy, Catalytic pyrolysis; Pre-exponential factor; *Spirulina platensis* residue

### 1. Introduction

By 2040, the world's energy demand is estimated to have increased by 56%, with fossil fuels still contributing about 80% of the required supply (Anggorowati et al., 2018). This expectation has motivated an acceleration of the utilization of renewable sources, including algae. Microalgae such as *Spirulina platensis* have tremendous potential to be converted as a renewable fuel (Pradana et al., 2018). After the removal of lipid content by extraction, biomass in the form of *Spirulina platensis* residue (SPR), used as a biofuel material, has the

\*Corresponding author's email: [abudiman@ugm.ac.id](mailto:abudiman@ugm.ac.id), Tel/Fax.: +62-274-902170  
doi: [10.14716/ijtech.v11i3.2967](https://doi.org/10.14716/ijtech.v11i3.2967)

potential to be converted through a process of pyrolysis (Jamilatun et al., 2017a; Kusrini et al., 2018; Jamilatun et al., 2019a).

Generally, a biofuel derived from the pyrolysis of SPR exhibits several deficiencies, including the presence of high levels of oxygenous and nitrogenous compounds. However, these disadvantages can be overcome through the use of a catalyst to reduce the levels of oxygenous and nitrogenous compounds (Bui et al., 2016). One suitable catalyst for upgrading the bio-oil is silica–alumina, which is widely used to support the production of petrochemicals, chemicals, and energy. The  $\text{Al}_2\text{O}_3$  can promote the formation of aromatic compounds, such as polycyclic aromatic hydrocarbons. And with its low acidity,  $\text{SiO}_2$  can also help remove oxygenated compounds and inhibit the formation of coke on the catalyst thanks to the porous medium (Aho et al., 2013; Busca, 2019; Jamilatun et al., 2019c). Jamilatun (2019c) reported that the catalytic pyrolysis on SPR using a silica–alumina catalyst (surface area of  $240.553 \text{ m}^2/\text{g}$ , pore size of  $3.3 \text{ nm}$ , average pore volume of  $0.199 \text{ cm}^3/\text{g}$ , and  $\text{SiO}_2/\text{Al}_2\text{O}_3$  of 1.71) could reduce oxygenated compounds 37.47% (without catalyst) to 12.82% (a decrease of 65.80%). Further investigation on the catalytic thermal decomposition of SPR is crucially demanded to accelerate the development of bio-oil production (Sunarno et al., 2018; Jamilatun et al., 2019b; Jamilatun et al., 2019c). Its kinetic analysis and the thermal decomposition mechanisms necessary to obtain pre-exponential factor (A) and the reaction kinetics constant (k) from catalytic pyrolysis are the critical tools for designing reactor developments for industrial-scale bio-oil production (Li et al., 2013).

One effective method of analyzing both thermal decomposition and reaction kinetics is thermogravimetry (TG). Thermogravimetric analysis (TGA) has become a proven technique for investigating the non-catalytic pyrolysis of algae, including *Chlorella* sp., *Tetraselmis suecica* (Kassim et al., 2014), *Spirulina* extraction wastes (Li et al., 2013; Jamilatun et al., 2017b), and *Sargassum* sp. (Kim et al., 2013). On the other hand, there is minimal research on catalytic pyrolysis using the TGA method with microalgae raw materials, but Jamilatun et al. (2017b) reported that analysis of thermal decomposition and pyrolysis reaction kinetics of SPR with TGA indicated that the activation energy ( $E_a$ ) for the heating rate of  $20^\circ\text{C}/\text{min}$  for Zones 1 and 2 was  $41.102 \text{ kJ}/\text{mol}$  and  $0.0001240 \text{ kJ}/\text{mol}$ . However, there has been almost no research work conducted on thermochemistry and kinetics of catalytic pyrolysis reactions using TGA. For this reason, research on catalytic pyrolysis of SPR needs to be developed, particularly with regard to pyrolysis thermochemical behavior and kinetics.

Based on TGA data, reaction kinetics can be approximated using a one-step reaction model derived from the Flynn–Wall–Ozawa and Kissinger–Akahira–Sunose methods (Kassim et al., 2014; Quan et al., 2016). In this method, a one-stage global single-reaction model can be determined via various approaches, such as the distributed activation energy model (DAEM), the iso-conventional method from Vyazovkin (Marriott et al., 2016), and nonlinear least squares regression (Kim et al., 2013). To the best knowledge of the authors, there is no previous study on biomass kinetic reactions incorporating natural and straightforward processes. Hence, as an alternative to establishing a one-stage global single-reaction model, a reaction model using a least squares method and MATLAB simulation tools was developed in this study. The data of catalytic thermal decomposition characteristics of SPR in TGA are required to determine the reaction kinetics, and the kinetics data are necessary to design the pyrolysis equipment for bio-oil production (Kim et al., 2013; Kassim et al., 2014; Quan et al., 2016).

This paper discusses the characteristics of thermal decomposition using a silica–alumina ( $\text{SiO}_2/\text{Al}_2\text{O}_3$ ) catalyst, including the extent of the catalyst's effect on SPR weight

reduction. This work uses TG and differential thermogravimetric (DTG) curves to obtain the temperature ranges for Stage I (drying), Stage II (pyrolysis), and Stage III (gasification). The kinetic reaction was calculated through a one-step global non-isothermal model and solved with a least squares fitting using MATLAB simulation.

## 2. Methods

### 2.1. Materials

Blue-green microalgae, *Spirulina platensis*, were extracted to produce algal oil and a solid residue. The built residue (SPR) was used as the raw material for this research. The wet SPR was initially dried at 70°C in an oven to a constant weight and then homogenized until its size reached about 0.105–0.177 mm. Analyses of the protein, lipid, and carbohydrate contents of the SPR sample, together with calorific value analysis, were performed at the Research and Development Center for Mineral and Coal Technology (TEKMIRA), Bandung, Indonesia (Jamilatun et al., 2017a).

The catalyst used in this research was SiO<sub>2</sub>/Al<sub>2</sub>O<sub>3</sub>, obtained from PT PERTAMINA Balongan Indonesia. The specifications of the SiO<sub>2</sub>/Al<sub>2</sub>O<sub>3</sub> were: (i) the ratio of SiO<sub>2</sub>/Al<sub>2</sub>O<sub>3</sub> was 1.67, and (ii) based on the BET method, the pore had a surface area of 240.553 m<sup>2</sup>/g, with a pore diameter of 3.3 nm and mean pore volume of 0.199 cm<sup>3</sup>/g to the total pore volume, and the contents of Na<sub>2</sub>O, K<sub>2</sub>O, CaO, and Fe<sub>2</sub>O<sub>3</sub> were 0.48%, 0.017%, 0.035%, and 0.282%, respectively. SEM-EDX analysis revealed that the SiO<sub>2</sub>/Al<sub>2</sub>O<sub>3</sub> catalyst comprised C, O, Al, and Si of 12.33, 55.73, 15.42, and 16.51 wt.%, respectively (Jamilatun et al., 2017b; Jamilatun et al., 2019c).

### 2.2. Methods and Analysis

#### 2.2.1. Pyrolysis test with TGA and thermochemical behavior

Thermal decomposition was examined using a TG–DTA (Perkin Elmer Pyris Diamond) at Leather Technology Academy, Yogyakarta (Politeknik ATK Yogyakarta). The mass of SPR, including the catalyst mixture (1:1 and 1:2 ratios) for each experiment, was 4–8 mg. Heating was carried out at a temperature range of 30 to 1000°C, and a rate of 20°C/min in the presence of 20 mL/min nitrogen gas. The selected heating rate had been previously tested by Jamilatun et al. (2017a).

#### 2.2.2. Kinetics analysis

The one-stage global single-reaction model was used to obtain the reaction rate constant ( $k$ ), including  $A$  and  $E_a$ . Although the pyrolysis of SPR biomass includes various very complex reactions, they can be considered as a single overall reaction (Kassim et al., 2014), with the equation for the reaction given as (Agrawal and Chakraborty, 2013)



As shown in Equation 1, the pyrolysis with TG is non-isothermal, which can be observed as the change in SPR mass over time until the end of pyrolysis. The formed volatile matter mass could not be observed. The conversion change at any time ( $dX/dt$ ) is affected by  $k$ , as the function of temperature ( $T$ ), and conversion ( $f(X)$ ) (Agrawal and Chakraborty, 2013).

$$\frac{dX}{dt} = k(T) \cdot f(X) \quad (2)$$

for,

$$f(X) = (1-X)^n \quad (3)$$

where  $n$  is the order of the reaction (this is assumed to be one). Moreover, the SPR conversion ( $X$ ) is calculated using the following equation (Quan et al., 2016):

$$X = \frac{m_o - m_t}{m_o} \quad (4)$$

where  $X$  represents the conversion as a function of weight ( $m$ ) from time 0 to time  $t$ . By initially providing the values of  $A$ ,  $E_a$ , and universal gas constant ( $R$ ) data,  $k$  can be calculated using

$$k = A \cdot \exp\left(\frac{-E_a}{RT}\right) \quad (5)$$

Combining Equations 2–5 results in

$$\frac{dX}{dt} = A \cdot \exp\left(\frac{-E_a}{RT}\right) (1-X)^n \quad (6)$$

$$T = T_0 + \beta(t) \quad (7)$$

$$\beta = \frac{dT}{dt} \quad (8)$$

where  $\beta$  is the heating rate ( $^{\circ}\text{C}/\text{s}$ ),  $T_0$  and  $T$  are the initial temperature and the temperature at a given  $t$  (K), respectively.

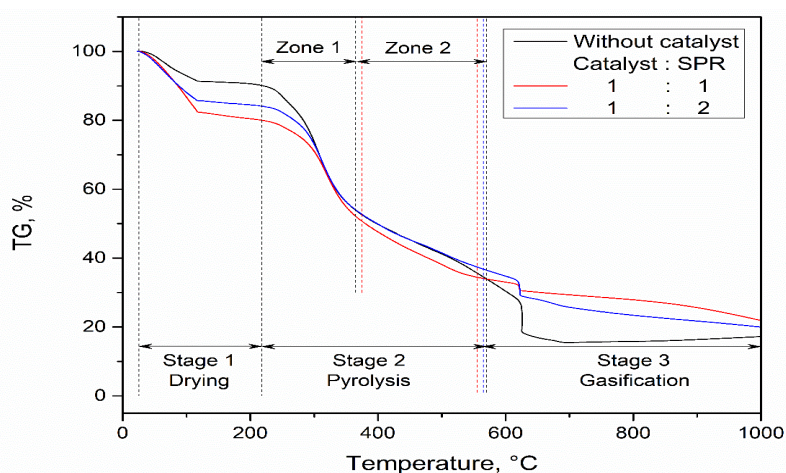
The  $A$  and  $E_a$  were then validated using the least squares method. The sum of squared errors (SSE) was calculated using the method in Jamilatun et al. (2017b):

$$\text{SSE} = \sum\{(X)_{\text{model}} - (X)_{\text{data}}\}^2 \quad (9)$$

### 3. Results and Discussion

#### 3.1. Thermal Decomposition and Thermochemical Characteristics

The catalytic thermal decomposition characteristics of SPR were evaluated at a heating rate of  $20^{\circ}\text{C}/\text{min}$  in the presence of the  $\text{SiO}_2/\text{Al}_2\text{O}_3$  catalyst. The results of the thermal decomposition for the catalyst-to-SPR weight ratios of 1:1, 1:2, and without catalyst can be seen in Figure 1, and the division of stages information is listed in Table 1.



**Figure 1** Thermal decomposition of SPR for the cases of the catalytic process with catalyst-to-SPR weight ratios of 1:1 and 1:2 and non-catalytic method at a heating rate of  $20^{\circ}\text{C}/\text{min}$

The weight reduction of the SPR (obtained from the slope of the curve) can be seen in Figure 1. Catalytic and non-catalytic thermal decompositions exhibited a similar temperature range ( $30\text{--}230^{\circ}\text{C}$ ) in Stage I. Catalytic pyrolysis exhibited slight differences in

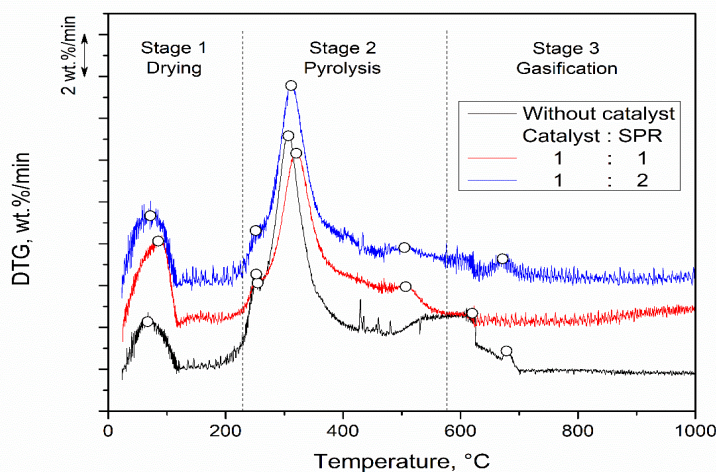
the temperature range for the ratios of 1:1 and 1:2, as shown in Table 1. The temperature ranges were 230–555°C and 230–565°C in Stage II, and 555–1000°C and 565–1000°C in Stage III, respectively. This temperature range contrasts with the non-catalytic pyrolysis, which exhibited a temperature range of 230–570°C in Stage II and 570–1000°C in Stage III. These phenomena may indicate that the catalyst reduces  $E_a$ ; hence, the reaction proceeds more rapidly, resulting in faster pyrolysis (14.68 min) than without a catalyst (15.10 min).

**Table 1** Division of stages upon catalytic and non-catalytic pyrolysis of SPR

Catalyst/SPR	1:1	1:2	Without catalyst
Stage I, °C (drying)	30–230	30–230	30–230
Stage II, °C (pyrolysis)	230–555	230–565	230–570
Stage III, °C (gasification)	555–1000	565–1000	570–1000
Pyrolysis time (Stage II), min	14.68	15.07	15.10

Furthermore, Stage II can be subdivided into two pyrolysis zones: Zone 1 (230–375°C for the 1:1 ratio and 230–365°C for the 1:2 ratio), with a rapid rate of weight reduction, and Zone 2 (375–555°C for the 1:1 ratio and 365–565°C for the 1:2 ratio), with a slower reduction rate. Meanwhile, for non-catalytic pyrolysis, Zones 1 and 2 ended at 350 and 570°C, respectively. Based on that, the use of a catalyst seems to affect the final temperature of the pyrolysis. In Zone 1, the final pyrolysis temperature with the catalyst (375°C) was higher than that without the catalyst (350°C), while in Zone 2, the temperature with the catalyst was lower (555°C) than that without the catalyst (570°C). Overall, without considering the presence of the pyrolysis zone, pyrolysis was achieved faster with the use of a catalyst, with a temperature range of 230–555 °C, as compared to without a catalyst at 230–570°C. This can be explained by the use of the catalyst possibly decreasing the activation energy so that it can accelerate the reaction, resulting in pyrolysis being achieved more quickly and in the lower temperature range.

DTG curves might be used to shed some light, based on the catalytic thermal decomposition of proteins and lipids, following the peaks summarized in Table 2 as a representation of the curves shown in Figure 2. The magnitude of the peak can describe the effect of temperature increase on the release of volatile matter (wt.%) for each time (min).



**Figure 2** TG-DTG curve for catalytic thermal decomposition of SPR at a heating rate of 20°C/min: (a) the catalyst-to-SPR weight ratio of 1:1; (b) catalyst-to-SPR weight ratio of 1:2

From Figure 2, it can be observed that at a 20°C/min heating rate and 1:1 weight ratio, one peak was present in Stage I, three peaks were present in Stage II, and only one peak was present in Stage III. The evaporation of water (via O–H bond termination) occurred at 82.05°C at a rate of 4.35 wt.%/min. In the first zone of Stage II, two peaks were present at 262.30 and 318.05°C, with weight loss rates equal to 2.18 and 8.40 wt.%/min, respectively. Conversely, only one peak was observed in Zone 2, at 516.76°C, with a weight loss rate of 1.78 wt.%/min. The peaks in the pyrolysis zone indicate the release of volatile matter, meaning the decomposition of proteins and carbohydrates occurring through the termination of O–O, N–O, C–N, N–H, N=N, C=N, C–C, C=C, O=H, C–O, O–H, C=O, and C–H bonds. This phenomenon is the same as in a study by [de Wild et al. \(2011\)](#), showing that at the peaks in Zones 1 and 2, there is a breaking of the O–O, N–O, C–N, N–H, N=N, and C=N bonds with the decomposition of proteins, then a termination of C bonds C, C=C, and O=H bonds in cellulose decomposition, completion of C–C, C–O, O–H, C=O, and C–H bonds in hemicellulose decomposition, and termination of C bonds C, C=O and C–O in lignin decomposition.

Using a similar method applied to deduct the information in the 1:1 weight ratio case, peaks for non-catalytic thermal decomposition and catalytic decomposition at a 1:2 weight ratio were determined, and the results are shown in Table 2 and Figure 2b. For the non-catalytic process, a peak was observed at a similar position in Stage II, meaning in the temperature range where pyrolysis occurred. The volatile matter was released at a rate of 11.28 wt.%/min during non-catalytic decomposition at 305.62°C. Meanwhile, for catalytic decomposition, in summary, three peaks initially appeared at lower temperatures (253.95, 312.67, and 506.56°C) for the 1:2 ratio than for the 1:1 ratio (at 262.3, 318.05 and 516.77°C). However, the rates of volatile matter release with catalyst-to-SPR weight ratios of 1:1 and 1:2 were relatively similar, at 2.18–2.89, 8.40–9.78, and 1.78–1.83 wt.%/min.

**Table 2** Peaks observed on DTG curves for catalytic and non-catalytic thermal decomposition of SPR at a heating rate of 20°C/min

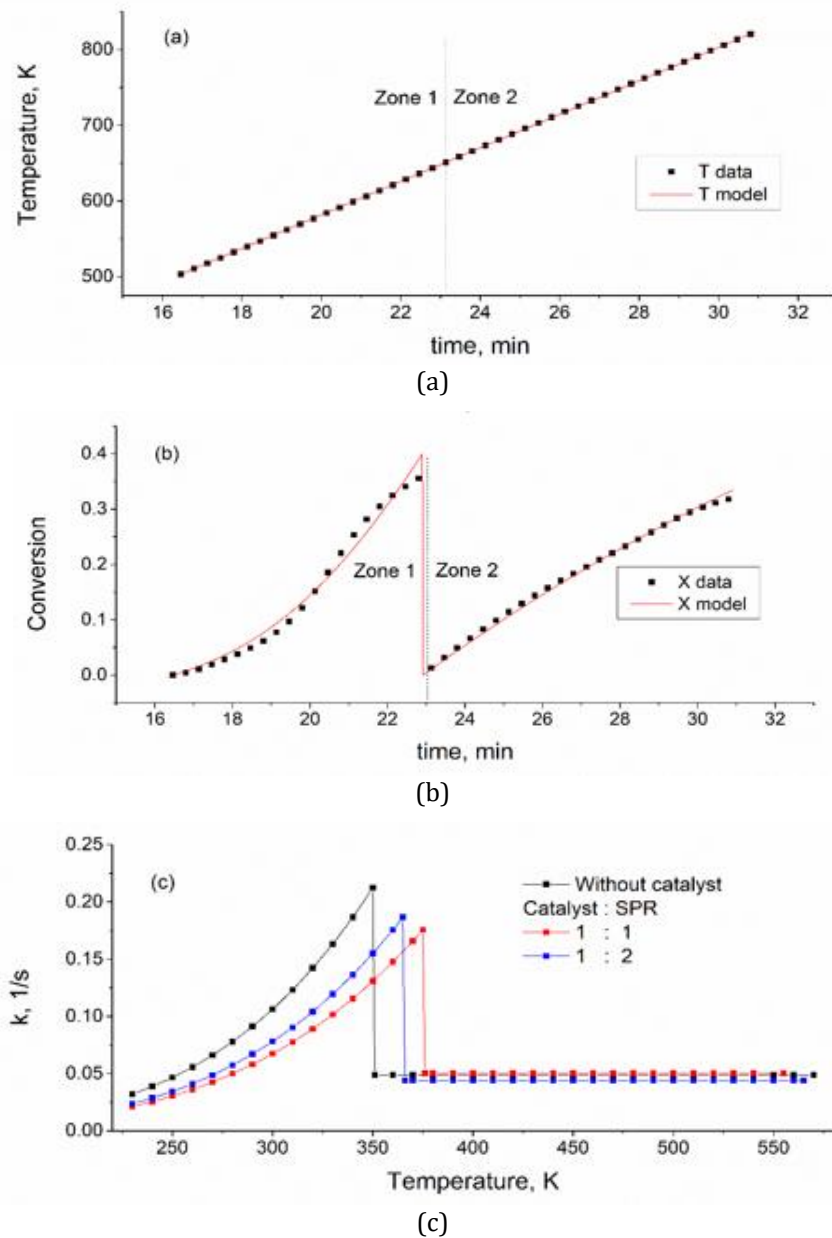
Catalyst/SPR		Without catalyst	1:1	1:2
Stage I (Drying)				
Peak 1	Temperature, °C	65.38	82.05	68.26
	DTG, wt.%/min	2.31	4.35	3.41
Stage II (Pyrolysis)				
Peak 1	Temperature, °C	254.60	262.30	253.95
	DTG, wt.%/min	4.40	2.18	2.89
Peak 2	Temperature, °C	305.62	318.05	312.67
	DTG, wt.%/min	11.28	8.40	9.78
Peak 3	Temperature, °C	610.44	516.77	506.56
	DTG, wt.%/min	2.91	1.78	1.83
Stage III (Gasification)				
Peak 1	Temperature, °C	681.08	618.83	675.65
	DTG, wt.%/min	0.97	0.51	1.45

### 3.2. Reaction Kinetics

The reaction kinetics of catalytic pyrolysis for the one-stage global single-reaction model can be derived from Equation 1, while the values of A and Ea can be calculated using Equations 2–5. By employing a least squares approach, the SSE calculation in MATLAB can be performed using Equation 9. The temperature (T) in Equation 8 is the pyrolysis temperature as influenced by time (t) and heating rate ( $\beta$ ). Therefore, the relationship

between temperature ( $T_{\text{data}}$  and  $T_{\text{model}}$ ) and pyrolysis time ( $t$ ) in Zones 1 and 2 must be evaluated for the relative error. Evidence that the relative error is small can be observed in the selected experimental data for the catalyst-to-SPR ratio of 1:1; the results are presented in Figure 3a.

From Figure 3a, it can be observed that the line of temperature ( $T_{\text{model}}$ ) versus time ( $t$ ) in Zones 1 and 2 coincide with the scatter data ( $T_{\text{data}}$  vs.  $t$ ). This relationship can be interpreted as evidence that the relationships between experimental data and models have the same relative values. Furthermore, the calculated conversion ( $X_{\text{model}}$ ) and the conversion observed in the experiment ( $X_{\text{data}}$ ) were employed to calculate the SSE using Equation 9. The relationship between both of these conversions with time ( $t$ ) at a catalyst-to-SPR weight ratio of 1:1 can be seen in Figure 3b.



**Figure 3** Kinetic parameters calculated for SPR pyrolysis at a heating rate of 20°C/min in Zones 1 and 2 for a catalyst-to-SPR weight ratio of 1:1: (a) relationship between time ( $t$ ) and pyrolysis temperature ( $T$ ); (b) relationship between time ( $t$ ) and conversion ( $X$ ); (c) relationship between the rate of reaction constant ( $k$ ) and reaction temperature ( $T$ ) with and without the catalyst

From the results of the simulation, with the values of  $A$  and  $E_a$  without and with a catalyst provided in Table 3, it can be observed that without the catalyst,  $A$  and  $E_a$  were 593.30 and 41.10 kJ/mol, respectively. In contrast, at a catalyst-to-SPR ratio of 1:1, these values became 266.37 and 39.46 kJ/mol, respectively, and at a catalyst-to-SPR ratio of 1:2, the values were 406.31 and 40.771 kJ/mol, respectively. The use of the catalyst decreased  $E_a$  due to the addition of new reaction pathways. Because catalytic pyrolysis is a very complex mechanism, the obtained  $E_a$  is affected by many reactions, including cracking, decarboxylation, decarbonylation, hydrocracking, hydrogenation, and hydrodeoxygenation (Purwanto et al., 2015; Supramono et al., 2015).

The decline of  $E_a$  can be interpreted as evidence that the catalytic pyrolysis reaction occurs more readily. In the calculation of  $k$  in Table 3 for Zone 1, it can be observed that with an increase of pyrolysis temperature,  $k$  rose accordingly. However, it appears that at a heating rate of 20°C/min and without the catalyst, the value of  $k$  is only slightly higher than with the catalyst. This is due to the shift in the final pyrolysis temperature range, meaning it shifts to higher temperatures; therefore, in the case without the catalyst,  $k$  is even higher than that with the catalyst (Kim et al., 2013; Marriott et al., 2016; Quan et al., 2016).

In addition, Table 3 also shows the calculated data for  $A$ ,  $E_a$ , and  $k$  for Zone 2. It can also be observed that irrespective of the presence of a catalyst, the value of  $A$  is relatively similar. In contrast, the  $E_a$  value with the catalyst (0.0552–0.0853 J/mol) is much lower than without the catalyst (0.1421 J/mol). The values of  $k$  with and without the catalyst are almost the same (in the range of 0.0488–0.0505 s<sup>-1</sup>), indicating that the temperature rise does not affect the amount of  $k$ , yielding relatively stable  $k$  values. The value of  $E_a$  in Zone 2 is a composite  $E_a$  of many reactions during pyrolysis (Li et al., 2013).

**Table 3** Reaction kinetic parameters of the SPR with and without the catalyst at a heating rate of 20°C/min for Zones 1 and 2

Catalyst/ SPR	$A$	$E_a$ (kJ/mol)	SSE	Temperature range, (°C)		$k$ (s <sup>-1</sup> ) low temp.	$k$ (s <sup>-1</sup> ) high temp.
Zone 1							
Without	593.30	41.10	0.0506	230	350	0.0320	0.2124
1:2	406.31	40.77	0.1005	230	365	0.0237	0.1865
1:1	266.37	39.46	0.0924	230	375	0.0213	0.1755
Zone 2							
Without	0.0488	1.42x10 <sup>-4</sup>	0.0421	351	570	0.0488	0.0488
1:2	0.0440	5.52x10 <sup>-5</sup>	0.0298	365	565	0.0440	0.0440
1:1	0.0505	8.53x10 <sup>-5</sup>	0.0151	375	555	0.0505	0.0505

Table 3 lists the kinetic parameters, and the results are presented in Figure 3c, showing the relationship between the SPR pyrolysis temperature and  $k$  for the catalyst-to-SPR ratios of 1:1 and 1:2 in Zones 1 and 2. Both with and without the catalyst, at a heating rate of 20°C/min in Zone 1,  $k$  during the pyrolysis is relatively low (0.021248–0.212346 sec<sup>-1</sup>), about one-third of that at a heating rate of 40°C/min (0.0759–0.6797 sec<sup>-1</sup>) (Jamilatun et al., 2017a). The value of  $k$  with the catalyst is slightly lower (0.021248–0.175527 sec<sup>-1</sup>) than that without the catalyst (0.031980–0.212346 sec<sup>-1</sup>). As for Zone 2, the curves coincide with each other to show the same  $k$  value (0.044000–0.050449 sec<sup>-1</sup>), which is not affected by temperature rise. Due to the influence of  $A$ , this value seems to be low (0.0440–0.0505 sec<sup>-1</sup>). The small amount of  $k$  in Zone 2 indicates that mass transfer had begun to take effect. As observed, the presence of catalysts causes a reduction in  $E_a$ .



However, its reaction rate decreases due to the lower value of  $k$ , contributed by the decline of  $A$ . Such phenomena may indicate a reduction of the molecular collision because it is hindered by the presence of the catalyst.

#### 4. Conclusions

This study evaluated TG-DTG analyses as a feasible method for determining SPR pyrolysis characteristics. The release of volatile matter, seen in the DTG curve as a sharp peak, was observed in non-catalytic pyrolysis. In contrast, volatile matter release was relatively similar in the presence of the catalyst. Based on TG-DTG data, the presence of catalyst was able to reduce the pyrolysis time and temperature range, with observed data of 230–570°C (15.10 min); 230–565°C (15.07 min), and 230–555°C (14.68 min) for the cases of no catalyst, catalyst-to-SPR weight ratio of 1:2, and catalyst-to-SPR weight ratio of 1:1, respectively. In the same case sequence, the kinetic study reported the reduction of activation energy in Zone 1 as 41.10, 40.77, and 39.46 kJ/mol. However, the pre-exponential factor supports also appeared lower, at 593.30, 406.31, and 266.37. The reduction of activation energy due to the use of the catalyst is not in line with the increase of  $k$  due to the quite low pre-exponential factor. However, the rate in Zone 2 was not significantly affected because the values of the kinetic parameters were rather small and relatively similar to one another, in the range of  $8.53 \times 10^{-5}$ – $1.42 \times 10^{-4}$  kJ/mol and 0.0505–0.0488 for each activation energy and pre-exponential factor, respectively.

#### Acknowledgements

The authors are very grateful to the Ministry of Research and Technology/National Agency for Research and Innovation of the Republic of Indonesia for financial support.

#### References

- Agrawal, A., Chakraborty, S., 2013. A Kinetic Study of Pyrolysis and Combustion of Microalgae *Chlorella vulgaris* using Thermo-Gravimetric Analysis. *Bioresource Technology*, Volume 128, pp. 72–80
- Aho, A., DeMartini, N., Pranovich, A., Krogell, J., Kumar, N., Eränen, K., Holmbom, B., Salmi, T., Hupa, M., Murzin, D.Y., 2013. Pyrolysis of Pine and Gasification of Pine Chars–Influence of Organically Bound Metals. *Bioresource Technology*, Volume 128, pp. 22–29
- Anggorowati, H., Jamilatun, S., Cahyono, R.B., Budiman, A., 2018. Effect of Hydrochloric Acid Concentration on the Conversion of Sugarcane Bagasse to Levulinic Acid. *In: IOP Conference Series: Materials Science and Engineering*, Volume 299, pp 1–6
- Bui, H-H., Tran, K-Q., Chen, W-H., 2016. Pyrolysis of Microalgae Residues–A Kinetic Study. *Bioresource Technology*, Volume 19, pp. 362–366
- Busca, G., 2019. *Silica-Alumina Catalytic Materials: A Critical Review*. Catalysis Today, In Press, Corrected Proof
- de Wild, P.J., Reith, H., Heeres, E., 2011. Biomass Pyrolysis for Chemicals. *Biofuels*, Volume 2(2), pp. 185–208
- Jamilatun, S., Budiman, A., Budhijanto, B., Rochmadi, R., 2017a. Non-Catalytic Slow Pyrolysis of *Spirulina platensis* Residue for Production of Liquid Biofuel. *International Journal of Renewable Energy Research*, Volume 7(4), pp. 1901–1908
- Jamilatun, S., Budhijanto, B., Rochmadi, R., Budiman, A., 2017b. Thermal Decomposition and Kinetic Studies of Pyrolysis of *Spirulina platensis* Residue. *International Journal of Renewable Energy Development*, Volume 6(3), pp. 193–201
- Jamilatun, S., Budhijanto, B., Rochmadi, R., Yuliestyan, A., Budiman, A., 2019a. Effect of Grain

- Size, Temperature and Catalyst Amount on Pyrolysis Products of *Spirulina platensis* Residue (SPR). *International Journal of Technology*, Volume 10(3), pp. 541–550
- Jamilatun, S., Budhijanto, B., Rochmadi, R., Yuliestyan, A., Budiman, A., 2019b. Valuable Chemicals Derived from Pyrolysis Liquid Products of *Spirulina platensis* Residue. *Indonesian Journal of Chemistry*, Volume 19(3), pp. 703–711
- Jamilatun S., Budiman, A., Anggorowati, H., Yuliestyan, A., Surya Pradana, Y., Budhijanto, B., Rochmadi, R., 2019c. Ex-Situ Catalytic Upgrading of *Spirulina platensis* Residue Oil using Silica Alumina Catalyst. *International Journal of Renewable Energy Research*. Volume 9(4), pp. 1733–1740
- Kim, S-S., Ly, H.V., Kim, J., Choi, J.H., Woo, H.C., 2013. Thermogravimetric Characteristics and Pyrolysis Kinetics of Alga *Sagarssum* sp. Biomass. *Bioresource Technology*, Volume 139, pp. 242–248
- Kassim, M.A., Kirtania, K., de la Cruz, D., Cura, N., Srivatsa, S.C., Bhattacharya, S., 2014. Thermogravimetric Analysis and Kinetic Characterization of Lipid-Extracted *Tetraselmis suecica* and *Chlorella* sp. *Algal Research*, Volume 6(Part A), pp. 39–45
- Kusrini, E., Supramono, D., Degirmenci, V., Pranata, S., Bawono, A.A., Ani, F.N., 2018. Improving the Quality of Pyrolysis Oil from Co-firing High-Density Polyethylene Plastic Waste and Palm Empty Fruit Bunches. *International Journal of Technology*, Volume 9(7), pp. 1498–1508
- Li, L., Zhao, N., Fu, X., Shao, M., Qin, S., 2013. Thermogravimetric and Kinetic Analysis of *Spirulina* Wastes under Nitrogen and Air Atmospheres. *Bioresource Technology*, Volume 140, pp. 152–157
- Marriott, A.S., Hunt, A.J., Bergström, E., Thomas-Oates, J., Clark, J.H., 2016. Effect of Rate of Pyrolysis on the Textural Properties of Naturally Templated Porous Carbons from Alginic Acid. *Journal of Analytical and Applied Pyrolysis*, Volume 121, pp. 62–66
- Quan, C., Gao, N., Song, Q., 2016. Pyrolysis of Biomass Components in a TGA and a Fixed-Bed Reactor: Thermochemical Behaviors, Kinetics, and Product Characterization. *Journal of Analytical and Applied Pyrolysis*, Volume 121, pp. 84–92
- Purwanto, W.W., Supramono, D., Muthia, R., Firdaus, M.F., 2015. Effect of Biomass Types on Bio-Oil Characteristics in a Catalytic Fast Pyrolysis Process with a Ni/ZSM-5 Catalyst, *International Journal of Technology*, Volume 6(7), pp. 1069–1075
- Pradana, Y.S, Masruri, W., Azmi, F.A, Suyono, E.A., Sudibyoy, H., Rochmadi, R., 2018. Extractive-Transesterification of Microalgae *Arthrospira* sp. using Methanol-Hexane Mixture as Solvent. *International Journal of Renewable Energy Research*, Volume 8(3), pp. 1499–1507
- Supramono, D., Devina, Y.M., Tristantini, D., 2015. Effect of Heating Rate of Torrefaction of Sugarcane Bagasse on Its Physical Characteristics. *International Journal of Technology*, Volume 6(7), pp. 1084–1093
- Sunarno, S., Rochmadi, R., Mulyono, P., Aziz, M., Budiman, A., 2018. Kinetic Study of Catalytic Cracking of Bio-Oil over Silica-Alumina Catalyst. *BioResources*, Volume 13(1), pp. 1917–1929