

International Journal of Renewable **Energy Research-IJRER**

HOME ABOUT LOGIN REGISTER ARCHIVES ANNOUNCEMENTS

SEARCH CURRENT USER

Home > Vol 12, No 2 (2022)

International Journal of Renewable Energy Research (IJRER)

..........

The International Journal of Renewable Energy Research (IJRER) is not a for profit organization. IJRER is a quarterly published, open source journal and operates an online submission with the peer review system allowing authors to submit articles online and track their progress via its web interface. IJRER accepts the DOAJ's definition of open access. In addition; IJRER publication ethics and publication malpractice statement is mainly based on the Code of Conduct and Best-Practice Guidelines for Journal Editors (Committee on Publication Ethics (COPE), 2011)

IJRER seeks to promote and disseminate knowledge of the various topics and technologies of renewable (green) energy resources. The journal aims to present to the international community important results of work in the fields of renewable energy research, development, application, or design. The journal also aims to help researchers, scientists, manufacturers, institutions, world agencies, societies, etc. to keep up with new developments in theory and applications and to provide alternative energy solutions to current issues such as the greenhouse effect, sustainable and clean energy issues.

The IJRER journal aims for a publication speed of 90 days from submission until final publication. IJRER uses the LOCKSS archival system and cited in Google Scholar, EBSCO, SCOPUS, and WEB of Science (Clarivate Analytics), CrossRef.

The coverage of IJRER includes the following areas, but not limited to:

- Green (Renewable) Energy Sources and Systems (GESSs) as Wind power, Hydropower, Solar Energy, Biomass, Biofuel, Geothermal Energy, Wave Energy, Tidal energy, Hydrogen & Fuel Cells, Li-ion Batteries, Capacitors
- New Trends and Technologies for GESSs
- Policies and strategies for GESSs
- Production of Energy Using Green Energy Sources
- Applications for GESSs
- Energy Transformation from Green Energy System to Grid
- Novel Energy Conversion Studies for GESSs
- Driving Circuits for Green Energy Systems Control Techniques for Green Energy Systems
- Grid Interactive Systems Used in Hybrid Green Energy Systems
- Performance Analysis of Renewable Energy Systems
- Hybrid GESSs
- Renewable Energy Research and Applications for Industries
- GESSs for Electrical Vehicles and Components
- Artificial Intelligence Studies in Renewable Energy Systems
- Computational Methods for GESSs
- Machine Learning for Renewable Energy Applications
- GESS Design
- Energy Savings Sustainable and Clean Energy Issues
- Public Awareness and Education for Renewable Energy
- Future Directions for GESSs
- Thermoelectric Energy

Click Here for Author Guidelines

Click Here for Template for Peer Review Papers

Click Here for Template for Accepted Papers



NOTIFICATIONS

View

Subscribe

JOURNAL CONTENT



Browse

By Issue

By Author

By Title

FONT SIZE

INFORMATION

For Readers

For Authors

For Librarians

Journal Help

Online ISSN: 1309-0127

Publisher: Gazi University

International Journal of Renewable Energy Research (IJRER)

IJRER is cited in SCOPUS, EBSCO, WEB of SCIENCE (Clarivate Analytics);

IJRER has been cited in Emerging Sources Citation Index from 2016 in web of science. WEB of SCIENCE between 2019-2021;

h=27.

Average citation per item=5.19

Impact Factor=(1409+1606+1660)/(204+189+170)=8.3

Announcements

Citation of IJRER in WoS

Posted: 2022-06-12

Citation of IJRER in SCOPUS

Posted: 2022-06-12

CiteScore of IJRER in SCOPUS

Quartile: Q2

Posted: 2022-03-07

Aim of IJRER

The *International Journal of Renewable Energy Research* (IJRER) seeks to promot journal aims to present to the international community important results of work researchers, scientists, manufacturers, institutions, world agencies, societies, etc. current issues such as the greenhouse effect, sustainable and clean energy issues

Posted: 2021-08-12

www.icSmartGrid.org, June 27-29, 2022, istanbul/Turkey

10th International IEEE Conference on Smart Grid, icSmartGrid, is going to be org

Posted: 2022-06-11

Statistics of IJRER in 2020

Statistics

Year	$\leq 2021 \geq >$
Issues published	4
Items published	188
Total submissions	611
Peer reviewed	601
Accept	191 (32%)
Decline	410 (68%)
Days to review	15
Days to publication	98
Registered users	12974 (1171 new)
Registered readers	10753 (985 new)
Online ISSN: 1309-0127	

www.ijrer.org ijrereditor@gmail.com; ilhcol@gmail.com; IJRER is cited in SCOPUS, EBSCO, WEB of SCIENCE (Clarivate Analytics)

Posted: 2022-06-12

www.icrera.org, September 26-29, 2021, Ankara/Turkey

10th International Conference on Renewable Energy Research and Application is $\underline{\varsigma}$

Posted: 2020-12-28

IJRER SCOPUS RECORD 2019-2021

CiteScore Highest percentile

International Journal of	:	98.0%
Renewable Energy	3,7	98/235
Research		Energy Engineering and Power Technolc

Posted: 2021-06-04

Source title

IJRER Citation in SCOPUS-2017-2020

2017			2018			
Cite score	SJR	SNIP	Cite score	SJR	SNIP	Cite score
0.94	0.262	0.675	3.4	0.315	0.899	4.4

Posted: 2020-06-06

More Announcements...

Vol 12, No 2 (2022): June

Table of Contents

Articles

Random search optimization algorithm based control of supercapacitor integrated with solar photovoltaic system under climate conditions	PDF 611-622
<u>Techno-Enviro-Economic Evaluation for Hybrid Energy System</u> <u>Considering Demand Side Management</u> T.M. Tawfik, M.A. Badr, O.E. Abdellatif, H.M. Zakaria, M. EL- Bayoumi	<u>PDF</u> 623-635
Decentralized Adaptive-Virtual-Impedance-Based Predictive Power for Mismatched Feeders in Islanded Microgrids shamsul aizam zulkifli, Mubashir Hayat Khan, Ronald Jackson, Elhassan Garba, Nadia Zeb	<u>PDF</u> 636-645
IMPACT OF SMALL-SCALE GEOTHERMAL POWER PLANT REPLENISHMENT WITH A LIFE CYCLE ASSESSMENT Aron Pangihutan Christian Tampubolon, Hadiyanto Hadiyanto, Endang Kusdiyantini	<u>PDF</u> 646-658
High Gain Boost Converter Fed Single-Phase Sine Pulse Width Modulated Inverter Ramanjaneya Reddy Udumula, Phani Sri Rahul Kotana, Hima Bindu SK, Srikanth Goud B	<u>PDF</u> 659-666
Analysis and Design of a Special Type Power Transformer Used in Solar Power Plants Emir Yükselen, Ires Iskender	<u>PDF</u> 667-673
A Simple Hysteresis Control Strategy in Voltage Regulated Three Phase Four Wire System for Photovoltaic Application Leonardus Heru Pratomo, Sandy Pratama Poetra, Slamet Riyadi	<u>PDF</u> 674-684
Flexible Dynamic Sun-Tracking System (STS) Employing Machine Vision Control Approach Franch Maverick Arellano Lorilla, Renyl Barroca	<u>PDF</u> 685-691
<u>Classification of Solar Variability Using K-Means Method for The</u> <u>Evaluation of Solar Photovoltaic Systems Performance</u> Sara Ragab Mahmoud Farghaly, Chin Kim Gan	PDF 692-702
<u>Impact of incremental piecewise linear cost/benefit functions on</u> <u>DC-OPF based deregulated electricity markets</u> Abdelmadjid Arab, Fatiha Lakdja, Yamina Ahlem Gherbi, Fatima Zohra Gherbi	PDF 703-711
<u>A Comparative Performance Evaluation of Ternary ZnxCd1-xS</u> and Binary CdS window Layer in CIGS Solar Cell SAZNIN AKTER LAMIA, E.M.K Ikball Ahamed, Piyas Chowdhury, Ahsan Habib	<u>PDF</u> 712-720
Effect of Design Parameter Variation on Flat Plate Solar Collector Efficiency Using Nano Working Fluids Talib Onimisi Ahmadu, Muideen Bolarinwa Balogun, Hamisu Adamu Dandajeh	<u>PDF</u> 721-729
Energy management of Renewable Energy Sources based on Support Vector Machine Ehab Issa, Mohamed Al-Gazzar, Mohammed Seif	<u>PDF</u> 730-740

International Journal of Renewable Energy Research (IJRER)

<u>Mathematical Development of Duty Cycles Computing to Four</u> <u>Switches 2?-Inverter Advanced SVM for TPIM Drive</u> Intissar Moussa, Adel Khedher	<u>PDF</u> 741-747
Equatorial solar tracker control using MPPT technique Hicham Bouzakri, Ahmed Abbou, Zakaria Abousserhane, Rafika El Idrissi	<u>PDF</u> 748-758
Assessing Techno-Economic Value of Battery Energy Storage with Grid-Connected Solar PV Compensation Schemes for Malaysian Commercial Prosumers Nur Iqtiyani Ilham, Nofri Yenita Dahlan, Mohamad Zhafran	<u>PDF</u> 759-767
Hussin An Extensive Review on Fault Detection and Fault-tolerant Control of Multilevel Inverter with Applications Siva Priya A, KALAIARASI Nallathambi	<u>PDF</u> 768-798
<u>A Review of Control Strategies and Metaheuristic Algorithms</u> <u>Used in DC Microgrids</u> Erdal IRMAK, Izviye Fatimanur Tepe	PDF 799-818
Local and Central Control of a Wind Farm for Active Power Adjustment Abdelkarim Masmoudi, Achraf ABDELKAFI, Lotfi Krichen, Abdelaziz Salah Saidi	PDF 819-826
A brief study on the influence of the index of revolution on the performance of Gorlov Helical Turbine V. Jayaram, B. Bavanish	<u>PDF</u> 827-845
Maximum Power Point Tracking for Permanent Magnet Synchronous Generator based Wind Park Application Ch Rami Reddy, R. B. R. Prakash, P. Srinivasa Varma, M. Dilip Kumar, A. Giri Prasad, E. Shiva Prasad	<u>PDF</u> 846-862
EXPERIMENTAL COMPARATIVE STUDY MPPT BETWEEN P&O AND SLIDING CONTROL OF A SMALL PV SYSTEM Seddik BENHADOUGA, Abdelhakim BELKAID, Rida FARHAN, ilhami COLAK, Mounir MEDDAD, Adil Eddiaif	PDF 863-869
Decentralized Hybrid Fuzzy-Sliding Mode Control of Multi- machine Power System Seddik BENHADOUGA, Abdelhakim BELKAID, ilhami COLAK, Djamel BOUKHETALA, Farès BOUDJEMA, Mounir MEDDAD, Riad KHENFER, Adil Eddiaid	<u>PDF</u> 870-879
Real-time FPGA based simulator enabled Hardware-In-the-Loop for fuzzy control dual-sources HESS HATIM JBARI, Rachid Askour, Badr Bououlid Idrissi	<u>PDF</u> 880-891
Facile Synthesis of Copper Iodide at Low Temperature as Hole Transporting Layer for Perovskite Solar Cell Omsri Vinasha Aliyaselvam, Faiz Arith, Ing Jia Rong, Shahril Izuan Zin, Fara Ashikin Ali, Ahmad Nizamuddin Mustafa	<u>PDF</u> 892-898
Comparing the Global Warming Impact from Wind, Solar Energy and Other Electricity Generating Systems through Life Cycle Assessment Methods (A Survey) Abdullah Marashli, AlMothana Gasaymeh, Mohammad Shalby	<u>PDF</u> 899-920
Risk Based Day-ahead Energy Resource Management with Renewables via Computational Intelligence PRATIK KANTILAL MOCHI, Kartik S. Pandya, Dharmesh Dabhi, Vipul Rajput	PDF 921-929
Experimental and Numerical analysis of VCR diesel engine fuelled with Blends of Jatropha Curcas Methyl Esters S. N. Nagesh	<u>PDF</u> 930-941
Decentralized Optimal Dispatch of Reactive Power Sources in Power Systems Based on Augmented Lagrangian Method Minh Hoa Nguyen, Nhut Tien Nguyen, Van Hoan Pham	<u>PDF</u> 942-949
<u>Cross-validation of the operation of photovoltaic systems</u> <u>connected to the grid in extreme conditions of the highlands</u> <u>above 3800 meters above sea level.</u> Saul Huaquipaco Encinas, Wilson Negrão Macêdo, Henry Pizarro, Reynaldo Condori, Jose Manuel Ramos, Oscar Vera, Jose Emmanuel Cruz, Wilson Mamani, Norman Beltran	<u>PDF</u> 950-959
Improvement of Power Quality in grid Integrated Smart grid using Fractional-order Fuzzy Logic Controller DHARAMALLA CHANDRA SEKHAR, PVV Rama Rao, R. Kiranmayi	<u>PDF</u> 960-969
Optimal Placement of Charging Station and Distributed Generator along with Scheduling in Distribution System using Arithmetic Optimization Algorithm Naresh Kumar Golla, SURESH KUMAR SUDABATTULA, Velamuri Suresh	<u>PDF</u> 970-980
<u>Comprehensive Evaluation of Materials for Small Wind Turbine</u> <u>Blades Using Various MCDM Techniques</u> Ravindra K. Garmode, Vivek R. Gaval, Sandip A. Kale, Sanjay D. Nikhade	<u>PDF</u> 981-992
Experimental Study of Modified Absorber Plate Integrated with Aluminium Foam of Solar Water Heating System	<u>PDF</u> 993-999

Muhammad Hasan Basri, jalaluddin Haddada, Rustan Tarakka, Muhammad Syahid, M. Anis Ilahi Ramadhani	
<u>Power Tracking Capability Enhancement of a Grid-Tied Partially</u> <u>Shaded Photovoltaic System Through MPC Based Maximum</u> <u>Power Point Technique</u> Subhashree Choudhury, Jiban Ballav Sahu, Byamakesh Nayak	PDF 1000-1012
Grid-connected PV System with a modified-Neural Network Control Abderrahmane ELHOR, Orlando Soares	PDF 1013-1022
<u>Combustion Characteristics of a Biomass-Biomass Co-combustion</u> <u>using Thermogravimetric Analysis</u> Pichet Ninduangdee, Porametr Arromdee, Arkom Palamanit, Kittinun Boonrod, Suriya Prasomthong	PDF 1023-1031
Performance assessment of newly designed solar water treatment system Krishna Kumar Sinha, Mukesh Kumar Gupta, Rahul Kumar, M. K. Banerjee	PDF 1032-1040
Comparison of photovoltaic production forecasting methods mohamed hamza kermia, Jérôme Bosche, Dhaker Abbes	<u>PDF</u> 1041-1051
Coordinated IPFC and SMES Strategy for Stability Analysis of Renewable Energy Based Contemporary Interconnected Power System with FOPID Controller Dr. SRIKANTH GOUD, Ch Nagasai Kalyan, S Rajasekaran, G Swapna, A.N Venkateswarlu, Ch Rami Reddy	PDF 1052-1062
The environmental and economic benefits of a hybrid renewable energy system considering demand side management T.M. Tawfik, M.A Badr, O.E. Abdellatif, H.M. Zakaria, M. EL- Bayoumi	PDF 1063-1075
Renewable Energy Resources in Bangladesh: Prospects, Challenges and Policy Implications Abu Yousuf, Md Shahadat Hossain, Md. Anisur Rahman, Ahasanul Karim, Ashiqur Rahman	<u>PDF</u> 1076-1096
Solution of Profit Based Unit Commitment Including Wind Energy Using Improved Shuffled Frog Leaping Algorithm Mary Anita, Roma Raina, Jacob Raglend	PDF 1097-1104
<u>Real-Time Implementation of Energy Management for</u> <u>Photovoltaic/Battery/Diesel Hybrid System Based on LabVIEW</u> Doaa Mohamed Atia, Hanaa Tolba El-Madany, Yousry Atia, Mohamed zahran	PDF 1105-1116
A Qualitative Investigation on Multiport Converters for Renewable Energy Sourced DC Loads M. R. Faridha Banu, R. Jayapragash	<u>PDF</u> 1117-1130
Energy Security: Multidimensional Analysis for South American Countries Dhevbi Cervan, Christian V. Rodriguez, Carlos Inga E.	PDF 1131-1139
Effect of Data Transformation on the Diagnostic Accuracy of Transformer Faults and the Performance of the Supervised Classifiers Sherif S. M. Ghoneim, Ibrahim B. M. Taha, Rizk Fahim, Saad A. Mohamed Abdelwahab	PDF 1140-1150
Design of Hybrid Controller for Voltage Profile Enhancement at Battery Energy Storage System Terminal of Solid State Transformer Based Charging of Electric Vehicles Dinakar Yeddu, Loveswara Rao Burthi	PDF 1151-1163
<u>The Study of Aerodynamics and productivity of the Savonius</u> <u>Rotor with Supplementary Blades</u> Mohanad Al-Ghriybah, Ismail Hdaib, Zakaria Anas Al-Omari, Yaseen Al-Husban	PDF 1167-1175
Power loss analysis of Traditional PV array Configurations under different shading conditions B. s. s. Santosh, M. Mohamed Thameem Ansari, P. Kantarao, G. Kusuma	PDF 1176-1203

Online ISSN: 1309-0127

Publisher: Gazi University

IJRER is cited in SCOPUS, EBSCO, WEB of SCIENCE (Clarivate Analytics);

 $\ensuremath{\text{IJRER}}$ has been cited in Emerging Sources Citation Index from 2016 in web of science.

WEB of SCIENCE between 2019-2021;

h=27,

Average citation per item=5.19

Impact Factor=(1409+1606+1660)/(204+189+170)=8.3



International Journal of Renewable Energy Research-IJRER

HOME ABOUT LOGIN REGISTER SEARCH CURRENT ARCHIVES ANNOUNCEMENTS	USER Username <mark>1siti_jamilatun1</mark>
Home > About the Journal > Editorial Team	Password ••••••••••••••••••••••••••••••••••••
Editorial Team	Login
Editor in Chief Prof. Dr. Ilhami COLAK, Gazi University, Editor-in-Chief, IJRER, Turkey	NOTIFICATIONS <u>View</u> <u>Subscribe</u>
Associate Editors	JOURNAL CONTENT
Professor Mamadou Lamine Doumbia, University of Quebec at Trois-Rivieres, Canada Prof. Dr. Constantin FILOTE, Stefan cel Mare University, Romania Professor Jaeho Choi, Chungbuk National University, Republic of Korea Professor Tadashi Suetsugu, Japan Professor Tadashi Suetsugu, Japan Professor Nobumasa Matsui, Nagasaki Institute of Applied Science, Japan Professor Erdal Irmak, Gazi University, Turkey Associate Prof. Abdelhakim BELKAID, Bordj Bou Arreridj University, Algeria Prof. Dr. Ersan Kabalci, Nevsehir University, Turkey Associate Prof. Dr. Hamdi Tolga Kahraman, Karadeniz Technical University, Turkey Assoc. Prof. Dr. Hidenori Maruta, Nagasaki University, Japan Assoc. Prof. Dr. Mehmet Yesilbudak, Nevsehir Haci Bektas Veli University, Turkey Dr. Robert M. Cuzner, University, Turkey	Search Search Scope All ✓ Search Browse • <u>By Issue</u> • <u>By Author</u> • <u>By Title</u> FONT SIZE
<u>Dr. Hiroo Sekiya</u> , Chiba University, Japan <u>Dr. Fabio Viola</u> , Università degli Studi di Palermo, Italy <u>Dr. Toshiyuki Zaitsu</u> , Technology Omron Co., Japan <u>Dr. Onder Eyecioglu</u> , Bolu Abant Izzet Baysal University, Turkey <u>Dr. Massimo Caruso</u> , Università degli Studi di Palermo <u>Dr. Abdou Tankari Mahamadou</u> , CERTES Laboratory - IUT of Creteil University of Creteil, France <u>Dr. Eklas Hossain</u> , Oregon Tech, United States <u>Dr. Natarajan Prabaharan</u> , SASTRA Deemed University, India <u>Dr. Nahla Bouaziz</u> , University of Tunis El Manar, Tunisia	INFORMATION • For Readers • For Authors • For Librarians Journal Help
Layout Editors	

Associate Prof. Dr. Hamdi Tolga Kahraman, Karadeniz Technical University, Turkey Mr. Abdul Quader Munshi, Bangladesh Mr Vishal Charan, Fiji national university, Fiji Miss Ayse Colak, University of Cardiff, United Kingdom Dr. Natarajan Prabaharan, SASTRA Deemed University, India

Copyeditors

<u>Mr. Fatih ISSI</u>, Cankiri Karatekin University, Turkey <u>Dr. Catalin Felix Covrig</u>, Netherlands <u>Mr. Naki Guler</u>, Gazi University, Turkey <u>Mr Vishal Charan</u>, Fiji national university, Fiji <u>Mr. MD Rishad Ahmad</u>, The University of Manchester, United Kingdom <u>Miss Ayse Colak</u>, University of Cardiff, United Kingdom <u>Dr. Natarajan Prabaharan</u>, SASTRA Deemed University, India

Proofreader

<u>Assoc. Prof. Dr. Mehmet Yesilbudak</u>, Nevsehir Haci Bektas Veli University, Turkey <u>Mr Vishal Charan</u>, Fiji national university, Fiji <u>Miss Ayse Colak</u>, University of Cardiff, United Kingdom <u>Dr. Natarajan Prabaharan</u>, SASTRA Deemed University, India

Online ISSN: 1309-0127

Publisher: Gazi University

IJRER is cited in SCOPUS, EBSCO, WEB of SCIENCE (Clarivate Analytics);

IJRER has been cited in Emerging Sources Citation Index from 2016 in web of science.

Editorial Team

h=27,

Average citation per item=5.19

WEB of SCIENCE between 2019-2021;

Impact Factor=(1409+1606+1660)/(204+189+170)=8.3



International Journal of Renewable Energy Research-IJRER

HOME ABOUT USER HOME SEARCH CURRENT ARCHIVES ANNOUNCEMENTS		USER You are logged in as
Home > Archives > Vol 10, No 4 (2020)		<pre>1siti_jamilatun1</pre>
Vol 10, No 4 (2020)		• <u>Log Out</u>
December		NOTIFICATIONS
		 <u>View</u> (72 new) <u>Manage</u>
DOI: <u>https://doi.org/10.20508/ijrer.v10i4</u>		
Table of Contents		CONTENT Search
Articles		Search Scope
Assessment of Series Resistance Components of a Solar PV Module Depending on Its Temperature Under Real Operating	<u>PDF</u> 1554-1565	All V
<u>Conditions</u> Said Bounouar, Rachid Bendaoud, Houssam Amiry, Bouchaib Zohal, Fatima Chanaa, Elhadi Baghaz, Charaf Hajjaj, Said Yadir, Abdelhaq EL Rhassouli, Mohammadi Benhmida		Browse By Issue By Author By Titlo
Artificial Neural Networks Based Solar Radiation Estimation using Backpropagation Algorithm Amar Choudhary, Deependra Pandey, Saurabh Bhardwaj	<u>PDF</u> 1566-1575	• <u>by nue</u>
Intra-day Variability Quantification from Ground-based Measurements of Global Solar Irradiance Omaima El ALani, Hicham Ghennioui, Abdellatif Ghennioui	<u>PDF</u> 1576-1587	FONT SIZE
Experimental Investigation on the Port Timing of a Compressed Air Engine with Exhaust Predicting Technique Nikhilkumar Jagjivanbhai Chotai, Vivek Patel, Vimal Savsani	PDF 1588-1594	For Readers For Authors For Librarians
Analysis the Impact of Renewable Energy Based-Wind Farms Installed with Electrical Power Generation System on Reliability Assessment Aiman Abdel Kader Tawfiq, Mohamed Abedel-Raouf, Amal Abdel Gawad, Mohamed Farabat	<u>PDF</u> 1595-1607	Journal Help
<u>Techno-economic Analysis of a Hybrid Solar Dryer with a Vacuum</u> <u>Tube Collector for Hibiscus Cannabinus L Fibre</u> Ag Sufiyan Abd Hamid, Adnan Ibrahim, Jalal Assadeg, Emy Zairah Ahmad, Kamaruzzaman Sopian	PDF 1608-1613	
<u>Carbon dioxide capture using Adsorption Technology in Diesel</u> <u>Engines</u> Saravanan Supramani, Ramesh kumar Chidambaram	PDF 1614-1620	
Optimal Energy Management Strategies of a Parallel Hybrid Electric Vehicle Based on Different Offline Optimization Algorithms	PDF 1621-1637	
Marwa Ben Ali, Ghada Boukettaya <u>Design and Simulation of Current Sensor based Electronic Load</u> <u>Controller for Small Scale Three Phase Self Excited Induction</u> <u>Generator System</u> V. Krishna Murali, V Sandeep	<u>PDF</u> 1638-1644	
Awareness of Secondary School Students in Petaling Jaya Malaysia Towards Renewable Energy Hazlee Azil Illias, Nabilah Syuhada Ishak, Nurul Aini Mohd Nor Alam	<u>PDF</u> 1645-1654	
<u>Mathematical Modeling and Aerothermal Simulation of a Small-</u> <u>scale Solar Updraft Power Generator</u> Hadyan Hafizh, Ahmad Fudholi, M. H. Yazdi, Abrar Ridwan	PDF 1655-1663	
Above-ground Biomass Allometric Equation and Dynamics Accumulation of Eucalyptus Camaldulensis and Acacia Hybrid Plantations in Northern Thailand Warakhom Wongchai, Anucha Promwungkwa, Woravit Insuan	PDF 1664-1673	
<u>A Sliding Mode Controller Approach for Three Phase Single Stage</u> Seven Level Multilevel Inverter for Grid Connected Photovoltaic	<u>PDF</u> 1674-1684	

<u>System</u> K. Reddy Rajasekhara, V. Bhaskar Reddy Naga, M. Kumar Vijaya	
<u>A Review on Two-Stage Back End DC-DC Converters in On-Board</u> <u>Battery Charger for Electric Vehicle</u> Dhanalakshmi Ramani, P. Usha Rani, P. Usha Rani	PDF 1685-1695
Optimization and Reliability Evaluation of Hybrid Solar-Wind Energy Systems for Remote Areas Animesh Masih, Dr. H K Verma	1696-1707
Model to Generate Daily and Hourly Solar Radiation Sequences for Tropical Climates Bao The Nguyen, Viet Van Hoang, Hiep Chi Le	PDF 1708-1724
Optimization and Performance Evaluation of Hybrid Renewable System for Minimizing Co2 Emissions in Libya: Case Study Hazim Moria, A M Elbreki, Ahmed M Ahmed, Monaem Elmnifi	<u>PDF</u> 1725-1734
Determination of Wind Potential by Two Components Mixture Probability Distribution Models in the Ankara, TURKEY Selim Gunduz, Tayfun Servi, Ulku Erisoglu, Levent Yalcin	1735-1742
<u>Innovative and Simple PV Generator Procedure to Test PV</u> <u>Inverter According to EN50530 Standard Static MPPT Efficiency</u> Manelle HASNAOUI MILADI, Houda BEN ATTIA SETHOM, Afef BENNANI-BEN ABDELGHANI, Ilhem SLAMA-BELKHODJA	<u>PDF</u> 1743-1754
Assessment of Power Harvesting in Electronic Modules Using Phase Change Material with Null Electricity: An Experimental Study K. Gopi Kannan, R. Kamatchi	PDF 1755-1763
Solar Power Time Series Prediction Using Wavelet Analysis Soufiane Gaizen, Ouafia Fadi, Ahmed Abbou	<u>PDF</u> 1764-1773
<u>Techno-economic Assessement of Hybrid Energy System for a</u> <u>Stand-alone Load in Morocco</u> jamila Elhaini, Abdelmjid SAKA	PDF 1774-1782
Comparison of Performance Evaluation of Grid-Connected PV System for 3D Single Family House Using Building Information Modeling Technology: A Case Study in Elazig, Turkey Abdiljabbar Rafi Homood, Salih Habib Najib Albarazanch, Sami Ekici, Betul Bektas Ekici	<u>PDF</u> 1783-1792
Prioritization of Decentralized Renewable Energy Technologies for Rural Areas of Bundelkhand Region, India Using Analytical Hierarchy Process (AHP) Sudeep Yadav, Gaurav Srivastava, Priyanka Yadav, Balendu Shekhar Giri	<u>PDF</u> 1793-1801
Renewable Energy Assisted High Temperature Heating System for Plastic to Fuel Conversion Unit K. R. Bharath, Sarada Balaram	PDF 1802-1809
<u>Cascaded Multilevel Inverter for PV-Active Power Filter</u> <u>Combination into the Grid-Tied Solar System</u> Mariem Tayari, Abdessettar Guermazi, Moez Ghariani	PDF 1810-1819
<u>Non-catalytic and Catalytic Pyrolysis of Spirulina Platensis</u> <u>Residues (SPR) in Fixed-Bed Reactors: Characteristic and Kinetic</u> <u>Study with Primary and Secondary Tar Cracking Models</u> Siti jamilatun, Endah Sulistiawati, Shinta Amelia, Arief Budiman	PDF 1820-1828
An Optimal Energy Management of Grid-Connected Residential Photovoltaic-Wind-Battery System under Step-rate and Time-of- Use Tariffs Merveme Azaroual, Mohammed Ouassaid, Mohamed Maaroufi	PDF 1829-1843
Smart Management in the Modernization of Intelligent Grid Incorporating with Distribution Generation: A Systematic Scrutiny HONEY BABY 1 Javakumar	<u>PDF</u> 1844-1856
<u>Day-Ahead Energy Management for Isolated Microgrids</u> <u>Considering Reactive Power Capabilities of Distributed Energy</u> <u>Resources and Reactive Power Costs</u> Shady Mamdouh Sadek, Walid Atef Omran, Mohamed Ahmed Moustafa, Hossam Eldin Abdallah Talaat	<u>PDF</u> 1857-1868
Design of a Novel Converter Between Li-Ion Battery and Supercapacitor to Feed SAR Loads for Satellite Applications Gencer Tulay, Ires Iskender	PDF 1869-1878
Economic Valuation of Electrical Wind Energy in Egypt Based on Levelized Cost of Energy Montaser Abd El Sattar, Wessam Arafa Hafez, Adel A. Elbaset, Ali H. Kasem Alaboudy	<u>PDF</u> 1879-1891
Predict the Decay of the Thermal Performance of Solar Parabolic Trough Concentrators Due to Dust Accumulation Mohamed Hassan Ahmed	<u>PDF</u> 1892-1898
Local Volt/var Droop Control Strategies for Wind Generators in Distribution Networks Minh Hoa Nguyen, Van Hoan Pham	PDF 1899-1906

7/2/22, 3:11 PM	Vol 10, No 4 (2020))
	Assessment and Damping of Low Frequency Oscillations in Hybrid Power System Due to Random Renewable Penetrations by Optimal FACTS Controllers Narayan Nahak, Sankalpa Bohidar, Ranjan Kumar Mallick	<u>PDF</u> 1907-1918
	<u>The Rotating Speed Set of Wind Turbine Using the Pendulum as</u> <u>an Angle Blades Control</u> Y. Yulianto, Agus Pracoyo, Bambang Priyadi	<u>PDF</u> 1919-1926
	Dynamic Frequency Tracking for Voltage and Frequency Regulation of Wind Driven Doubly Fed Induction Generator in Standalone mode S. R. Mohanrajan, A. Vijayakumari, K. Kottayail Sasi	<u>PDF</u> 1927-1939
	<u>A Proposed Passive Islanding Detection Approach for Improving</u> <u>Protection Systems</u> Mohamed Ahmed Dawoud, Doaa Khalil Ibrahim, Mahmoud Ibrahim Gilany, Aboulfotouh El'Garably	PDF 1940-1950
	Control of Grid Frequency under Unscheduled Load Variations: A Two Layer Energy Management Controller in Urban Green Buildings S.N.V. Bramareswara Rao, Kottala Padma	PDF 1951-1961
	<u>A Novel Hybrid Maximum Power Point Tracking Technique With</u> <u>Zero Oscillation Based On P&O Algorithm</u> P. E SARIKA, Josephkutty Jacob, Sheik Mohammed, Shiny Paul	<u>PDF</u> 1962-1973
	Enhancing the Energy Utilization of Hybrid Renewable Energy Systems Yasser E Elsayed, Naggar H. Saad, Abdalhalim Zekry	<u>PDF</u> 1974-1987
	Minimization of Power Losses with Different Types of DGs Using <u>CSA</u> Anand Kumar Pandey, K. S. Sujatha, Sheeraz Kirmani	<u>PDF</u> 1988-1999
	Performance Optimization of ZnS/CIGS Solar Cell with over 25% Efficiency Enabled by Using a CuIn3Se5 OVC Layer Abu Kowsar, Md. Billal Hosen, Md. Karamot Ali, Md.	<u>PDF</u> 2000-2005

Asaduzzaman, Ali Newaz Bahar

Online ISSN: 1309-0127

Publisher: Gazi University

IJRER is cited in SCOPUS, EBSCO, WEB of SCIENCE (Clarivate Analytics);

 $\ensuremath{\text{IJRER}}$ has been cited in Emerging Sources Citation Index from 2016 in web of science.

WEB of SCIENCE between 2019-2021;

h=27,

Average citation per item=5.19

Impact Factor=(1409+1606+1660)/(204+189+170)=8.3

Non-catalytic and Catalytic Pyrolysis of *Spirulina platensis* residue (SPR) in Fixed-Bed Reactors: Characteristic and Kinetic Study with Primary and Secondary Tar Cracking Models

Siti Jamilatun*‡, Endah Sulistiawati*, Shinta Amelia*, Arief Budiman**

* Department of Chemical Engineering, Faculty of Industrial Technology, Universitas Ahmad Dahlan, Jl. Ringroad Selatan, Kragilan, Tamanan, Kec. Banguntapan, Bantul, Daerah Istimewa Yogyakarta 55191, Indonesia

** Department of Chemical Engineering, Faculty of Engineering, Universitas Gadjah Mada, Jl. Grafika No. 2, Kampus UGM, Yogyakarta, 55281, Indonesia

(sitijamilatun@che.uad.ac.id, endahsulistiawati@che.uad.ac.id, shinta.amelia@che.uad.ac.id, abudiman@ugm.ac.id)

[‡]Corresponding Author; first author, Tel: +62 0274-563515 ext 4211,

Fax: +62 0274-564604, sitijamilatun@che.uad.ac.id

Received: 04.10.2020 Accepted: 29.10.2020

Abstract- *Spirulina platensis* residue (SPR) pyrolysis can produce tar fuels. The use of a silica-alumina catalyst will improve fuel quality by reducing oxygenate compounds. The kinetics of non-catalytic reactions and SPR catalytic pyrolysis have studied using the primary and secondary cracking model approaches. Data obtained from a fixed-bed reactor at 300-600 ^oC is the weight of tar each time, weight gas, and char gained at the end of the process. A pyrolysis scheme is made to determine the reaction of product formation with primary and secondary cracking models. From the calculation of pyrolysis without catalyst, the activation energy obtained in primary cracking is E₁, E₂, E₃, while for secondary cracking is E₄ and E₅. The optimum condition in primary cracking is E₃. The SPR reaction becomes char (B \rightarrow C(1)) with the lowest activation energy of 15.418 kJ/mol (k₃ in the range of 0.1044-0.0279 sec⁻¹), while for secondary cracking, the tar (1) reaction becomes char (T(1) \rightarrow C(2)) of 15.151 kJ/mol (k₅ in the range 1.80.10⁻⁶-5.48.10⁻⁷sec⁻¹). In pyrolysis with silica-alumina catalyst (10, 20 and 40 wt.%), The more catalyst used, the smaller the E_a, and optimal for primary cracking in the use of catalyst 40 wt.%, .ie., in the decomposition of SPR to char, E₃ of 3.004 kJ/mol (k₃ in the range 0.0616-0.0528 sec⁻¹). For secondary cracking in the use of catalysts 10, 20, and 40 %, E₄ and E₅ are relatively high, i.e., in the range of 40.855-52.085 kJ/mol (k₄ and k₅ in the range 3.89.10⁻⁶-8.40.10⁻⁷sec⁻¹).

Keywords: Spirulina platensis residue; silica-alumina; fixed-bed reactor; primary and secondary cracking models; activation energy.

1. Introduction

Pyrolysis of *Spirulina platensis* residue (SPR) produces tar, gas, and char [1-5]. Until now, pyrolysis technology is still exciting to discuss because of its inexpensive and straightforward technique. Unfortunately, tar products cannot be applied as fuel because the oxygenate compounds are high enough to cause corrosion in engines [6-8]. Therefore it is necessary to find a solution to reduce the content of

oxygenated compounds in tar while knowing the composition of the product yield, one of which is catalytic pyrolysis using silica-alumina in a fixed-bed reactor. The use of silica-alumina can reduce the average O/C ratio from non-catalytic to catalytic pyrolysis SPR by 69.66 %, i.e., from 0.55 to 0.155 [6].

For this reason, it is essential to study the kinetics and the mechanism of the catalytic pyrolysis reaction with silicaalumina for the development of quality fuels. For this reason,

it is crucial to study the kinetics and the mechanism of the catalytic pyrolysis reaction with silica-alumina for the development of quality fuels. The reaction mechanism and cracking modeling are needed to determine each product formation; then, it can predict which product is the most easily formed [9-10]. The ultimate goal is to use the data obtained to design fuel plants from commercial-scale SPR biomass.

Calculation of reaction kinetics determines the activation energy and reaction speed constants generally obtained from Thermogravimetric analysis data [10]. Kinetics study of Chlorella vulgaris pyrolysis calculated by the isoconversional method model by Flynn Wall Ozawa (FWO) and Kissinger Akahira Sunose (KAS) with the catalysts of CaO, MgO, K₂CO₃, BaCO₃, and Na₂CO₃, average activation in the range of 99.60-134.05 kJ/mol from without catalysts 109.7 kJ/mol [11]. Calculations with the Coats-Redfern integral method by Balasundram et al., 2017 [12] with a rice husk catalyst can reduce the activation energy from without a catalyst 49.78 to 45.24 kJ/mol. Spirulina platensis residue pyrolysis kinetics study using Thermogravimetric Analyzer, which was completed with the least-squares method, obtained activation energy (Ea) for each heating rate of 10, 20, 30, 40, and 50 ^oC/min was 35.455, 41.102, 45.702, 47.892 and 47.562 kJ/mol [13].

The study of reaction kinetics by modeling the data obtained from fixed-bed reactors is still small compared to the thermogravimetric analysis. Therefore, the study of reaction kinetics with a fixed-bed reactors database without catalysts and catalysts is needed to obtain the activation energy value and constant reaction speed. Biomass pyrolysis through a series of competitive reactions is involved, while the exact mechanism is still unknown. For this reason, kinetic schemes that are widely applicable still require a more in-depth study [14-20].

This study studies silica-alumina catalysts' effect on the kinetics of the residual *Spirulina platensis* reaction in a fixedbed reactor. Kinetics solution using the primary and secondary cracking model approaches. The reaction mechanism used for the primary and secondary models is explained in Figure 1.

1.1. Secondary tar cracking model

The primary and secondary tar cracking reaction mechanism proposed by Prakash and Karunanti, 2008 [14], is shown in Figure 1.



Figure 1. Primary and Secondary cracking model [14]

1.2. Model formulation

The kinetic scheme in Figure 1 illustrates the thermal decomposition of primary pyrolysis, which is biomass (B) to

gas (G_1) , tar (T), and char (C_1) . Secondary pyrolysis is tar (T_1) decomposed into char (C_2) and gas (G_2) .

This model based on the following assumptions [14-16]:

- 1. The solid is constant and is not affected by temperature.
- 2. Heat transfer takes place by conduction on solids. Thermal conductivity and heat capacity is constant.
- 3. The biomass's pyrolysis speed increases as temperature increases, while the reaction rate constant (k) follows Arrhenius's law.
- The reaction speed is first order, and the reaction is endothermic, with primary and secondary pyrolysis processes.
- 5. There is no temperature gradient at the pore center.
- 6. At r = 0 of solid particles, $[\partial T/\partial r]_{(r=0)}=0$

$$\frac{\partial X_B}{\partial_t} = -(k_1 + k_2 + k_3)X_B \tag{1}$$

$$\frac{\partial X_T}{\partial_t} = k_2 X_B - (k_4 + k_5) X_T \tag{2}$$

$$\frac{\partial X_C}{\partial_t} = k_3 X_B + k_5 X_T \tag{3}$$

$$\frac{\partial X_G}{\partial t} = k_1 X_B + k_4 X_T \tag{4}$$

Pyrolysis is done with isothermal way, so the Arrhenius equation approximates k:

$$k = AEXP\left[\left(\frac{-E}{RT}\right)\right] \tag{5}$$

Notation B, T, C, and G are biomass (SPR), tar, char, and gas. The initial condition for Equation (1-5) is:

$$t = 0, X_B = X_{B0} = 1, X_{C0} = X_{G0} = X_{T0} = 0$$
(6)

The value k of each reaction follows the Arrhenius equation, as in Equation 5. There are four ordinal differential equations (Equations 1-4) that can be solved simultaneously by numerical methods. The obstacle in completing this model is that it cannot separate the biomass and charcoal, and the weight is observed.

Changes in biomass weight in the reactor could not find because the remaining biomass with char that formed each time mixed so that the amount could not observe. The data that can see from experiments is the weight of tar created each time; therefore, the secondary cracking model can complete in the following way.

$$W_{B0} = W_{C end} + W_{T end} + W_{G end} \tag{7}$$

Or in weight fraction,

$$X_{B0} = 1 = X_{T end} + X_{C end} + X_{G end}$$
 (8)

 W_{B0} , $W_{C end}$, $W_{T end}$, and $W_{G end}$ notations are the initial SPR biomass's weight, the final char weight, the final tar weight, and the last gas weight. Each notation is the initial SPR biomass weight fraction, the final char weight fraction, the final tar weight fraction, and the ultimate gas weight fraction.

Values k_1 , k_2 , k_3 , k_4 , and k_5 , are tested to obtain the minimum average error.

$$Error_{rate\ relatif} = \left\{ \sum [(X_G)_{count} - (X_G)_{data}] + \sum [(X_T)_{hitungan} - (X_T)_{data}] + \sum [(X_C)_{hitungan} - (X_C)_{data}] \right\}$$
(9)

The flow of completion from the model can see in Figure 2.



Figure 2. Flow chart of mathematical equation primary and secondary models

2. Methodology

2.1 Materials

Dry *Spirulina platensis* residue (SPR) obtained from solid residue of *Spirulina platensis* (SP) extraction with solvent. The ultimate, proximate, and Higher Heating Value (HHV) analyzed samples from SPR. Laboratorium Pangan dan Hasil Pertanian, Departemen Teknologi Pertanian, and Laboratorium Pangan dan Gizi, Pusat Antar Universitas (PAU) UGM, carried out the proximate analysis. As for the ultimate, it performed at Laboratorium Pengujian, Puslitbang Tekmira, Bandung [4,8,9,13]. The results of sample testing shown in Table 1.

From PT. Pertamina Balongan obtained the silica-alumina catalyst powder. Use of catalyst in pellets made by mixing 95 wt.% silica-alumina with 5 (five) wt.% Kaolin, then adding enough distilled water. The mixture is mixed until homogeneous and then printed with a 4 mm pellet diameter and 6 mm height. Silica alumina pellets dried in the sun for 2 (two) days, and then heating is carried out in a furnace at 500 °C for 2 (two) hours. The Laboratorium Pengujian dan Penelitian Terpadu (LPPT), UGM, conducted the silica-alumina catalyst analyzed by SEM-EDX (Scanning Electron Microscope – Energy Dispersive X-ray) and BET [6-9,20]. The International Frontier Division, Dept. Transdisciplinary

Science and Technology School of Environmental and Society, Tokyo Institute of Technology, Japan carried out X-ray fluorescence (XRF).

2.2. Methods

SPR microalgae pyrolysis experiments carried out with and without catalyst in a fixed-bed reactor made of stainless steel with dimensions: inner diameter = 40 mm, outer width = 44 mm, and height = 600 mm [12-15]. The reactor is equipped with a heater. The tool diagram for the fixed-bed reactor system is presented in Figure 3 [4,6-9].



Figure 3. Series of experimental devices

Fifty (50) g SPR was put into the reactor, tightly closed, and heated. The reactor was heated externally by an electric furnace, and the temperature-controlled by a NiCr-Ni thermocouple placed outside the furnace. The tested sample was heated with a constant heating rate from room temperature to the desired temperature and kept steady for 1 hour. The liquid product is coming out of the condenser collected in an accumulator, and gas production is measured. Liquid products (tar) separated by decantation. After the experiment does, the number of solids (char) left behind was taken and weighed. The total liquid products (bio-oil and water phase), gas, and gas are calculated by the equation [4,6-9,13,15-21]:

$$Y_L = \frac{W_L}{W_M} 100\%$$
 (10)

$$Y_{B0} = \frac{W_{B0}}{W_M} 100\%$$
(11)

$$Y_A = \frac{W_A}{W_M} 100\%$$
 (12)

$$Y_{C} = \frac{W_{C}}{W_{M}} 100\%$$
(13)

$$Y_G = 1 - (Y_L - Y_C)$$
 (14)

In this case, Y_L , Y_{B0} , Y_A , Y_C , and Y_G notations are liquid product yields, bio-oil, water phase, char, and gas. Meanwhile, W_M , W_L , W_A , W_{B0} , and W_C are the initial SPR weight, the liquid product's value, the water phase, bio-oil, and char.

3. Results

3.1. Characteristics of Spirulina platensis residue (SPR)

The result of SPR proximate, ultimate, and HHV analysis of the study results are presented in Table 1.

 Table 1. Characteristics of Spirulina platensis residue
 (SPR)[4].

Component	SPR
Composition analysis (%)	
Lipid	0.09
Carbohydrate	38.51
Protein	49.60
Proximate analysis (%)	
Moisture	9.99
Ash	8.93
Volatiles	68.31
Fixed carbon	12.77
Ultimate analysis (%)	
Sulfur	0.55
Carbon	41.36
Hydrogen	6.60
Nitrogen	7.17
Oxygen	35.33
O/C, the molar ratio	0.64

Based on Table 1 can seem that SPR has a composition; component C is 41.36 wt.%, H is 6.60 wt.%, and N is 7.17 wt.%, O is 35.33 wt.%. Meanwhile, for the proximate analysis, lipid at SPR 0.09 wt.%, carbohydrate is 25.59 wt.%, and protein is 49.60 wt.% [12]. The molar ratio of O/C is 0.64 [4].

The UGM conducted a silica-alumina catalyst analyzed by SEM-EDX (Scanning Electron Microscope – Energy Dispersive X-ray) and BET at the Laboratorium Pengujian dan Penelitian Terpadu (LPPT), UGM. SEM-EDX yields are weight percent C, O, Al, and Si respectively 8.41, 55.78, 24.64, and 11.17 %. Whereas from BET for surface area and pore diameter is 240.533 m²/gram and 3.3 nm. XRF microscopy analyzes obtained by weight percent SiO₂, Al₂O₃ is 60.28 and 35.25 wt.%,

3.2. The yield of SPR pyrolysis products with fixed-bed reactors

Figure 4 shows that the SPR non-catalytic and catalytic pyrolysis obtained product yields calculated by Equation (10-14).





Figure 4a shows that the higher the pyrolysis temperature for non-catalytic and catalytic pyrolysis, the tar yield will rise to the optimum temperature, then decrease again. This phenomenon is because secondary cracking occurs from tar formed in primary cracking; tar decomposes into gas and char. The optimum temperature and yield formed for non-catalytic and silica-alumina use of 0, 10, 20, and 40 % are 550 °C (42.01 %), 500 °C (40.55 %); 500 °C (36.55 %), and 500 °C (32.55 %). The use of silica-alumina catalysts reduces tar yield; this phenomenon is caused by silica-alumina being able to activate secondary cracking by forming new reaction paths. The tar formed in primary cracking will decompose to form gas with a very significant and slight addition of char, as shown in Figures 4b and 4c. In Figure 4c, we can see the optimum addition of gas at the use of a catalyst of 20 %. The range of gas without catalyst yields and the use of catalysts 0, 10, 20, and 40 % are 25.03-33.28, 31.52-37.34, 34.78-44.45, and 30.71-44.67 %.

3.3. Effect of temperature and amount of silica-alumina on the O/C ratio

The O/C ratio can illustrate the fuel quality, the impact of heat, and the amount of silica-alumina shown in Figure 5.



Figure 5. Effect of temperature and use of catalyst on O/C biooil SPR

The figure shows that the higher the temperature for noncatalytic and catalytic pyrolysis has the same tendency, namely the decrease in the O/C ratio. The silica-alumina use can reduce the O/C ratio from 0.47-0.74 for non-catalytic to 0.11-0.20 at optimum silica-alumina conditions by 40 %. As a comparison of fuel quality by referring to the O/C ratio, for petroleum oil, bio-oil from wood, C. *Protothecoides*, SPR without (0 %) and with catalysts (10, 20 and 30 %) pyrolysis obtained O/C average are 0.553 0.330, 0.340, and 0.155, respectively [13]. The use of silica-alumina catalysts is very significant to reduce the content of oxygenate compounds [13,21].

3.4. Model Test with Fixed-bed Reactor

3.4.1. Non-Catalytic Pyrolysis

The two-stage pyrolysis model involved primary and secondary tar crackings, while the reaction scheme can see in Figure 6.

Figure 6 shows SPR weight fraction and SPR pyrolysis products at a temperature of 300 $^{\circ}$ C from the experiment (X_{Data}) and calculation results (X_{Model}) at various times. From the picture, it can see the data that can observe from the experimental results at 300 $^{\circ}$ C is the weight fraction of tar (X_{Tar}) each time, while char (X_{Char}) and gas (X_{Gas}) can only calculate at the end of the experiment. SPR Fraction (X_{SPR}) is only known at the beginning of the investigation. In massive operations, SPR and char cannot observe every time because they are mixed in solids. For this reason, Equation 8 becomes a reference in completing this model.



Figure 6. Relationship between pyrolysis time (minutes) and weight fraction (X_{Data} and X_{Model}) at 300 °C: (a) SPR; (b) Tar; (c) Char and (d) Gas

Figure 6 shows SPR weight fraction and SPR pyrolysis products at a temperature of 300 $^{\circ}$ C from the experiment (X_{Data}) and calculation results (X_{Model}) at various times. From the picture, it can see the data that can observe from the experimental results at 300 $^{\circ}$ C is the weight fraction of tar

 (X_{Tar}) each time, while char (X_{Char}) and gas (X_{Gas}) can only calculate at the end of the experiment. SPR fraction (X_{SPR}) is only known at the beginning of the investigation. In massive operations, SPR and char cannot observe every time because

they are mixed in solids. For this reason, Equation 8 becomes a reference in completing this model.

The model's weight fraction is calculated by entering k_i for i = 1-5 in equation (1-4) until value $X_{total}=1$ (Equation 8) with

an error between X_{Data} , and X_{Model} that has the smallest value. After obtaining k_i for a temperature of 300-600 °C, k_i was used to calculate A_i and E_i , where i = 1-5. The values of k_1 , k_2 , k_3 , k_4 , and k_5 at a temperature of 300-600 °C are presented in Table 2.

Т, ⁰ С	$k_1(sec^{-1})$	$k_2(sec^{-1})$	$k_3(sec^{-1})$	$k_4(sec^{-1})$	$k_5(sec^{-1})$	Error, %
300	0.0237	0.0107	0.0279	5.48.10-7	5.48.10-7	5.45
400	0.0240	0.0839	0.0722	5.88.10-7	6.42.10-7	8.17
500	0.0940	0.0839	0.0722	7.78.10-7	7.99.10-7	8.91
550	0.0940	0.0984	0.0722	1.49.10-6	1.39.10-6	7.10
600	0.1201	0.1743	0.1044	1.80.10-6	1.70.10-6	4.12

Table 2. The values of k₁, k₂, k₃, k₄, and k₅ at temperatures of 300-600 °C in pyrolysis

Each temperature obtained the values of k_1 , k_2 , k_3 , k_4 , and k_5 , a relationship made between 1/T and Ln k_i , where i = 1-5. This relationship is illustrated in Figure 7.





Figure 7. Relationship between 1/T and $\ln k$: (a) $\ln k_1$, (b) $\ln k_2$, (c) $\ln k_3$, (d) $\ln k_4$ and (e) $\ln k_5$

Furthermore, from Figure 7, values A_1 - A_5 and E_1 - E_5 will be obtained as outlined in Table 3.

Table 3. Value of A_i and E_i in the primary and secondary tar cracking model

Reaction	Ai	E _i (J/mol)
$k_1, B \rightarrow G(1)$	3.8574	25,414.60
$k_2, B \rightarrow T(1)$	18.0366	33,778.51
$k_3, B \rightarrow C(1)$	0.8301	15,418.08
$k_4, T(1) \rightarrow G(2)$	1.377.10-5	16,283.77
k5, T(1)→C(2)	1.138.10-5	15,150.82

Table 3 shows that the sequence of activation energies of the greatest is $B \rightarrow T(1)$, $B \rightarrow G(1)$, $T(1) \rightarrow G(2)$, $B \rightarrow C(1)$, and $T(1) \rightarrow C(2)$. This value can interpret that it takes the most energy to convert biomass into Tar (1) or intermediate

product tar. The benefits of E_1 - E_5 prove that secondary cracking does occur, and the reaction of Tar (1) turns to Gas (2) and Char (2).

3.4.2. Catalytic Pyrolysis

Table 4 shows that the higher the pyrolysis temperature for all catalyst uses, the greater the k_1 - k_5 . The higher the heat of the reaction, the more energy the molecules get. The energy obtained is used to increase molecular motion's kinetic energy, increasing collisions' frequency between particles and catalysts. Partial energy collisions use to break existing bonds and form new relationships. This phenomenon encourages chemical reactions, where more collisions increase reaction speed. The catalyst can reduce the activation energy with the same power, the number of accidents that work is more, and the reaction rate is faster.

Table 4. Values of k₁, k₂, k₃, k₄, and k₅ at temperatures of 400-600 °C in pyrolysis with catalyst

Catalyst 10 %							
T, ℃	$k_1(sec^{-1})$	$k_2(sec^{-1})$	k ₃ (sec ⁻¹)	$k_4(sec^{-1})$	k5(sec ⁻¹)	Error, %	
400	0.0489	0.0449	0.0468	6.45.10-7	6.45.10-7	7.49	
450	0.0646	0.0499	0.0469	7.57.10 ⁻⁷	7.24.10-7	3.74	
500	0.0994	0.0641	0.0601	8.77.10-7	8.60.10-7	1.80	
600	0.1670	0.1024	0.0911	4.55.10-6	4.55.10-6	2.14	
Catalyst 20) %						
T, ℃	$k_1(sec^{-1})$	$k_2(sec^{-1})$	$k_3(sec^{-1})$	$k_4(sec^{-1})$	$k_5(sec^{-1})$	Error, %	
400	0.0520	0.0476	0.0469	6.88.10 ⁻⁷	6.84.10-7	5.92	
450	0.0520	0.0479	0.0469	8.00.10-7	7.94.10-7	7.07	
500	0.0790	0.0704	0.0543	8.91.10-7	8.88.10-7	4.04	
600	0.1581	0.0953	0.0735	6.04.10-6	6.04.10-6	0.66	
Catalyst 40 %							
T, ℃	$k_1(sec^{-1})$	$k_2(sec^{-1})$	$k_3(sec^{-1})$	$k_4(sec^{-1})$	$k_5(sec^{-1})$	Error, %	
400	0.0537	0.0449	0.0528	8.40.10-7	8.35.10-7	10.69	
450	0.0546	0.0470	0.0528	9.16.10 ⁻⁷	9.15.10-7	11.86	
500	0.0547	0.0611	0.0528	9.56.10-7	9.54.10-7	8.17	
600	0.0964	0.0925	0.0616	3.89.10-6	3.79.10-6	1.62	

The data of k_1 - k_5 for pyrolysis with catalysts (10, 20, and 40 %) were used to calculate A_1 - A_5 and E_1 - E_5 , presented in Table 5. From the table, it can seem that the more catalysts used, the smaller E_1 , E_2 , E_3 , E_4 , and E_5 . This value can interpret that with the use of catalysts, the lower the activation energy, the more efficiently the reaction occurs. It is optimum at the use of the catalyst 40 wt.% at primary cracking, which is in the decomposition of SPR to gas, tar, and char are E_1 (14.03 kJ/mol), E_2 (17.89 KJ/mol), and E_3 (3.00 kJ/mol), respectively.

In the use of catalysts, 10 % with 400-600 $^{\circ}$ C the k₁, k₂ dan k₃ are obtained in the range 0.0489-0.1670, 0.0449-0.1024, and 0.0468-0.0911 sec⁻¹, respectively. Furthermore, for catalyst 20 % is obtained 0.0520-0.1581, 0.0476-0.0953, and 0.0469-0.0735 sec⁻¹, respectively. The use of a catalyst 40 % is obtained from 0.0537-0.0964, 0.0449-0.0925, and 0.0528-0.0616 sec⁻¹, respectively.

Table 5. Values of A_1 - A_5 and E_1 - E_5 (kJ/mol) on pyrolysis with catalysts

Catalyst (%)	E ₁ (kJ/mol)	A_1	E ₂ (kJ/mol)	A ₂	E ₃ (kJ/mol)	A ₃	E ₄ (kJ/mol)	A4	E5 (kJ/mol)	A5
0	21.79	1.17	25.70	2.63	3.58	0.07	22.71	3.10-5	22.55	3.10-5
10	30.00	10.13	18.18	1.13	14.61	0.60	52.09	0.005	46.64	0.002
20	27.91	6.53	17.08	0.94	12.32	0.40	51.63	0.005	51.82	0.005
40	14.03	0.59	17.89	1.02	3.00	0.09	41.22	0.001	40.86	0.001

4. Conclusions

Spirulina platensis residue (SPR) with shallow lipid content (0.09 wt.%), protein content (49.60 wt.%), and carbohydrate (38.51 wt.%) high enough to be pyrolyzed with and without catalyst (silica-alumina) produces bio-oil, water phase, gas, and char. With the primary and secondary tar cracking model, data obtained from experiments with fixed-bed reactors using SPR at 300-600 °C. Based on the calculation of pyrolysis without catalyst, the activation energy obtained in primary cracking is $E_1(B \rightarrow G(1))$, $E_2(B \rightarrow T(1))$, $E_3(B \rightarrow C(1))$. In contrast, for secondary cracking, it is $E_4(T(1) \rightarrow G(2))$ and E₅(T(1) \rightarrow C(2)). The successive activation energy values are 25.425, 33.779, 15.418, 16.284, and 15.151 kJ/mol. The easiest to react in primary cracking is SPR to char with the lowest activation energy of 15.151 kJ/mol. Still, in the secondary cracking, the activation energy for the reaction of tar, T(1) to gas (G(2)), and char (C(2)) is almost the same value, 16.284 and 15.151 kJ/mol. With the secondary tar cracking model on pyrolysis with various catalysts (10, 20, and 40 wt.%), the more catalysts used, the smaller E_a . It is optimum at the use of the catalyst 40 wt.%, which is in the decomposition of SPR to char, E₃ (3.00 kJ/mol).

Acknowledgment

The researcher would like to thank the internal research funding assistance through the Lembaga Penelitian dan pengabdian Masyarakat (LPPM) Ahmad Dahlan University Yogyakarta with a contract number: PD-237/SP3/LPPM-UAD/2020.

References

 M. Aziz, T. Oda, and T. Kashiwagi, "Novel power generation from microalgae: Application of different gasification technologies," International Conference on Renewable Energy Research and Applications (ICRERA), Palermo, pp. 745-749; doi: 10.1109/ICRERA. 2015. 7418510. 22-25 November 2015.

- [2] F. Banda, D. Giudici, S. Quegan, and K. Scipal, "The Retrieval Concept of the Biomass Forest Biomass Prototype Processor," Published in IGARSS 2018 - 2018 IEEE International Geoscience and Remote Sensing Symposium-IEEE Conference Publication, 05 November 2018, DOI: 10.1109/IGARSS.2018.8518434.
- [3] K. Shi, S. Shao, Q. Huang, X. Liang, L. Jiang, and Y. Li, "Review of catalytic pyrolysis of biomass for bio-oil," Published in 2011 International Conference on Materials for Renewable Energy & Environment-IEEE Conference Publication, pp. 317-321, 27 June 2011 DOI: 10.1109/ICMREE.2011.5930821.
- [4] K.E. Okedu, and M. Al-Hashmi, "Assessment of the Cost of various Renewable Energy Systems to Provide Power for a Small Community: Case of Bukha, Oman," International Journal of Smart Grid- ijSmartGrid, Vol.2, No.3, pp. 172-182, September 2018.
- [5] K. Ahmadou, M. Fujiwara, Y. Nakamura, K. Sato, H. Takami, K. Ahmadou, M. Fujiwara, Y. Nakamura, K. Sato, and H. Takami, "ILQ Optimal Voltage Control for Biomass Free-Piston Stirling Engine Generator System", International Journal of Smart Grid- ijSmartGrid, Vol.4, No.1, pp. 38-43, March 2020.
- [6] S. Jamilatun, Budhijanto, Rochmadi, A. Yuliestyan, A. Budiman, "Valuable Chemicals Derived from Pyrolysis Liquid Products of *Spirulina platensis* residue." Indones. J. Chem., Vol. 19, No. 3, pp. 703 – 711, 2019.
- [7] S. Jamilatun, Budhijanto, Rochmadi, A. Yuliestyan, A. Budiman, "Comparative Analysis Between Pyrolysis Products of *Spirulina platensis* Biomass and Its Residues." Int. J. Renew. Energy Dev., Vol. 8, No. 2, pp. 113 – 140, 2019.
- [8] S. Jamilatun, A. Budiman, H. Anggorowati, A. Yuliestyan, Y. Surya Pradana, Budhijanto, Rochmadi, "Ex-Situ

Catalytic Upgrading of *Spirulina platensis* residue Oil Using Silica Alumina Catalyst." International Journal of Renewable Energy Research. Vol. 9, No. 4, pp. 1733–1740, 2019.

- [9] M. Oku, T. Sakoda, N. Hayashi, and D. Tashima, "Basic characteristics of a heat and electricity combined generation system using biomass fuel," International Conference on Renewable Energy Research and Application (ICRERA), Milwaukee, WI, 2014, pp. 222-228; doi:10.1109/ICRERA. 2014 .7016560. 19-22 Oktober 2014.
- [10] C. Di Blasi, "Analysis of convection and secondary reaction effects within porous solid fuels undergoing pyrolysis. Combust. Sci. Technol., Vol. 90, pp. 315–340, 1993.
- [11] Q. Xu, X. Ma, Z. Yu, Z. Cai, "A kinetic study on the effects of alkaline earth and alkali metal compounds for catalytic pyrolysis of microalgae using thermogravimetry," Applied Thermal Engineering 73, 357-361, 2014.
- [12] V. Balasundram, N. Ibrahim, R.Md. Kasmani, M.K. Abd. Hamid, R. Isha, H. Hasbullah, and R.R. Ali, "Thermogravimetric catalytic pyrolysis and kinetic studies of coconut copra and rice husk for maximum possible production of pyrolysis oil," Journal of Cleaner Production 167, 218-228, 2017.
- [13] S. Jamilatun, Budhijanto, Rochmadi, A. Budiman, "Thermal Decomposition and Kinetic Studies of Pyrolysis of *Spirulina platensis* residue." International Journal of Renewable Energy Development, Vol. 6, No. 3, pp. 193– 201, 2017.
- [14] N. Prakash, T. Karunanithi, "Kinetic modeling in biomass pyrolysis – A Review." J. Appl. Sci. Res., Vol. 4, No. 12, pp. 1627-1636, 2008.

- [15] A. Anca-Counce, R. Mehrabian, I. Scharler, Obernberger, "Kinetic scheme of biomass pyrolysis considering secondary charring reactions." Energy Conversion and Management, Vol. 87, pp. 687–696, 2014.
- [16] B.M.E. Chagas, C. Dorado, M.J. Serapiglia, C.A. Mullen, A.A. Boateng, M.A.F. Melo, C.H. Ataide, "Catalytic pyrolysis-GC/MS of Spirulina: Evaluation of a highly proteinaceous biomass source for the production of fuels and chemicals," Fuel, Vol. 179, pp. 124–134, 2016.
- [17] A. Demirbas, M.F. Demirbas, "Importance of algae oil as a source of biodiesel," Energy Conversion, and Management. Vol. 52, pp. 163-170, 2011.
- [18] A. Sharma, V. Pareek, D. Zhang, "Biomass pyrolysis—A review of modeling. process parameters and catalytic studies", Vol. 50, pp. 1081-1096, 2015.
- [19] M. Aziz, T. Oda, T. Mitani, A. Uetsuji, and T. Kashiwagi, "Combined hydrogen product, ion and power generation from microalgae," International Conference on Renewable Energy Research and Applications (ICRERA), Palermo, pp. 923-927; doi:10.1109/ICRERA. 7418544. 22-25 November 2015.
- [20] S.J Ojolo, C.A. Osheku, M.G. Sobamowo, "Analytical investigations of kinetic and heat transfer in the slow pyrolysis of a biomass particle." Int. J. Renew. Dev., Vol. 2, No. 2, pp.105-115, 2013.
- [21] S. Jamilatun, Budhijanto, Rochmadi, J-I. Hayashi and A. Budiman "Catalytic pyrolysis of *Spirulina platensis* residue (SPR): Thermochemical behavior and kinetics," International Journal of Technology, 11(3), pp. 522-531, 2020.