



**e-ISSN: 1978-2993**

# Bulletin of Chemical Reaction Engineering & Catalysis

Volume 14, Issue 1, Year 2019 (Regular Issue: April 2019)

Available online since 25<sup>th</sup> January 2019 at: <https://bcrec.undip.ac.id/> or <https://bcrec.id>

Bull. Chem. React. Eng. Catal.	Vol. 14	No. 1	Pages: 1 - 237	Semarang, April 2019	e-ISSN: 1978-2993
-----------------------------------	---------	-------	-------------------	-------------------------	----------------------



Published by:

Department of Chemical Engineering, Diponegoro University

Masyarakat Katalis Indonesia – Indonesian Catalyst Society (MKICS)



## EDITORIAL TEAM

### EDITOR-IN-CHIEF

**Prof. Dr. I. Istadi**, Department of Chemical Engineering, Diponegoro University, Indonesia; E-mail: [istadi@che.undip.ac.id](mailto:istadi@che.undip.ac.id); (Scopus ID: 6506850769)

### REGIONAL EDITOR FOR ASIA-PACIFIC

**Prof. Dr. Hadi Nur**, Ibnu Sina Institute for Fundamental Science Studies, Universiti Teknologi Malaysia, 81310 UTM Skudai, Johor, Malaysia (Scopus ID: 6602169746)

**Prof. Dr. Y.H. Taufiq-Yap**, Centre of Excellence for Catalysis Science and Technology, Faculty of Science, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia (Scopus ID: 56272773200)

### REGIONAL EDITOR FOR EUROPE:

**Prof. Dr. Dmitry Yu. Murzin**, Laboratory of Industrial Chemistry and Reaction Engineering, Abo Akademi University; Biskopsgatan 8 20500, Turku/Åbo, Finland (Scopus ID: 18037974700)

### ASSOCIATE (MAIN HANDLING) EDITORS

**Prof. Dr. Andri Cahyo Kumoro**, Department of Chemical Engineering, Diponegoro University, Indonesia (Scopus ID: 22980375000)

**Assoc. Prof. Dr. Luqman Buchori**, Department of Chemical Engineering, Diponegoro University, Indonesia (Scopus ID: 55559743300)

**Prof. Dr. Heru Susanto**, Department of Chemical Engineering, Diponegoro University, Indonesia (Scopus ID: 15835800800)

**Prof. Dr. Mohammad Djaeni**, Department of Chemical Engineering, Diponegoro University, Indonesia (Scopus ID: 16027817500)

### INTERNATIONAL ADVISORY EDITORIAL BOARDS

#### **Prof. Dr. Bunjerd Jongsomjit**

Department of Chemical Engineering, Chulalongkorn University, Bangkok, Thailand (Scopus ID: 6603065177)

**Prof. Dr. Toru Wakihara**, Yokohama National University, Graduate School of Environment and Information Sciences, Yokohama, Japan, (Scopus ID: 12789042600)

#### **Prof. Dr. Valeria Di Sarli**

Institute for Research on Combustion - National Research Council of Italy (CNR), Piazzale V. Tecchio 80, 80125, Napoli, Italy (Scopus ID: 16021366800)

**Prof. Dr. Jose E. Castanheiro**, Dept. of Chemistry, University of Evora, CQE, Evora, Portugal (Scopus ID: 6506163997)

**Prof. Dr. Rafael Molina**, Estado Sólido y Catálisis Ambiental, Departamento de Química, Facultad de Ciencias, Universidad Nacional de Colombia, Carrera 30 45-03, Bogotá, D.C., Colombia (Scopus ID: 7202381846)

**Prof. Dr. Kalama Jalama**, Dept. of Chemical Engineering, University of Johannesburg, P.O. Box 17011, Doornfontein 2028, Johannesburg, South Africa (Scopus ID: 15029880600)

**Prof. Dr. Ho-Shing Wu**, Dept. of Chemical Engineering & Material Science, Yuan-Ze University, 135 Yuan Tung Road, Chung Li, Taoyuan, 32003, Taiwan, Province of China, (Scopus ID: 7405581723)

**Dr. R. Rodiansono**, Department of Chemistry, Lambung Mangkurat University, Indonesia (Scopus ID: 55785853800)

#### **Prof. Dr. Mostafa Barigou**

School of Chemical Engineering, University of Birmingham, Edgbaston, Birmingham B15 2TT, United Kingdom, (Scopus ID: 7003356054)

#### **Prof. Dr. S. Subagio**

Dept. of Chemical Engineering, Institut Teknologi Bandung, Jl. Ganesha 10, Bandung, Indonesia (Scopus ID = 51462066900)

#### **Prof. Dr. Raghunath V. Chaudhari**

Center for Environmental Beneficial Catalysis, Dept. of Chemical and Petroleum Engineering, The University of Kansas, 1501 Wakarusa Dr., Building B-Room 112B, Lawrence, KS 66047-1803, USA, (Scopus ID: 7101777898)

#### **Prof. Dr. Sibudjing Kawi**

Dept. of Chemical and Biochemical Engineering, National University of Singapore, Singapore, (Scopus ID: 7006257898)

#### **Prof. Dr. Nor Aishah Saidina Amin**

Faculty of Chemical and Natural Resources Engineering, Universiti Teknologi Malaysia, 81310 UTM Skudai, Johor, Malaysia, (Scopus ID: 35489910900)

#### **Assoc. Prof. Dr. Oki Muraza**

CENT & Dept. of Chemical Engineering, King Fahd University of Petroleum and Minerals, PO Box 5040 Dhahran 31261 KSA, Saudi Arabia, (Scopus ID: 22433275900)

#### **Prof. Dr. K. Kusmiyati**

Dept. of Industrial Engineering, Universitas Dian Nuswantoro, Semarang, Indonesia (Scopus ID: 7409816823)

#### **Assoc. Prof. Dr. Rino R. Mukti**

Division of Inorganic and Physical Chemistry, Faculty of Mathematics and Natural Sciences, Institut Teknologi Bandung, Jl. Ganesha no.10 Bandung 40132, Indonesia, (Scopus ID: 12244105600)

#### **Prof. Dr. Arief Widjaja**

Dept. of Chemical Engineering, Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia (Scopus ID: 13003143800)



### AIMS AND SCOPE

**Bulletin of Chemical Reaction Engineering & Catalysis (e-ISSN 1978-2993)**, an international journal, provides a forum for publishing the novel technologies related to catalyst, catalysis, chemical reactor, kinetics, and chemical reaction engineering. Scientific articles dealing with the following topics in chemical reaction engineering, catalysis science and engineering, catalyst preparation method and characterization, novel innovation of chemical reactor, etc., are particularly welcome.

This journal encompasses original research articles, review articles, and short communications, including: fundamental of catalyst and catalysis; fundamental of chemical reaction engineering; kinetics studies of chemical reaction engineering; materials and nano-materials for catalyst; kinetics studies of materials research; chemistry of catalyst and catalysis; applied chemical reaction engineering; applied catalysis; applied bio-catalysis; applied bio-reactor; membrane bio-reactor; chemical reactor design; catalyst regeneration; catalyst deactivation; surface chemistry of catalyst; bio-catalysis; enzymatic catalytic reaction; kinetic studies of enzymatic reaction; industrial practice of catalyst; industrial practice of chemical reactor engineering; application of plasma technology in catalysis and chemical reactor; and advanced technology for chemical reactors.

The manuscript articles should be submitted by online in MS Word / Open Office / PDF file format to Editorial Office through **Online Submission interface at: <https://ejournal2.undip.ac.id/index.php/bcrec>**. The Author must read the author guidelines of this journal first before submitting a manuscript.

### PUBLICATION INFORMATION

**Bulletin of Chemical Reaction Engineering & Catalysis (e-ISSN: 1978-2993)**

Short journal title: ***Bull. Chem. React. Eng. Catal.***

For year 2019, 3 issues (Volume 14, Issue 1 (April), Issue 2 (August), and Issue 3 (December)) are scheduled for publication. Commencement of publication: January 2008

Bulletin of Chemical Reaction Engineering & Catalysis, initialized as BCREC, published freely open access of fulltext PDF articles via journal website (<https://bcrec.undip.ac.id> or <https://bcrec.id>). The BCREC journal is published by Department of Chemical Engineering, Diponegoro University jointly with *Masyarakat Katalis Indonesia* - Indonesian Catalyst Society (MKICS).

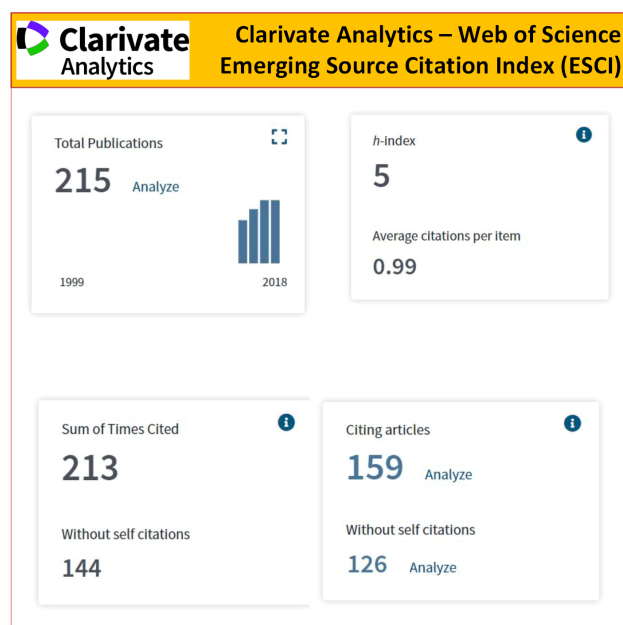
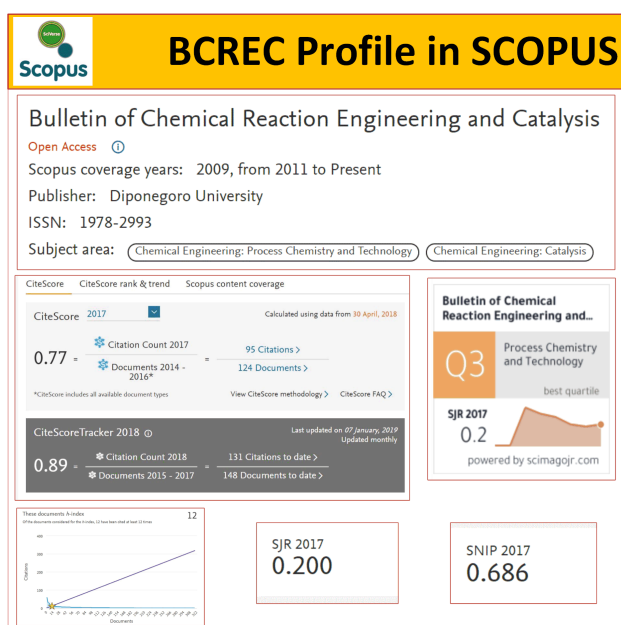
The BCREC journal has been indexed and abstracted by: Elsevier Products (Scopus, Compendex/Engineering Village), Web of Science (Emerging Source Citation Index) by Clarivate Analytics, Chemical Abstract Services, CABI, ASEAN Citation Index, DOAJ, Digital Dimensions, Microsoft Academics, and other reputable indexers.

Fulltext PDF of this journal has also been distributed around the world by EBSCO Publishing (Academic Search Complete, Academic Search Premiere, and Academic Search R&D packages) and ProQuest Databases started from Volume 4 Number 1 Year 2009 to present. The BCREC journal becomes a CrossRef Member since 2012, so that all articles published by this journal have DOI unique numbers.



## JOURNAL CITATIONS AND IMPACT FACTOR ANALYSIS (2019)

- \* Journal Impact Factor in Scimago (2018) : SJR = 0.200; SNIP = 0.686
- \* H-index in Scimago (2018) : 10 (2018)
- \* Scopus ID : 19900191860
- \* CiteScore Scopus Tracker (per January 2019) : 0.89
- \* H-index in Web of Science (Clarivate Analytics) : 5 (2018)
- \* Averaged Citation per Item in WoS Clarivate Analytics: 0.99
- \* Google Scholar (h-index / h5-index / i10-index) : 17 / 15 / 36
- \* Google Scholar Citation (total) : 1491
- \* Google Scholar Citation (5 years) : 1270
- \* Dimensions - Average Field Citation Ratio (FCR) : 0.28
- \* Dimensions - Citation per Publication : 1.32





### INDEXING AND ABSTRACTING

Bulletin of Chemical Reaction Engineering & Catalysis (e-ISSN: 1978-2993) has been covered (indexed and abstracted) by following indexing services:

1. Scopus - Elsevier (2009-now) (<https://www.scopus.com/sourceid/19900191860>)
2. EI Compendex - Engineering Village (2011-now)
3. EnCompassLIT - Engineering Village (2011-now)
4. Scimago Journal Ranking (<https://scimagojr.com/journalsearch.php?q=+19782993&tip=iss>)
5. Web of Science Core Collection Database from Clarivate Analytics (<http://ip-science.thomsonreuters.com/cgi-bin/jrnlst/jlresults.cgi?PC=MASTER&ISSN=1978-2993>)
6. Emerging Source Citation Index (from Clarivate Analytics, Web of Science) (<http://ip-science.thomsonreuters.com/cgi-bin/jrnlst/jlresults.cgi?PC=MASTER&ISSN=1978-2993>)
7. Dimensions - Digital Science ([https://app.dimensions.ai/discover/publication?and\\_facet\\_journal=jour.1142571&order=times\\_cited](https://app.dimensions.ai/discover/publication?and_facet_journal=jour.1142571&order=times_cited))
8. ASEAN Citation Index (2015-now) (<http://www.asean-cites.org/index.php?r=contents%2Findex&id=9>)
9. Microsoft Academic (2015-now) (<https://academic.microsoft.com/#/detail/2738450280>)
10. ResearchGate ([https://www.researchgate.net/journal/1978-2993\\_Bulletin\\_of\\_Chemical\\_Reaction\\_Engineering\\_and\\_Catalysis](https://www.researchgate.net/journal/1978-2993_Bulletin_of_Chemical_Reaction_Engineering_and_Catalysis))
11. Ingenta Connect (<http://www.ingentaconnect.com/content/doi/19782993>)
12. ProQuest Databases (since 2017) (<http://www.proquest.com/products-services/databases/>)
13. EBSCOhost - TOC Premier; Energy & Power Source; Academic Search Premier; Academic Search Alumni Edition; Academic Search R&D; Academic Search Complete (2009-.)
14. ROAD ISSN (<http://road.issn.org/issn/1978-2993-bulletin-of-chemical-reaction-engineering-amp-catalysis#.V9qpxTsSAyE>)
15. WorldCat OCLC - (<https://www.worldcat.org/profiles/bcrec/lists/3665652>)
16. CiteULike - (2012-now) (<http://www.citeulike.org/group/20135>)
17. Mendeley - (2012-now) (<http://www.mendeley.com/groups/3847801/bulletin-of-chemical-reaction-engineering-catalysis/>)
18. SHERPA/RoMEO - (<http://www.sherpa.ac.uk/romeo/search.php?source=journal&sourceid=29003&la=en&fIDnum=|&mode=simple>)
19. CrossRef Member- (2012-now) (<http://www.crossref.org>)
20. Index Copernicus - (<http://journals.indexcopernicus.com/masterlist.php?name=Master&litera=B&start=150&skok=30>)
21. CABI Direct (2011-now) - (<http://www.cabdirect.org/>)
22. SCIRUS - for scientific information (2010-now) (<http://www.scirus.com/>)
23. Chemical Abstract Service (2010-now) (CAS Source Index (CASSI) ; <http://www.cas.org>), a division of American Chemical Society (ACS).
24. Academic Journal Database (<http://journaldatabase.org/journal/issn1978-2993>)
25. ULRICHSWEB Global Serial Directory (<http://ulrichsweb.serialssolutions.com>)
26. Google Scholar ([https://scholar.google.com/citations?hl=en&user=PadKS\\_wAAAAJ](https://scholar.google.com/citations?hl=en&user=PadKS_wAAAAJ))
27. EPRINTS Undip (<http://eprints.undip.ac.id>)
28. Directory of Open Access Journal (DOAJ) (<http://www.doaj.org>)

For detail please visit here: <https://ejournal2.undip.ac.id/index.php/bcrec/pages/view/indexing>.





## TABLE OF CONTENTS

1. Influence of Phosphoric Acid Modification on Catalytic Properties of $\gamma$ - $\chi$ $\text{Al}_2\text{O}_3$ Catalysts for Dehydration of Ethanol to Diethyl Ether (Limlamthong, M., Chitpong, N., Jongsomjit, B.) .....	(1 - 8)
2. Synthesis of 2,2,4-Trimethyl-2,3-dihydro-1H-1,5-benzodiazepine using Treated Natural Zeolite Catalyst (Firdaus, M., Prameswari, M.D.) .....	(9 - 16)
3. Kinetic of Adsorption Process of Sulfonated Carbon-derived from Eichhornia crassipes in the Adsorption of Methylene Blue Dye from Aqueous Solution (Nurhadi, M., Widiyowati, I.I., Wirhanuddina, W., Chandren, S.) .....	(17 - 27)
4. Preparation of Nitrogen-Doped Carbon Material from Monosodium Glutamate and Its Catalytic Performance (Zhou, Y.M., Wang, X.H., Cai, K.Y., Wu, J.M., Wang, P., Song, M.) .....	(28 - 34)
5. Fischer-Tropsch Synthesis over Unpromoted $\text{Co}/\gamma\text{-Al}_2\text{O}_3$ Catalyst: Effect of Activation with CO Compared to $\text{H}_2$ on Catalyst Performance (Khangale, P.R., Meijboom, R., Jalama, K.) .....	(35 - 41)
6. Facile Synthesis of $\text{Ag}_3\text{PO}_4$ Photocatalyst with Varied Ammonia Concentration and Its Photo-catalytic Activities For Dye Removal (Febiyanto, F., Soleh, A., Amal, M.S.K., Afif, M., Sewiji, S., Riapanitra, A., Sulaeman, U.) .....	(42 - 50)
7. Silver Nanoparticles Supported on Chitosan as a Green and Robust Heterogeneous Catalyst for Direct Synthesis of Nitrogen Heterocyclic Compounds under Green Conditions (Hamzavi, S.F., Jamili, S., Yousefzadi, M., Moradi, A.M., Biuki, N.A.) .....	(51 - 59)
8. Kinetic Modeling of Flocculation and Coalescence in the System Emulsion of Water-Xylene-Terbutyl Oleyl Glycosides (Pawignya, H., Kusworo, T.D., Pramudono, P.) .....	(60 - 68)
9. A Green Synthesis of Polyimmonene Using Maghnite- $\text{H}^+$ , an Exchanged Montmorillonite Clay, as Eco-Catalyst (Derdar, H., Belbachir, M., Harrane, A.) .....	(69 - 78)
10. Design of a Synthetic Zinc Oxide Catalyst over Nano-Alumina for Sulfur Removal by Air in a Batch Reactor (Nawaf, A.T., Jarullah, A.T., Abdulateef, L.T.) .....	(79 - 92)
11. Recyclable Nanocrystalline Copper Based on $\text{MoO}_3/\text{SiO}_2$ as an Efficient Catalyst for Acylation of Amines (Deshmukh, J.M., Daga-de, S.P.) .....	(93 - 104)
12. Preparation of Metal-Free Nitrogen-Doped Carbon Material and Its Catalytic Performance (Wang, X., Yang, L., Cai, K.Y., Zhou, Y.M., Wang, P., Song, M.) .....	(105 - 111)
13. Mesoporous $\text{Co}_3\text{O}_4$ as a New Catalyst for Allylic Oxidation of Cyclohexene (Azzi, H., Rekkab-Hammoumraoui, I., Chérif-Aouali, L., Choukhou-Braham, A.) .....	(112 - 123)
14. Microwave-Assisted Synthesis of DUT-52 and Investigation of Its Photoluminescent Properties (Kesuma, R.F., Patah, A., Permana, Y.) .....	(124 - 129)
15. Algerian Acid Activated Clays as Efficient Catalysts for a Green Synthesis of Solketal by Chemoselective Acetalization of Glycerol with Acetone (Alali, K., Lebsir, F., Amri, S., Rahmouni, A., Srasra, E., Besbes, N.) .....	(130 - 141)
16. PEGylated $\text{MoS}_2$ Nanosheets: A Dual Functional Photocatalyst for Photodegradation of Organic Dyes and Photoreduction of Chromium from Aqueous Solution (Ntakadzeni, M., Anku, W.W., Kumar, N., Govender, P.P., Reddy, L.) .....	(142 - 152)
17. Development of $\text{CaO}/\text{PVA}$ Catalyst from Fish Bone for Biodiesel Production (Sulaiman, S., Jamaludin, N.F.A., Kabbashi, N.A.) .....	(153 - 157)
18. Egg-shell Treated Oil Palm Fronds (EG-OPF) as Low-Cost Adsorbent for Methylene Blue Removal (Hasan, R., Ahliyasah, N.A.F., Chong, C.C., Jusoh, R., Setiabudi, H.D.) .....	(158 - 164)
19. Intercalations and Characterization of Zinc/Aluminium Layered Double Hydroxide-Cinnamic Acid (Adam, N., Ghazali, S.A.I.S.M., Dzulkifli, N.N., Hak, C.R.C., Sarijo, S.H.) .....	(165 - 172)
20. Cymbopogon nardus Mediated Synthesis of Ag Nanoparticles for the Photocatalytic Degradation of 2,4-Dichlorophenoxyacetic Acid (Kamarudin, N.S., Jusoh, R., Setiabudi, H.D., Jusoh, N.W.C., Jaafar, N.F., Sukor, N.F.) .....	(173 - 181)
21. Microwave-assisted Synthesis of ZnO Nanoparticles Stabilized with Gum Arabic: Effect of Microwave Irradiation Time on ZnO Nanoparticles Size and Morphology (Pauzi, N., Zain, N.M., Yusof, N.A.A.) .....	(182 - 188)
22. Utilization of Lapindo Volcanic Mud for Enhanced Sono-sorption Removal of Acid Orange 52 (Kamarudin, N.H.N., Setiabudi, H.D., Jalil, A.A., Adam, S.H., Salleh, N.F.M.) .....	(189 - 195)
23. Synthesis of KCC-1 Using Rice Husk Ash for Pb Removal from Aqueous Solution and Petrochemical Wastewater (Hasan, R., Chong, C.C., Setiabudi, H.D.) .....	(196 - 204)
24. Evaluation of La-Doped CaO Derived from Cockle Shells for Photodegradation of POME (Ghazali, S.S., Kem, W.L., Jusoh, R., Abdullah, S., Shariffuddin, J.H.) .....	(205 - 218)
25. Synthesis of Titania Doped Copper Ferrite Photocatalyst and Its Photoactivity towards Methylene Blue Degradation under Visible Light Irradiation (Arifin, M.N., Karim, K.M.R., Abdullah, H., Khan, M.R.) .....	(219 - 227)
26. Catalytic CO Methanation over Mesoporous ZSM5 with Different Metal Promoters (Peng, T.L., Triwahyono, S., Jalil, A.A., Setiabudi, H.D., Aziz, M.A.A.) .....	(228 - 237)

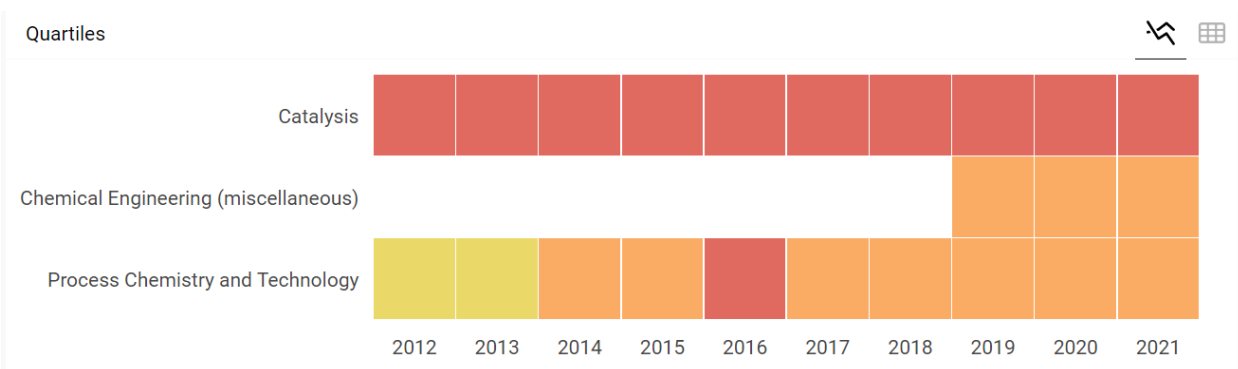


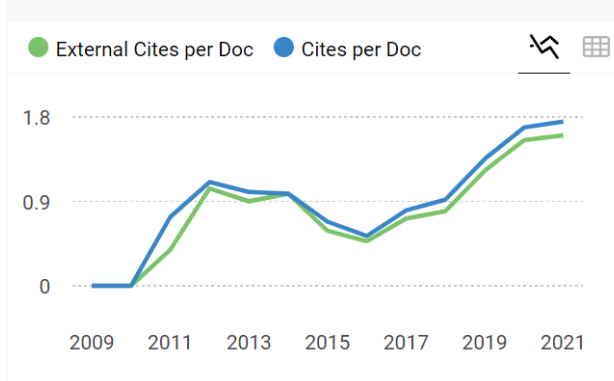
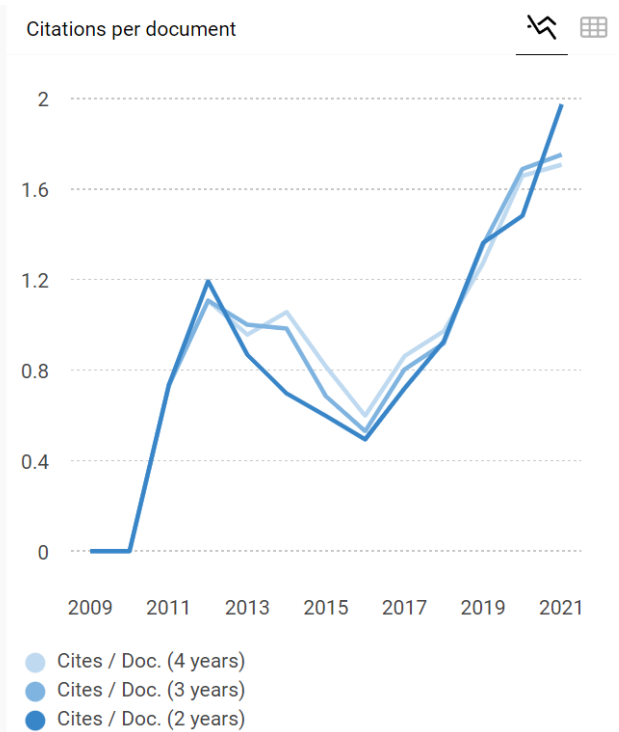
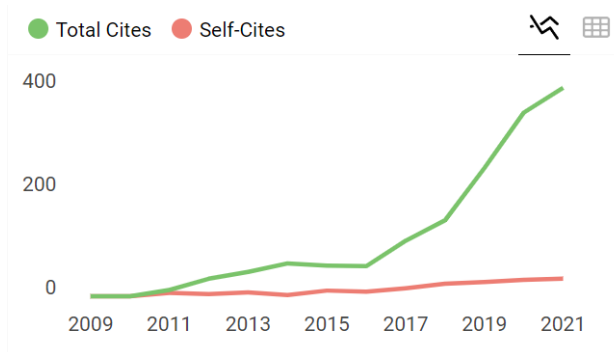
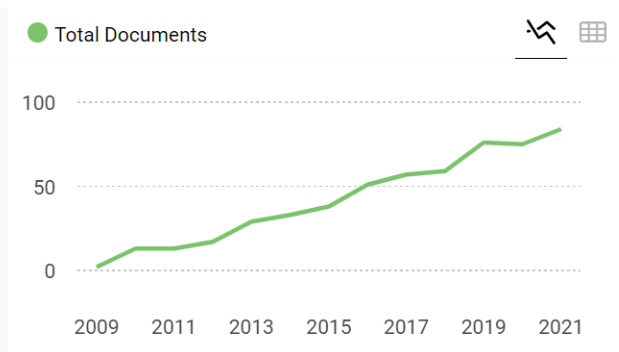
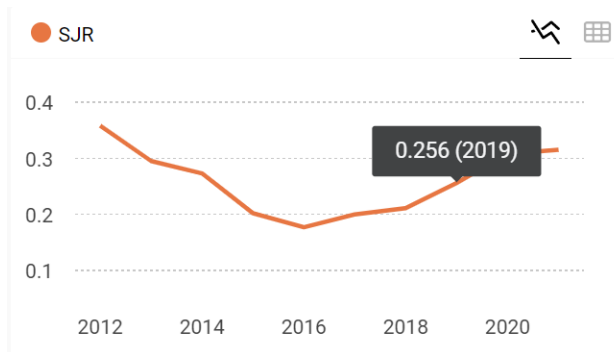
## Bulletin of Chemical Reaction Engineering and Catalysis

<b>COUNTRY</b>  <a href="#">Indonesia</a>   Universities and research institutions in Indonesia	<b>SUBJECT AREA AND CATEGORY</b>  <a href="#">Chemical Engineering</a> <ul style="list-style-type: none"> <li><a href="#">Catalysis</a></li> <li><a href="#">Chemical Engineering (miscellaneous)</a></li> <li><a href="#">Process Chemistry and Technology</a></li> </ul>	<b>PUBLISHER</b>  <a href="#">Diponegoro University</a>   Diponegoro University in Scimago Institutions Rankings
<b>H-INDEX</b>  <b>19</b>	<b>PUBLICATION TYPE</b>  Journals	<b>ISSN</b>  19782993
<b>COVERAGE</b>  2009-2021	<b>INFORMATION</b>  <a href="#">Homepage</a> <a href="#">How to publish in this journal</a> <a href="mailto:bcrec@live.undip.ac.id">bcrec@live.undip.ac.id</a>	

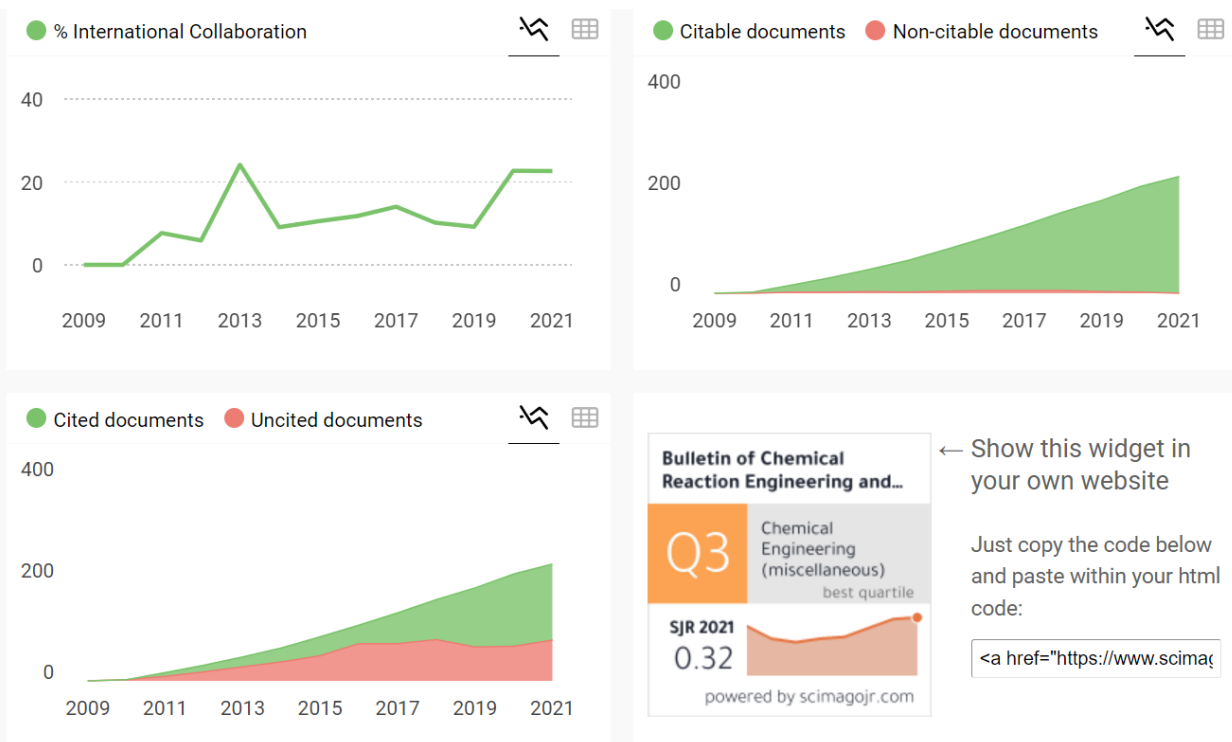
### SCOPE

Bulletin of Chemical Reaction Engineering & Catalysis, a reputable international journal, provides a forum for publishing the novel technologies related to the catalyst, catalysis, chemical reactor, kinetics, and chemical reaction engineering. Scientific articles dealing with the following topics in chemical reaction engineering, catalysis science, and engineering, catalyst preparation method and characterization, novel innovation of chemical reactor, kinetic studies, etc. are particularly welcome. However, articles concerned on the general chemical engineering process are not covered and out of the scope of this journal.









BULLETIN OF CHEMICAL REACTION ENGINEERING AND CATALYSIS

OPEN ACCESS

Publisher:

UNIV DIPONEGORO , KAMPUS UNDIIP TEMBALANG, SEMARANG, INDONESIA, 50275

ISSN / eISSN:

1978-2993

Web of Science Core Collection:

Emerging Sources Citation Index

Share This Journal

View profile page

\* Requires free login.



Research Article

## Facile Synthesis of $\text{Ag}_3\text{PO}_4$ Photocatalyst with Varied Ammonia Concentration and Its Photocatalytic Activities For Dye Removal

Febiyanto Febiyanto<sup>1</sup>, Agus Soleh<sup>1</sup>, Muhammad Sofi Khoerul Amal<sup>1</sup>, Mohammad Afif<sup>1</sup>, Sukma Sewiji<sup>2</sup>, Anung Riapanitra<sup>1</sup>, Uyi Sulaeman<sup>1\*</sup>

<sup>1</sup>Department of Chemistry, University of Jenderal Soedirman, Jl. Dr. Soeparno No. 61 Karangwangkal, Purwokerto, 53123, Indonesia.

<sup>2</sup>Department of Physics, University of Jenderal Soedirman, Jl. Dr. Soeparno No. 61 Karangwangkal, Purwokerto, 53123, Indonesia.

Received: 20<sup>th</sup> April 2018; Revised: 1<sup>st</sup> September 2018; Accepted: 4<sup>th</sup> September 2018;

Available online: 25<sup>th</sup> January 2019; Published regularly: April 2019

### Abstract

The highly active photocatalyst of  $\text{Ag}_3\text{PO}_4$  could be synthesized under ammonia solution using the facile co-precipitation method with the starting material of  $\text{AgNO}_3$  and  $\text{Na}_2\text{HPO}_4 \cdot 12\text{H}_2\text{O}$ . The variation of ammonia concentration was designed at 0.00, 0.05, 0.15, and 0.30 M. The products were characterized using X-ray diffraction, UV-diffuse reflectance spectroscopy, and scanning electron microscopy. The photocatalytic activities were evaluated using the Rhodamine B degradation under blue light irradiation. The effect of calcination, pH condition, and visible light source irradiation was carried out in the experiment. The highest photocatalytic activity was found in the sample prepared using the addition of ammonia solution at the concentration of 0.05 M. This photocatalytic activity was 4.13 times higher compared to the  $\text{Ag}_3\text{PO}_4$  prepared without the ammonia. The effective condition of photocatalytic activity was achieved at the sample prepared without calcination, degradation at pH of 7 and under blue light irradiation. Copyright © 2019 BCREC Group. All rights reserved

**Keywords:**  $\text{Ag}_3\text{PO}_4$  photocatalyst; photocatalytic activity; Rhodamine B; varied ammonia concentration

**How to Cite:** Febiyanto, F., Soleh, A., Amal, M.S.K., Afif, M., Sewiji, S., Riapanitra, A., Sulaeman, U. (2019). Facile Synthesis of  $\text{Ag}_3\text{PO}_4$  Photocatalyst with Varied Ammonia Concentration and Its Photocatalytic Activities For Dye Removal. *Bulletin of Chemical Reaction Engineering & Catalysis*, 14 (1): 42-50 (doi:10.9767/bcrec.14.1.2549.42-50)

**Permalink/DOI:** <https://doi.org/10.9767/bcrec.14.1.2549.42-50>

### 1. Introduction

Recently, the silver orthophosphate or  $\text{Ag}_3\text{PO}_4$  semiconductor has been attracting the attention of many researchers because of its promising catalyst properties which have higher photo-oxidation ability for organic pollutants or

dye removal. Silver orthophosphate has the band gap energy of 2.36 eV, that can absorb solar energy shorter than ~530 nm [1-6], possess stronger photo-oxidative capability than the previous photocatalyst [7-9], generating  $\text{O}_2$  from water splitting with a quantum efficiency nearly 90% in visible light irradiation [10]. In order to improve its photocatalytic activity in the visible light region, many approaches have been performed especially in catalyst fabrication design

\* Corresponding Author.

E-mail: [uyi\\_sulaeman@yahoo.com](mailto:uyi_sulaeman@yahoo.com) (U. Sulaeman),  
Telp: +62-281-638793, Fax: +62-281-638793

for a large-scale application. Among them, the synthesis of  $\text{Ag}_3\text{PO}_4$  assisted by ammonia solution [11-12] was reported. The use of ammonia solution as the additional component in the synthesis produces the varied-morphology of  $\text{Ag}_3\text{PO}_4$ , such as: the cubic-like structure, that exhibits a good photocatalytic activity than the irregular structure. Yan and co-workers [13] reported that the synthesis of  $\text{Ag}_3\text{PO}_4$  microcubes can improve their visible light driven photocatalytic degradation for Rhodamine B, methylene blue, and methylene orange. Xingyuan and co-workers [14] also reported that the synthesis of uniform and well defined  $\text{Ag}_3\text{PO}_4$  microcrystal showed high photocatalytic activity, three times higher compared to the  $\text{Ag}_3\text{PO}_4$  micro-particle.

Based on the above-mentioned information, the synthesis of  $\text{Ag}_3\text{PO}_4$  assisted by ammonia solution needs more deep investigation. There is no sufficient information of  $\text{Ag}_3\text{PO}_4$  preparation especially the effect of varied ammonia concentration, the temperature of calcination, pH degrees, and their photocatalytic properties under variation of visible light lamps. These samples were evaluated using the decomposition of Rhodamine B under visible light irradiation and characterized using the X-ray diffraction, UV-diffuse reflectance spectroscopy, and scanning electron microscopy. Catalyst with the highest photocatalytic activity was also treated with the variation of calcination temperature, pH, and visible light lamps to determine the effect of calcination, acid-base condition and light sources in photocatalytic reaction. In this research, the varied ammonia concentration, calcination treatment, pH and light sources significantly affected the photocatalytic activity. All information about our research has been discussed and compared in detail.

## 2. Materials and Methods

### 2.1 Materials

All the reagents are pro analysis and provided from Merck Darmstadt, F.R. Germany. Silver nitrate ( $\text{AgNO}_3$ ), disodium hydrogen phosphate 12-hydrate ( $\text{Na}_2\text{HPO}_4 \cdot 12\text{H}_2\text{O}$ ), and 25% ammonia were used without further purification. The LED lamp of blue, red, yellow, and green light (3W/220V) were used as the visible light source irradiation.

### 2.2 Preparation of Catalyst

The solutions of  $\text{AgNO}_3$ ,  $\text{Na}_2\text{HPO}_4 \cdot 12\text{H}_2\text{O}$ , and 25% ammonia are prepared under deionized water separately as solution-1, 2, and 3,

respectively. Solution-1 was prepared by dissolving the 2.5485 g of  $\text{AgNO}_3$  to 50 mL of deionized water and solution-2 was prepared by adding the 1.7895 g of  $\text{Na}_2\text{HPO}_4 \cdot 12\text{H}_2\text{O}$  to 50 mL of deionized water. These solutions were created under stirring to dissolve the precursors quickly. Solution-3 was created by adding the 25% of ammonia solution to the deionized water with the variations of ammonia concentration at 0.00 M, 0.05 M, 0.15 M, and 0.30 M in 100 mL of solution. The photocatalyst was synthesized by dripping solution-3 to the solution-1 under stirring until the color of the solution changed into blackish-brown due to the formation of Ag complexes with ammonia. Then, the solution-2 was added drop by drop to this mixture solution until the solution changed to a yellow-light suspension. The yellow-light precipitates were filtered and washed 3 times with deionized water. The resulting yellow-light precipitate was dried in an oven for 7 hours at 105 °C. The samples, with the concentration of 0.00 M, 0.05 M, 0.15 M, and 0.30 M, were named as  $\text{Ag}_3\text{PO}_4$ ,  $\text{Ag}_3\text{PO}_4\text{-0.05}$ ,  $\text{Ag}_3\text{PO}_4\text{-0.15}$ , and  $\text{Ag}_3\text{PO}_4\text{-0.30}$ , respectively. To know the effect of calcination temperatures, the catalyst with the highest photocatalytic activity was calcined at various temperatures of 300, 400, 500, 600, and 700 °C for 5 hours.

Chemical oxygen demand (COD) of photocatalytic activity results was evaluated using simple technique by APHA [15] with modification, typically a 10 mL of deionized water as control and Rhodamine B solution (before and after photocatalysis treatment) separately poured into 100 mL Erlenmeyer and then mixed with 0.1 g of  $\text{HgCl}_2$  and 2 mL of  $\text{KMnO}_4$  0.01 M, respectively. Control and Rhodamine B samples were heated under hotplate stirrer until boiled up for 5-10 minutes, then cooled until room temperature condition for a while. The aqueous solution of 2 mL of  $\text{H}_2\text{SO}_4$  4 N and 1 mL of KI 10% were poured into control and Rhodamine B samples, respectively. Subsequently, they were titrated using  $\text{Na}_2\text{S}_2\text{O}_3$  0.05 N aqueous solution and it can be stopped for a minute when the solution turned into a yellow light and thus added some droplets of amylum (solution then changed to be a blue dark color). The titration could be continued until the blue dark color of the solution was disappeared exactly. Noted that all samples were repeated by duplet examination. The concentration of samples can be calculated by the formula as follows:  $\text{COD dose} = ((A-B) \times N \times 8000)/S$ ; where A and B are volume (mL) of  $\text{Na}_2\text{S}_2\text{O}_3$  for control (deionized water) and sample (Rhodamine B before and after photocatalysis treatment), re-

spectively;  $N$  is the concentration of  $\text{Na}_2\text{S}_2\text{O}_3$  (0.05 N) and  $S$  is the volume (mL) sample which is used in this experiment (10 mL).

### 2.3 Characterization

The prepared samples were characterized by Scanning Electron Microscopy (SEM), UV-Vis Diffuse Reflectance (DRS), and X-ray Diffraction (XRD).

### 2.4 Photocatalytic Activity Test

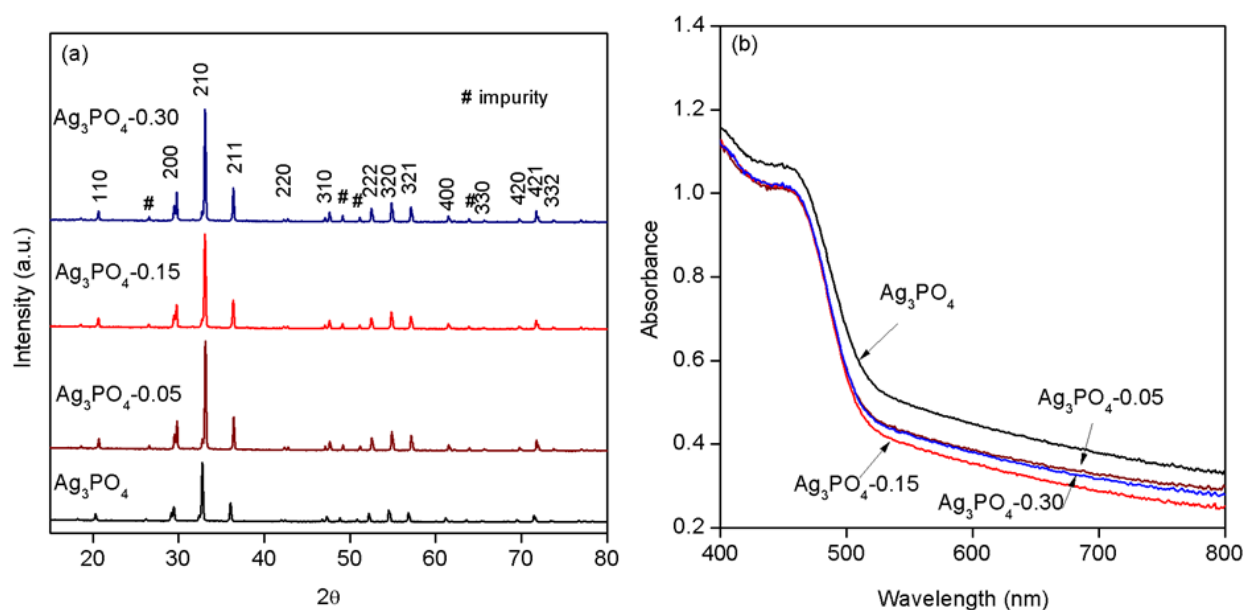
Typically, an amount of 0.1 gram catalysts mixed with 80 mL of 10 mg/L Rhodamine B under blue light irradiation. The distance between the surface of the suspension and lamp was set at 20 cm. The photodecomposition reaction initially set in the dark condition for 10 minutes to ensure the adsorption-desorption equilibrium between catalyst and dyes in suspension. When the lamp was turned on, the sample was drawn every 1 minute until a certain time for absorbance measurement. Afterward, the sample was centrifuged at 2000 rpm for 30 minutes and the concentration of filtrate was measured by UV-visible spectroscopy. The sample of highest photocatalytic activity was also evaluated under the red, green and yellow of LED lamps.

## 3. Results and Discussion

Figure 1(a) and (b) showed the X-ray diffraction and UV-Vis diffuse reflectance spectra of  $\text{Ag}_3\text{PO}_4$ ,  $\text{Ag}_3\text{PO}_4\text{-0.05}$ ,  $\text{Ag}_3\text{PO}_4\text{-0.15}$ , and  $\text{Ag}_3\text{PO}_4\text{-0.30}$  photocatalysts, respectively.

Based on Figure 1 (a), the diffraction peaks of all samples could be identified as body-centered cubic structure (JCPDS no. 06-0505) [16], with small impurity indicating that the  $\text{Ag}_3\text{PO}_4$  photocatalysts with or without the addition of 25% ammonia solution were successfully synthesized by facile co-precipitation method. Moreover, the sharp peaks could be distinctly observed on the samples with the addition of 25% ammonia solution, indicating that the ammonia-treated photocatalyst has a highly crystallized structure compared to the pristine  $\text{Ag}_3\text{PO}_4$  [18].

The diffuse reflectance spectra were shown in Figure 1 (b). The edge absorption of  $\sim 530$  nm was observed in all samples, indicating that the photocatalyst has a good photocatalytic ability in visible light irradiation. The addition of ammonia in the synthesis of  $\text{Ag}_3\text{PO}_4$  decreased the absorbance. These decreased absorptions were attributed to the differences in morphology or particle size of catalyst [2,19]. Xingyuan *et al* [14] explained that the decrease in particle size of photocatalyst could shift absorption to the lower wavelength as well as increased its band gap energy. Conversely, a higher particle size can absorb the light of the higher wavelength and then decrease their band gap energy of photocatalyst. Using the calculation of direct transition, the band gap energy of 2.39, 2.41, 2.46, 2.45 eV were found at the samples of  $\text{Ag}_3\text{PO}_4$ ,  $\text{Ag}_3\text{PO}_4\text{-0.05}$ ,  $\text{Ag}_3\text{PO}_4\text{-0.15}$ , and  $\text{Ag}_3\text{PO}_4\text{-0.30}$ , respectively (Table 1). It was also similar to the previous re-



**Figure 1.** XRD (a) and DRS (b) spectra of  $\text{Ag}_3\text{PO}_4$  and  $\text{Ag}_3\text{PO}_4$  photocatalyst assisted by various ammonia concentration

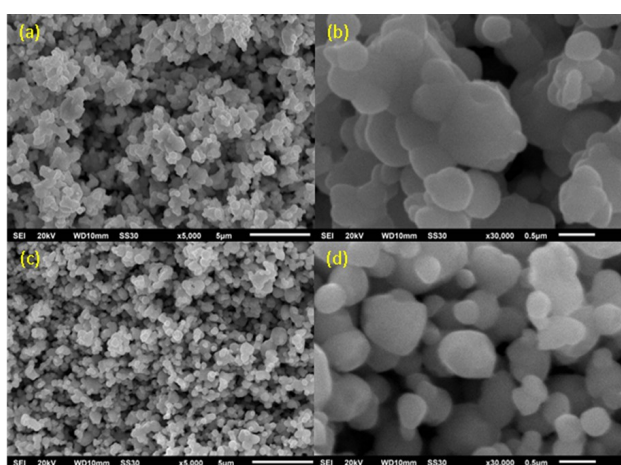
ports [20-21]. Therefore, these the band gap energies might not be the main reason for the enhanced photocatalytic activity.

The morphology of  $\text{Ag}_3\text{PO}_4$  and  $\text{Ag}_3\text{PO}_4\text{-}0.05$  can be seen in Figure 2. Sample without the addition of 25% ammonia solution exhibited a mixed morphology of spherical and irregular (Figure 2 (b)) with the particle size of  $\sim 0.5\text{--}2\text{ }\mu\text{m}$ . In contrast, the addition of 25% ammonia in the synthesis of  $\text{Ag}_3\text{PO}_4$  has successfully decreased the particle size to be  $\sim 0.2\text{--}1\text{ }\mu\text{m}$  (Figure 2 (d)). The agglomeration of the particle also could be decreased and the particles were more uniform compared to the pristine  $\text{Ag}_3\text{PO}_4$ . The decreased agglomeration and en-

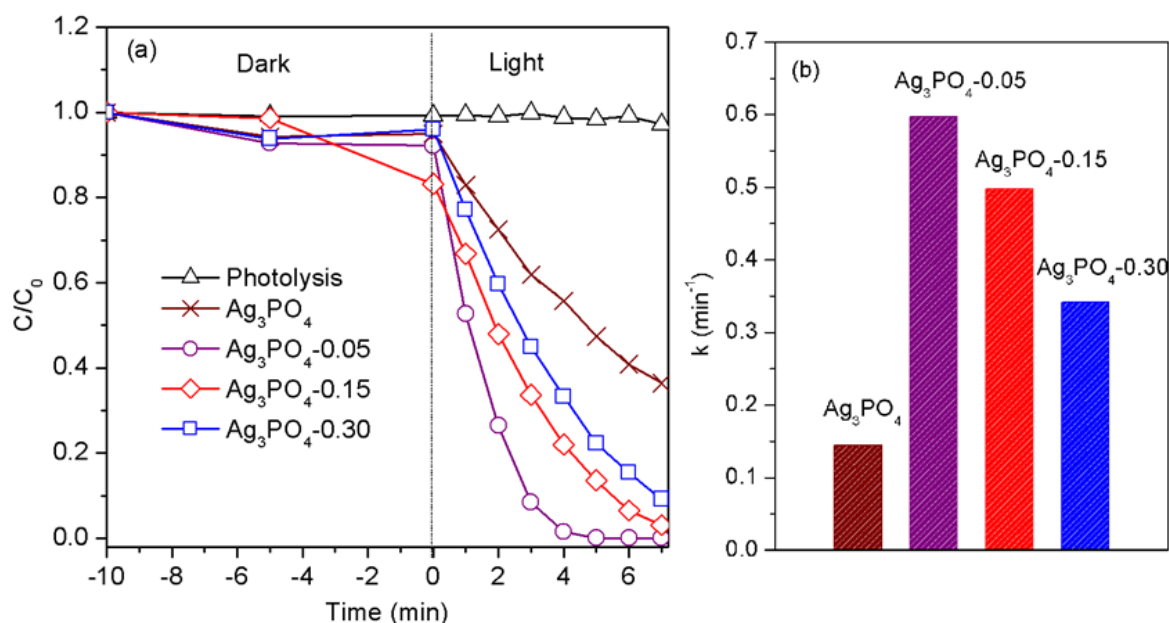
hanced homogeneity of particles might be caused by a formation of silver-amino ( $[\text{Ag}(\text{NH}_3)_2]^+$ ) complex. It was also similar to another report [11]. The  $[\text{Ag}(\text{NH}_3)_2]^+$  complex was created by the interaction of  $\text{Ag}^+$  and ammonia in the solution which was favorable to decrease the reaction rate and thus easily produced more well-structured particle or hindered the agglomeration. Moreover, these properties could increase the surface area and enhance the photocatalytic activity of the catalyst [22-25]. The high surface area could provide the more active site for photodecomposition of Rhodamine B.

Figure 3 (a) shows the photocatalytic activity of photocatalyst with and without the addition of a 25% ammonia solution. All samples have a good visible light driven-photocatalytic activity. The highest photocatalytic activity could be found in the sample of  $\text{Ag}_3\text{PO}_4\text{-}0.05$ , indicating that the addition of ammonia significantly affected the photocatalytic activity. However, the increase of ammonia concentration decreases the photocatalytic activities. A high photocatalytic activity of  $\text{Ag}_3\text{PO}_4\text{-}0.05$  photocatalyst is attributed to the smaller particle size and more uniform distribution that was obtained at the addition of 0.05 M ammonia solution.

The rate constant calculation in Rhodamine B photodegradation under blue light irradiation was also investigated using the pseudo-first-order kinetics model [26-27], as follows the formula:  $\ln(C_0/C) = kt$ ; where  $k$  is the rate



**Figure 2.** SEM images of  $\text{Ag}_3\text{PO}_4$  (a),  $\text{Ag}_3\text{PO}_4\text{-}0.05$  (c) and their magnifications of  $\text{Ag}_3\text{PO}_4$  (b) and  $\text{Ag}_3\text{PO}_4\text{-}0.05$  (d)



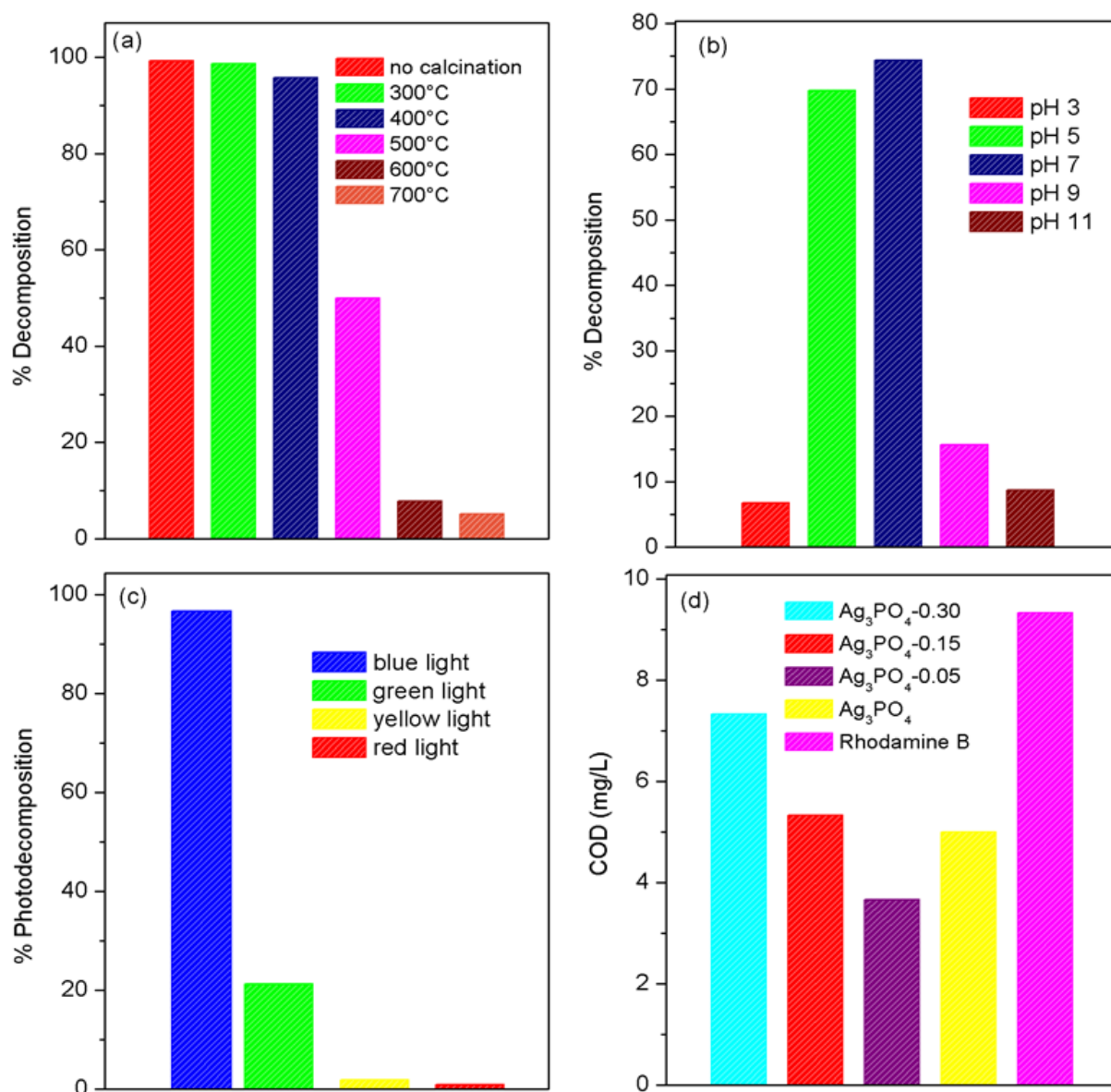
**Figure 3.** Photocatalytic activity (a) and rate constant (b) of  $\text{Ag}_3\text{PO}_4$  and  $\text{Ag}_3\text{PO}_4$  photocatalyst assisted by various ammonia concentration



constant,  $t$  is reaction time,  $C_0$  is initial concentration, and  $C$  is the concentration of dye in reaction time. According to the Figure 3(b) and Table 1, the photocatalytic reaction of Rhodamine B followed the pseudo-first-order-kinetics model. The rate constant of  $\text{Ag}_3\text{PO}_4$ ,  $\text{Ag}_3\text{PO}_4\text{-}0.05$ ,  $\text{Ag}_3\text{PO}_4\text{-}0.15$ , and  $\text{Ag}_3\text{PO}_4\text{-}0.30$  photocatalyst are 0.144, 0.597, 0.498, and 0.342  $\text{min}^{-1}$ , respectively. The rate constant of  $\text{Ag}_3\text{PO}_4\text{-}0.05$  photocatalyst shows 4.13 times higher than the  $\text{Ag}_3\text{PO}_4$  photocatalyst.

The highest photocatalyst ( $\text{Ag}_3\text{PO}_4\text{-}0.05$ ) was calcined at the various temperature and the results were shown in Figure 4(a). It showed that the calcination temperature had significant effects on photodegradation activi-

ties. The calcination at 300 °C and 400 °C showed that their photocatalytic activities were similar with the sample without calcination. The percent degradations of 98.71%, 95.80%, and 99.24% could be found in the sample calcined at 300 °C, 400 °C, and without calcination, respectively. The calcination at the higher temperature of 500 °C, 600 °C, and 700 °C showed the percent degradation of 49.94%, 7.93%, and 5.20%, respectively. The increase of temperature calcination more than 400 °C significantly decreased their photocatalytic activity. Some previous works reported that the calcination can influence the photocatalytic activity [28-29]. The calcination could also affect the active site, specific surface area, pore size



**Figure 4.** The effect of calcination temperature (a), pH condition (b), light sources (c) and COD test (d) of the photocatalyst in Rhodamine B photodegradation.

and pore volume of photocatalyst [30-32]. Dong and his co-workers [17] reported that the appropriate calcination treatment was beneficial to enhance the oxygen vacancies and create a defect on the  $\text{Ag}_3\text{PO}_4$  surfaces. These merits could promote the charge transfer and then increase the photocatalytic activities of the photocatalyst. Sulaeman and co-workers [33] also explained that the increase in calcination temperature increases the photocatalytic activity as well as the crystallinity of catalyst. However, calcination temperature in higher temperature could decrease the activity due to decreasing the active site or surface area of the catalyst.

The effect of pH on the photocatalytic reaction was also investigated and the results were shown in Figure 4(b). The higher photocatalytic activity could be observed in the neutral solution (pH=7) with the percent degradation of 74.39%, whereas the pH of 3, 5, 9, and 11 have the percent degradations of 6.79%, 69.77%, 15.66%, and 8.74%, respectively. In pH of 7, the surface of  $\text{Ag}_3\text{PO}_4$  has negative charge [34]. This surface can effectively attract the Rhodamine B dyes which have positive charges [34-35]. The adsorbed dyes onto  $\text{Ag}_3\text{PO}_4$  surfaces subsequently can be degraded directly under blue light irradiation.

The acid condition of the appropriate  $\text{H}^+$  ions (pH=5) enhanced the catalysis reaction through photogenerated  $\text{OH}^\bullet$  radicals that was generated by  $\text{H}_2\text{O}_2$  reacted with electron [36-37], but in the lowest pH condition (pH=3), the photocatalytic activity of catalyst could be poor. These could be explained by two plausible reasons: (1) catalyst like silver orthophosphate can be degraded in the lowest or extreme pH degrees (pH < 5). In the extreme acid situation, the  $\text{Ag}_3\text{PO}_4$  can be oxidized into  $\text{Ag}^+$  ions which dissolved clearly in Rhodamine B solution and subsequently decreasing their photocatalytic activity. In our experiment, the  $\text{Ag}_3\text{PO}_4$ -0.05 photocatalyst (without calcination) disappeared easily when the reaction time either less than

or reached to ~17 minutes of reaction time in pH 3, or (2) the low photocatalytic activity of catalyst could be caused by a successive  $\text{H}^+$  ions in suspension where anchored along the  $\text{Ag}_3\text{PO}_4$  surfaces thus creates a positive charge on the  $\text{Ag}_3\text{PO}_4$  surfaces. These can suppress the dyes adsorption due to the repulsion of catalyst and dyes [38]. Conversely, although in the appropriate base condition where  $\text{OH}^-$  ions are able to produce the photo-generated  $\text{OH}^\bullet$  radicals through hole and electron reaction mechanism [39-40], in the higher or extreme base condition, the photocatalytic activity decreases due to the reduction of  $\text{Ag}^+$  ions to  $\text{Ag}^0$  [23]. It could be considered that the optimum pH was achieved at a neutral condition or a pH of 7. The pH treatment (acid or base condition) decreases the photocatalytic activity due to disturbing the interaction of dye and the surface of the catalyst.

The effect of visible light sources was presented in Figure 4(c). Based on Figure 4(c), the photodegradation ability of  $\text{Ag}_3\text{PO}_4$ -0.05 photocatalyst under visible light sources were subsequently determined by light exposure test of red, yellow and green light of LED lamps. Compared to the other visible-light sources, the  $\text{Ag}_3\text{PO}_4$ -0.05 photocatalyst has higher photocatalytic activity under blue light irradiation with the percentage of Rhodamine B photodegradation was 96.67% whereas the visible-light sources of red, yellow and green were 0.93%, 1.92%, and 21.27%, respectively. It can be concluded that the optimum photocatalytic activity of  $\text{Ag}_3\text{PO}_4$ -0.05 photocatalyst is achieved under blue light irradiation ( $\lambda = \sim 445 \text{ nm}$ ). It is because that the blue light has a lower wavelength with the energy of  $\sim 2.79 \text{ eV}$ . This energy could promote the excitation of the electron in the valence band (VB) to the conduction band (CB) of  $\text{Ag}_3\text{PO}_4$  photocatalyst [33].

The COD (chemical oxygen demand) investigation was performed to find out the demineralization ability of catalysts (Figure 4(d)). Based on the experiment, it was found that

**Table 1.** Summary data of pure  $\text{Ag}_3\text{PO}_4$  and  $\text{Ag}_3\text{PO}_4$  photocatalyst assisted by various ammonia concentration

Photocatalysts	Band gap energy (eV)	$K_{app}$ ( $\text{min}^{-1}$ )	$\text{R}^2$
$\text{Ag}_3\text{PO}_4$	2.39	0.1442	0.9951
$\text{Ag}_3\text{PO}_4$ -0.05	2.41	0.5972	0.9384
$\text{Ag}_3\text{PO}_4$ -0.15	2.46	0.4980	0.9649
$\text{Ag}_3\text{PO}_4$ -0.30	2.45	0.3416	0.9791



Ag<sub>3</sub>PO<sub>4</sub>-0.05 photocatalyst showed the highest demineralization activity than those of all samples. The COD value of 9.33, 5.00, 3.66, 5.33 and 7.33 mg/L was observed at the samples of before photodecomposition, after photodecomposition using the Ag<sub>3</sub>PO<sub>4</sub>, Ag<sub>3</sub>PO<sub>4</sub>-0.05, Ag<sub>3</sub>PO<sub>4</sub>-0.15, and Ag<sub>3</sub>PO<sub>4</sub>-0.30, respectively. It was suggested that Rhodamine B was not only decolorized but also degraded by photocatalyst. However, the results ascribed that all catalysts could not completely degrade the dyes into small molecules such as CO<sub>2</sub>, H<sub>2</sub>O or non-toxic minerals due to the complexity of cyclohexane or bulky structure of Rhodamine B. We had supposed that the left complex compound of Rhodamine B could be completely degraded by prolonging reaction time. Wilhelm and Stephan [41] had also assumed that the complete demineralization of Rhodamine B needs a longer reaction time.

#### 4. Conclusions

The addition of 25% ammonia in the synthesis of Ag<sub>3</sub>PO<sub>4</sub> could affect the photocatalytic activity. The highest photocatalytic activity could be achieved at the addition of 0.5 M ammonia solution. This treatment could successfully decrease the particle size and increase the homogeneity of catalyst that improves the photocatalytic activity up to 4.13 times higher compared to the Ag<sub>3</sub>PO<sub>4</sub> synthesized without ammonia solution. The excellent condition of photocatalytic activity was achieved at the sample prepared without calcination, degradation at pH of 7 and under blue light irradiation.

#### Acknowledgments

This research was financially supported by Directorate of Research and Community Services, Directorate General of Development and Research Enhancement, Ministry of Research, Technology and Higher Education of the Republic of Indonesia in the Scheme of Competency Grant, Contract Number: 059/SP2H/LT/DRPM/2018.

#### References

[1] Yi, Z., Ye, J., Kikugawa, N., Kako, T., Ouyang, S., Williams, H.S., Yang, H., Cao, J., Luo, W., Li, Z., Liu, Y., Withers, R.L. (2010). An Orthophosphate Semiconductor with Photooxidation Properties Under Visible-Light Irradiation. *Nature Materials*, 9: 559-564.

[2] Febiyanto, Eliani, I.V., Riapanitra, A., Sulaeman, U. (2016). Synthesis and Visible Light Photocatalytic Properties of Iron Oxide-Silver

Orthophosphate Composites. *AIP Conference Proceedings*, 1725: 020021.

[3] Ge, M. (2014). Photodegradation of Rhodamine B and Methyl Orange by Ag<sub>3</sub>PO<sub>4</sub> Catalyst Under Visible Light Irradiation. *Chinese Journal of Catalysis*, 35: 1410-1417.

[4] Qamar, M., Elsayed, R.B., Alhooshani, K.R., Ahmed, M.I., Bahnemann, D.W., (2015). Chemoselective and Highly Efficient Conversion of Aromatic Alcohols Into Aldehydes Photo-Catalyzed by Ag<sub>3</sub>PO<sub>4</sub> in Aqueous Suspension Under Simulated Sunlight. *Catalysis Communications*, 58: 34-39.

[5] Dong, P., Yin, Y., Xu, N., Guan, R., Hou, G., Wang, Y. (2014). Facile Synthesis of Tetrahedral Ag<sub>3</sub>PO<sub>4</sub> Mesocrystal and Its Enhanced Photocatalytic Activity. *Materials Research Bulletin*, 60: 682-689.

[6] Riapanitra, A., Futiha, I., Sulaeman, U., Yin, S., Sato, T. (2015). The Role of Fe<sup>2+</sup> Ions on The Photocatalytic Reaction of Ag<sub>3</sub>PO<sub>4</sub> for Rhodamine B Degradation. *Advanced Materials Research*, 1112: 158-162.

[7] Bi, Y., Hu, H., Ouyang, S., Lu, G., Cao, J., Ye, J. (2012). Photocatalytic and Photoelectric Properties of Cubic Ag<sub>3</sub>PO<sub>4</sub> Sub-Microcrystals With Sharp Corners and Edges. *Chem. Commun.* 48: 3748-3750.

[8] Bi, Y., Ouyang, S., Umezawa, N., Cao, J., Ye, J. (2011). Facet Effect of Single Crystalline Ag<sub>3</sub>PO<sub>4</sub> Sub-microcrystals on Photocatalytic Properties. *J. Am. Chem. Soc.*, 133: 6490-6492.

[9] Vu, T.A., Dao C.D., Hoang, T.T.T., Nguyen, K.T., Le, G.H., Dang, P.T., Tran, H.T.K., Nguyen, T.V., (2013). Highly Photocatalytic Activity of Novel Nano-Sized Ag<sub>3</sub>PO<sub>4</sub> for Rhodamine B Degradation Under Visible Light Irradiation. *Materials Letter*, 92: 57-60.

[10] Jiao, Z., Zhang, Y., Yu, H., Lu, G., Ye, J., Bi, Y. (2013). Concave Trisoctahedral Ag<sub>3</sub>PO<sub>4</sub> Microcrystals with High-Index Facets and Enhanced Photocatalytic Properties. *Chem. Commun.*, 49: 636-638.

[11] Wang, H., He, L., Wang, L., Hu, P., Guo, L., Han, X., Li, J. (2012). Facile Synthesis of Ag<sub>3</sub>PO<sub>4</sub> Tertrapod Microcrystals with An Increased Percentage of Exposed {110} Facets and Highly Efficient Photocatalytic Properties. *Cryst. Eng. Comm.*, 14: 8342-8344.

[12] Zhang, B., Wang, X., Liu, C., Tan, K., Xie, Z., Zheng, L. (2013). High-Efficiently Visible Light-Responsive Photocatalysts: Ag<sub>3</sub>PO<sub>4</sub> Tertahedral Microcrystals with Exposed {111} Facets of High Surface Energy. *Journal of Materials Chemistry A*, 1: 12635-12640.

[13] Yan, X., Gao, Q., Qin, J., Yang, X., Li, Y., Tang, H. (2013). Morphology-Controlled Syn-

- thesis of  $\text{Ag}_3\text{PO}_4$  Microcubes with Enhanced Visible-Light-Driven Photocatalytic Activity. *Ceramics International*, 39: 9715-9720.
- [14] Guo, X., Chen, C., Yin, S., Huang, L., Qin, W. (2015). Controlled Synthesis and Photocatalytic Properties of  $\text{Ag}_3\text{PO}_4$  Microcrystal. *Journal of Alloys and Compounds*, 619: 293-297.
- [15] APHA. (1995). Standard Method for The Examination of Water and Wastewater, 19<sup>th</sup> ed. American Public Health Association, Washington.
- [16] Wang, W.S., Du, H., Wang, R.X., Wen, T., Xu, A.W. (2013). Heterostructured  $\text{Ag}_3\text{PO}_4/\text{AgBr}/\text{Ag}$  Plasmonic Photocatalyst with Enhanced Photocatalytic Activity and Stability Under Visible Light, *Nanoscale*, 5: 3315-3321.
- [17] Dong, P., Hou, G., Liu, C., Zhang, X., Tian, H., Xu, F., Xi, X., Shao, R. (2016). Origin of Activity and Stability Enhancement for  $\text{Ag}_3\text{PO}_4$  Photocatalyst After Calcination. *Materials*, 9(968): 1-17.
- [18] Rawal, S.B., Sung, S.D., Lee, W.I. (2012). Novel  $\text{Ag}_3\text{PO}_4$  Composites for Efficient Decomposition of Gaseous 2-Propanol Under Visible-Light Irradiation, *Catalysis Communicatio*s, 17:131-135.
- [19] Yanhong, Y., Guan, H., Liu, S., Jiang, R. (2014).  $\text{Ag}_3\text{PO}_4/\text{Fe}_2\text{O}_3$  Composite Photocatalyst with An n-n Heterojunction Semiconductor Structure Under Visible-Light Irradiation, *Ceramics International*, 40: 9095-9100.
- [20] Sulaeman, U., Liu, B., Yin, S., Sato, T. (2017). Synthesis of  $\text{Ag}_3\text{PO}_4$  using Hydrophilic Polymer and Their Photocatalytic Activities under Visible Light Irradiation. *Bulletin of Chemical Reaction Engineering & Catalysis*, 12(2): 206-211.
- [21] Sulaeman, U., Febiyanto, F., Yin, S., Sato, T. (2016). The Highly Active Saddle-like  $\text{Ag}_3\text{PO}_4$  Photocatalyst Under Visible Light Irradiation. *Catalysis Communications*, 85: 22-25.
- [22] Xu, Y.S., Zheng, W.D. (2013). Morphology-Controlled Synthesis of  $\text{Ag}_3\text{PO}_4$  Microcrystals for High Performance Photocatalyst. *CrystEngComm*, 15: 5407-5411.
- [23] Liu, Y., Wang, J., Lu, H., Li, M., Chen, P., Fang, L. (2014). Facile Synthesis of Visible-Light-Driven  $\text{Ag}_3\text{PO}_4$  Nanocrystals Base on  $\text{IP}_6$  Micelles. *Catalysis Communications*, 55: 65-69.
- [24] Feng, S., Xu, H., Liu, L., Song, Y., Li, H., Xu, Y., Xia, J., Yin, S., Yan, J. (2012). Controllable Synthesis of Hexagonal-Shaped  $\beta\text{-AgI}$  Nanoplates in Reactable Ionic Liquid and Their Photocatalytic Activity. *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, 410: 23-30.
- [25] Yang, T., Yan, X., Guo, R., Zhang, W., Li, W., You, J. (2013).  $\text{Ag}/\text{AgBr}/\text{BiOBr}$  Hollow Hierarchical Microspheres with Enhanced Activity and Stability For RhB Degradation Under Visible Light Irradiation. *Catalysis Communications*, 42: 30-34.
- [26] Permadani, I., Phasa, D.A., Pratiwi, A.W., Rahmawati, F. (2016). The Composite of  $\text{ZrO}_2\text{-TiO}_2$  Produced from Local Zircon Sand as A Photocatalyst for The Degradation of Methylene Blue in A Single Batik Dye Wastewater. *Bulletin of Chemical Reaction Engineering & Catalysis*, 11(2): 133-139.
- [27] Sun, S., Chen, C., Sun, J., Peng, Q., Lu, K., Deng, K. (2013). Enhancement of Catalytic Degradation of Rhodamine B Under Sunlight with Au Loading  $\text{TiO}_2$  Nanotube Arrays. *Procedia Environmental Sciences*, 18: 620-624.
- [28] He, G., Qian, M., Sun, X., Chen, Q., Wang, X., Chen, H. (2013). Graphene Sheets-Based  $\text{Ag}/\text{Ag}_3\text{PO}_4$  Heterostructure for Enhanced Photocatalytic Activity and Stability Under Visible Light. *Powder Technology*, 246: 278-283.
- [29] Wang, B., Wang, L., Hao, Z., Luo, Y. (2015). Study on Improving Visible Light Photocatalytic Activity of  $\text{Ag}_3\text{PO}_4$  Through Morphology Control. *Catalysis Communications* 58: 117-121.
- [30] Kan, W.E., Roslan, J., Isha, R. (2016). Effect of Calcination Temperature on Performance of Photocatalytic Reactor System for Seawater Pretreatment. *Bulletin of Chemical Reaction Engineering & Catalysis*, 11(2): 230-237.
- [31] Guan, X., Shi, J., Guo, L., (2013).  $\text{Ag}_3\text{PO}_4$  Photocatalyst: Hydrothermal Preparation and Enhanced  $\text{O}_2$  Evolution Under Visible-Light Irradiation. *International Journal of Hydrogen Energy*, 38: 11870-11877.
- [32] Zhang, L., He, Y., Wu, Y., Wu, T. (2011). Photocatalytic Degradation of RhB Over  $\text{MgFe}_2\text{O}_4/\text{TiO}_2$  Composite Materials. *Materials Science and Engineering B*, 176: 1497-1504.
- [33] Sulaeman, U., Nisa, I.R., Riapanitra, A., Yin, S., Sato, T. (2014). The Highly Active Photocatalyst of Silver Orthophosphate Under Visible Light Irradiation for Phenol Oxidation. *Advanced Materials Research*, 896: 141-144.
- [34] Luo, L., Li, Y., Hou, J., Yang, Y. (2014). Visible Photocatalysis and Photostability of  $\text{Ag}_3\text{PO}_4$  Photocatalys. *Applied Surface Science*, 319: 332-338.
- [35] Santhi, T., Prasad, A.L., Manonmani, S. (2014). A Comparative Study of Microwave and Chemically Treated *Acacia nilotica* Leaf

- as An Eco Friendly Adsorbent For The Removal of Rhodamine B Dye From Aqueous Solution. *Arabian Journal of Chemistry*, 7: 494-503.
- [36] Zhang, F.J., Xie, F.Z., Zhu, S.F., Liu, J., Zhang, J., Mei, S.F., Zhao, W. (2013). A Novel Photofunction  $\gamma$ -C<sub>3</sub>N<sub>3</sub>/Ag<sub>3</sub>PO<sub>4</sub> Bulk Heterojunction for Decolorization of Rh.B. *Chemical Engineering Journal*, 228: 435-441.
- [37] Liu, W., Wang, M., Xu, C., Chen, S., Fu, X. (2013). Ag<sub>3</sub>PO<sub>4</sub>/ZnO: An Efficient Visible-Light-Sensitized Composite with Its Application in Photocatalytic Degradation of Rhodamine B. *Materials Research Bulletin*, 48: 106-113.
- [38] Ejhieh, A.N., Shamsabadi, M.K. (2013). Decolorization of A Binary Azo Dyes Mixture Using CuO Incorporated Nanozeolite-X as A Heterogeneous Catalyst and Solar Irradiation. *Chemical Engineering Journal*, 228: 631-641.
- [39] Chen, G., Sun, M., Wei, Q., Zhang, Y., Zhu, B., Du, B. (2013). Ag<sub>3</sub>PO<sub>4</sub>/Graphene-Oxide Composite with Remarkably Enhanced Visible-Light-Driven Photocatalytic Activity Toward Dyes in Water. *Journal of Hazardous Materials*, 244-245: 86-93.
- [40] Wang, X., Utsumi, M., Yang, Y., Shimizu, K., Li, D., Zhang, Z., Sugiura, N. (2013). Removal of Microcystins (-LR, -YR, -RR) by Highly Efficient Photocatalyst Ag/Ag<sub>3</sub>PO<sub>4</sub> Under Simulated Solar Light Condition. *Chemical Engineering Journal*, 230: 172-179.
- [41] Wilhelm, P., Stephan, D. (2007). Photodegradation of Rhodamine B in Aqueous Solution Via SiO<sub>2</sub>@TiO<sub>2</sub> Nano-Spheres. *Journal of Photochemistry and Photobiology A: Chemistry*, 185: 19-25.