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Dapatkan arah Transportasi Umum ke Departemen Teknik Kimia

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Table of Contents

THE 2ND INTERNATIONAL SYMPOSIUM OF INDONESIAN CHEMICAL ENGINEERING 2021: Enhancing Innovations and Applications of Chemical Engineering for Accelerating Sustainable Development Goals

PREV NEXT

Conference date: 6–7 October 2021
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PRELIMINARY

No Access . February 2023

Preface: 2nd ISIChem 2021: Enhancing Innovations and Applications of Chemical Engineering for Accelerating Sustainable Development Goals

AIP Conference Proceedings **2667**, 010001 (2023); https://doi.org/10.1063/12.0013074

No Access . February 2023

Committees: Enhancing Innovations and Applications of Chemical Engineering for Accelerating Sustainable Development Goals

AIP Conference Proceedings **2667**, 010002 (2023); https://doi.org/10.1063/12.0016718

FOOD SCIENCE AND TECHNOLOGY

No Access . February 2023

The effect of incubation temperature and pH buffer in β-galactosidase produced by *Lactobacillus lactis*

Nancy Siti Djenar, Joko Suryadi, Geraldy Andreas Sitepu and Army Adi Sutanningsih

AIP Conference Proceedings **2667**, 020001 (2023); https://doi.org/10.1063/5.0112340

SHOW ABSTRACT

No Access . February 2023

Drying of tomato slices using solar drying method

Suherman Suherman, Riri Marza Rilna, Naufal Afriandi, Evan Eduard Susanto and Hadiyanto Hadiyanto

AIP Conference Proceedings **2667**, 020002 (2023); https://doi.org/10.1063/5.0112428

SHOW ABSTRACT

No Access . February 2023

The effect of solvents and extraction time on anthocyanin extraction from butterfly pea (*Clitoria ternatea* L.)

Amin Abdillah Harahap, Kelvin Letare S. and Nuniek Hendrianie

AIP Conference Proceedings **2667**, 020003 (2023); https://doi.org/10.1063/5.0112770

SHOW ABSTRACT

No Access . February 2023

Comparison of sequential microwave/ultrasound and microwave extraction of total phenolic compounds from *Moringa oleifera* L.

Aji Prasetyaningrum, Bakti Jos, Kristinah Haryani and Gian Restu Prinanda

AIP Conference Proceedings **2667**, 020004 (2023); https://doi.org/10.1063/5.0130082

SHOW ABSTRACT

No Access . February 2023

Poly(methyl methacrylate) acid modified κ-carrageenan/alginate: Synthesis and physico-chemical characterization

Aji Prasetyaningrum, Dwi Purwati, Nur Rokhati, Yudhy Dharmawan and Ratnawati Ratnawati

AIP Conference Proceedings **2667**, 020005 (2023); https://doi.org/10.1063/5.0130085

SHOW ABSTRACT

No Access . February 2023

Microwave-assisted pretreatment and span 80 addition to improve the enzymatic hydrolysis of chitosan

Nur Rokhati, Heru Susanto, Nur ʻAini Hamada, Aprilia Khadijah Putri, Martin Raynaldi Simanjuntak and Widyah Anggraini

AIP Conference Proceedings **2667**, 020006 (2023); https://doi.org/10.1063/5.0129783

SHOW ABSTRACT

No Access . February 2023

Moisture removal observation of onion slice drying at various temperature

Putri Rousan Nabila, Ratnawati Ratnawati and Mohamad Djaeni

BROWSE VOLUMES

AIP Conference Proceedings **2667**, 020007 (2023); https://doi.org/10.1063/5.0112555

SHOW ABSTRACT

No Access . February 2023

Effect of plastic waste pollution in seawater to microplastic contamination in salt fields at Rembang

Nilawati Nilawati, Sunarsih Sunarsih and Sudarno Sudarno

AIP Conference Proceedings **2667**, 020008 (2023); https://doi.org/10.1063/5.0114071

SHOW ABSTRACT

No Access . February 2023

Optimization of black cumin oil separation process with food grade qualification using hydrodistillation method through pre-extraction treatment variation

Achmad Ferdiansyah Pradana Putra, Elisabeth Ratnani Wahyu Hapsari and Achmad Haris Sofani

AIP Conference Proceedings **2667**, 020009 (2023); https://doi.org/10.1063/5.0112561

SHOW ABSTRACT

No Access . February 2023

Stability of fish oil emulsion using modified alginate as emulsifier

Dyah H. Wardhani, Eni Sumarsih, Hana N. Ulya, Ryan S. Cahyono, Yusuf R. Rafidianto, Andri C. Kumoro and Nita Aryanti

AIP Conference Proceedings **2667**, 020010 (2023); https://doi.org/10.1063/5.0112254

SHOW ABSTRACT

No Access . February 2023

Optimization hydrogen peroxide oxidation of cassava starch to improve psychochemical properties with surface response method

Siswo Sumardiono, Fitri A. Idris, Eko Tribowo and Heri Cahyono

AIP Conference Proceedings **2667**, 020011 (2023); https://doi.org/10.1063/5.0115168

SHOW ABSTRACT

No Access . February 2023

Modification of cassava starch by hydrolysis and peroxide oxidation to improve physicochemical properties and application for coated peanut production

Noer Abyor Handayani, Albert Iskandar Koeswoyo, Sherly Zagita Listyani Nurhatta and Siswo Sumardiono

AIP Conference Proceedings **2667**, 020012 (2023); https://doi.org/10.1063/5.0113496

SHOW ABSTRACT

No Access . February 2023

Analog rice production using granulation, hot extrusion, and cold extrusion methods: An overview

Heny Kusumayanti, Siswo Sumardiono and Bakti Jos

AIP Conference Proceedings **2667**, 020013 (2023); https://doi.org/10.1063/5.0113814

SHOW ABSTRACT

No Access . February 2023

Heavy metals contamination in sea cucumber (*Phylloporus spiculatus*) at Kenjeran, Surabaya, Indonesia: Cracker product of small-medium sized enterprise

Ririn Sumiyani, Nurmalina Muliani, Catharina Ratna and Orchidea Rachmaniah

AIP Conference Proceedings **2667**, 020014 (2023); https://doi.org/10.1063/5.0112417

SHOW ABSTRACT

No Access . February 2023

The effect of ozonation on the physicochemical, thermal, and morphological properties of starch: An overview

Heri Cahyono, Bakti Jos and Siswo Sumardiono

AIP Conference Proceedings **2667**, 020015 (2023); https://doi.org/10.1063/5.0113548

SHOW ABSTRACT

ENERGY CONVERSION AND MANAGEMENT

No Access . February 2023

The input voltage and reaction time from dielectric barrier discharge treatment affect the biogas production and the reduction of pollutants in palm oil mill effluent

Reni Desmiarti, Nola Tri Utami, Muhammad Adios, Ofta Bima Sakti, Dharma Raka Saputra, Adinda Ratu Permata, Ariadi Hazmi and Maulana Yusup Rosadi

AIP Conference Proceedings **2667**, 030001 (2023); https://doi.org/10.1063/5.0114936

SHOW ABSTRACT

No Access . February 2023

Various active materials implications on the performance of all organic redox flow battery (AORFB) in aqueous electrolyte

Dessy Ariyanti and Aprilina Purbasari

AIP Conference Proceedings **2667**, 030002 (2023); https://doi.org/10.1063/5.0112201

SHOW ABSTRACT

Types and variations of buffer concentrations effect on biohydrogen productivity from sago dregs with fermentation method

Abdullah Abdullah, Hario Satmoko and Wahyu Zuli Pratiwi

AIP Conference Proceedings **2667**, 030003 (2023); https://doi.org/10.1063/5.0113935

SHOW ABSTRACT

No Access . February 2023

Bioethanol production from rice straw waste by enzyme catalyst using separated hydrolysis and fermentation (SHF) method

Indra Gunawan and Indro Sumantri

AIP Conference Proceedings **2667**, 030004 (2023); https://doi.org/10.1063/5.0112290

SHOW ABSTRACT

No Access . February 2023

Mini review of coal liquefaction using solvent extraction

Vitro Rahmat, Joko Wintoko, Muhammad Mufti Azis and Suryo Purwono

AIP Conference Proceedings **2667**, 030005 (2023); https://doi.org/10.1063/5.0113618

SHOW ABSTRACT

No Access . February 2023

The opportunity of using hydrogen produced from electrocoagulation process of hospital liquid waste as renewable energy source

Reno Pratiwi, Slamet Slamet, Raharjo Muttaqin and Dianah Salsha Dilla

AIP Conference Proceedings **2667**, 030006 (2023); https://doi.org/10.1063/5.0115636

SHOW ABSTRACT

No Access . February 2023

Experimental study on gasification of wood waste pellet and dual-fuel operation of diesel engine

Herri Susanto, Fadil Abdul Rahman, Gendewa Utomo and Indra Purwadi

AIP Conference Proceedings **2667**, 030007 (2023); https://doi.org/10.1063/5.0129754

SHOW ABSTRACT

No Access . February 2023

Production of electricity from food waste using microbial fuel cell and hydrolytic microorganisms

Fitria Nur Laily, Sri Rachmania Juliastuti, Raden Darmawan, Simpliste Dusabe, Nuniek Hendrianie, Orchidea Rachmaniah, Nurhikmah Nurhikmah and Novanda Radita Putraditama

AIP Conference Proceedings **2667**, 030008 (2023); https://doi.org/10.1063/5.0112304

SHOW ABSTRACT

SEPARATION AND PURIFICATION TECHNOLOGY

No Access . February 2023

Fouling reduction evaluation of PVA coated sZnO-PSf composite membrane in natural rubber wastewater treatment

Tutuk Djoko Kusworo, Budiyono Budiyono, Kristinah Haryani, Dani Puji Utomo, Yeni Maryani Candra and Nur Asiyah

AIP Conference Proceedings **2667**, 040001 (2023); https://doi.org/10.1063/5.0112322

SHOW ABSTRACT

No Access . February 2023

Novel sulfonated zinc oxide embedded polysulfone (PSf-sZnO) membrane for rubber wastewater treatment

Tutuk Djoko Kusworo, Budiyono Budiyono, Kristinah Haryani, Dani Puji Utomo, Yeni Maryani Candra and Nur Asiyah

AIP Conference Proceedings **2667**, 040002 (2023); https://doi.org/10.1063/5.0112321

SHOW ABSTRACT

Ultrasound assisted extraction of microalgae *Spirulina sp.*

Alinda Fitrotun Nisya, Rochmadi Rochmadi and Arief Budiman

AIP Conference Proceedings **2667**, 040003 (2023); https://doi.org/10.1063/5.0112300

SHOW ABSTRACT

No Access . February 2023

Extraction of caffeine from dark Chinese tea using ethyl lactate solvent and its encapsulation with alginate and chitosan

Aprilina Purbasari, Edoardo Gilang Savio and Jabbar Akbar

AIP Conference Proceedings **2667**, 040004 (2023); https://doi.org/10.1063/5.0112284

SHOW ABSTRACT

No Access . February 2023

Production of fuelgrade bioethanol as a renewable alternative fuel by utilizing rice husk waste as a nano adsorbent with ultrasonic milling process

Abdullah Farhan Taqiyya, Nanda Putri Rahmawati, Ilham Avicenna Iksanto and Tutuk Djoko Kusworo

AIP Conference Proceedings **2667**, 040005 (2023); https://doi.org/10.1063/5.0113771

SHOW ABSTRACT

No Access . February 2023

The extraction of kaffir lime *(Citrus hystrix DC.)* peel and leaf essential oil by using water distillation and steam distillation methods

Maulidah Haniati, Alifah Nur Aini Fajrin, Putri Amalia Devianda, Annas Wiguno, Rizky Tetrisyanda and Kuswandi Kuswandi

AIP Conference Proceedings **2667**, 040006 (2023); https://doi.org/10.1063/5.0112771

SHOW ABSTRACT

No Access . February 2023

Comparison of pretreatment process of sodium hydroxide and soaking in aqueous ammonia for delignification of rice husk

Indro Sumantri, Yordianto Yordianto, Priscila Indah Ratnasari, Hadiyanto Hadiyanto and Suherman Suherman

AIP Conference Proceedings **2667**, 040007 (2023); https://doi.org/10.1063/5.0114052

SHOW ABSTRACT

No Access . February 2023

Model of fouling mechanism in ultrafiltration and micellar-enhanced ultrafiltration membrane for reactive dye removal

Nita Aryanti, Vania Frimasgita Giraldi, Heru Susanto, Tutuk Djoko Kusworo, I. Nyoman Widiasa and Nur Rokhati

AIP Conference Proceedings **2667**, 040008 (2023); https://doi.org/10.1063/5.0118033

SHOW ABSTRACT

No Access . February 2023

Preparation of CNT used surfactant for activity CNT-TiO_2 composites

Desi Heltina, Nadhia Gasani Putri, Utari Avisa, Arif Partama and Komalasari Komalasari

AIP Conference Proceedings **2667**, 040009 (2023); https://doi.org/10.1063/5.0113672

SHOW ABSTRACT

No Access . February 2023

Extraction of kaffir lime essential oil (*Citrus hystrix DC.*) with ethanol/n-hexane solvents

Anik Andayani, Maudina Alfira Adzany, Putri Amalia Devianda, Annas Wiguno and Kuswandi Kuswandi

AIP Conference Proceedings **2667**, 040010 (2023); https://doi.org/10.1063/5.0112749

SHOW ABSTRACT

No Access . February 2023

Preparation and performance of interlayer-free organosilica

Noor Aisya Maulida, Siti Humaeroh Fitriah, Aliah Aliah, Erdina Lulu Atika Rampun and Muthia Elma

AIP Conference Proceedings **2667**, 040011 (2023); https://doi.org/10.1063/5.0112161

SHOW ABSTRACT

No Access . February 2023

Rubber wastewater treatment using integrated process ozonation-PSf-sZnO membrane filtration

Tutuk Djoko Kusworo, Dani Puji Utomo, Yeni Maryani Candra, Nur Asiyah and Muhammad Itsar Hanif

AIP Conference Proceedings **2667**, 040012 (2023); https://doi.org/10.1063/5.0112320

SHOW ABSTRACT

No Access . February 2023

Cellulose acetate – Based mixed matrix membrane for methylene blue wastewater treatment

Putu Doddy Sutrisna, Ronaldo Pangestu Hadi, Candra Wijaya, Jessy Liliani and Christoper Robby

AIP Conference Proceedings **2667**, 040013 (2023); https://doi.org/10.1063/5.0112184

SHOW ABSTRACT

Production of nano filter mask as a Covid-19 prevention effort by using an integrated nanofiltration membrane nanosilver-TiO_2-chitosan

Vinalia Agustiani, Aufa Rasendriya, Lailatul Khoiriyah and Tutuk Djoko Kusworo

AIP Conference Proceedings **2667**, 040014 (2023); https://doi.org/10.1063/5.0112270

SHOW ABSTRACT

No Access . February 2023

Purification technology of fermented bioethanol using reflux system distillation

Hargono Hargono, Noer Abyor Handayani, Siswo Sumardiono and Muhammad Fahmi Zakaria

AIP Conference Proceedings **2667**, 040015 (2023); https://doi.org/10.1063/5.0114502

SHOW ABSTRACT

No Access . February 2023

The effect of solid waste clay bath pre-treatment on characteristic of $CaCO_3$ product

Rezi Miravion, Hadiyanto Hadiyanto, Luqman Buchori and Widayat Widayat

AIP Conference Proceedings **2667**, 040016 (2023); https://doi.org/10.1063/5.0114231

SHOW ABSTRACT

BROWSE VOLUMES

ADVANCED AND SMART MATERIAL DEVELOPMENT

No Access . February 2023

Study of doping Sn atom in silicene nanoribbons in the presence of an external electric field

Hoang Van Ngoc

AIP Conference Proceedings **2667**, 050001 (2023); https://doi.org/10.1063/5.0112575

SHOW ABSTRACT

No Access . February 2023

Utilization of fly ash as granular adsorbent material for removal of naphthol dyes

Aprilina Purbasari, Purwanto Purwanto, Bambang Pramudono, Slamet Priyanto and Evi Fitriani

AIP Conference Proceedings **2667**, 050002 (2023); https://doi.org/10.1063/5.0112271

SHOW ABSTRACT

No Access . February 2023

Pristine and modified graphene oxide utilization for organic pollutants removal

Dessy Ariyanti, Dina Lesdantina and Aprilina Purbasari

AIP Conference Proceedings **2667**, 050003 (2023); https://doi.org/10.1063/5.0112202

SHOW ABSTRACT

No Access . February 2023

The influence of calcium chloride and potassium chloride cross-linking agent on the physical properties of chitosan-carrageenan composite film

Nur Rokhati, Farida D. Hapsari and Aji Prasetyaningrum

AIP Conference Proceedings **2667**, 050004 (2023); https://doi.org/10.1063/5.0129789

SHOW ABSTRACT

No Access . February 2023

Mechanical properties of natural filling materials for eggshell, rice husk and kenaf in the production of natural rubber latex foam (NRLF) : Review

Ayuni Yustira, Maulida Lubis, Hafifuddin Arif and Andre Pranata

AIP Conference Proceedings **2667**, 050005 (2023); https://doi.org/10.1063/5.0113145

SHOW ABSTRACT

No Access . February 2023

Enhance the surface functionality of sugarcane bagasse and rice husk-based magnetic nanoparticle biocomposites by amine group

AIP Conference Proceedings **2667**, 050006 (2023); https://doi.org/10.1063/5.0112267

SHOW ABSTRACT

No Access . February 2023

Performance of antimicrobial ZnO nanoparticle synthesized by biological method: Literature review

Vita Wonoputri, Jason Wijaya, Vincent Augusta Primayudha, Shafira Khairunnisa and Tjokorde Walmiki Samadhi

AIP Conference Proceedings **2667**, 050007 (2023); https://doi.org/10.1063/5.0118678

SHOW ABSTRACT

No Access . February 2023

Decreased levels of FFA (free fatty acid) kemiri Sunan oil with adsorption process using modified Yogyakarta natural zeolite

Didi Dwi Anggoro, Luqman Buchori, Lutfi Hargita Septiawan and Salma Talitha Sani

AIP Conference Proceedings **2667**, 050008 (2023); https://doi.org/10.1063/5.0112332

SHOW ABSTRACT

No Access . February 2023

Study of adsorption capacity on textile dyes and heavy metal (Pb^{2+}) using modified natural zeolite

Didi Dwi Anggoro, Bagas Nur Prayoga, Nabiilah Salsabiil and Luqman Buchori

AIP Conference Proceedings **2667**, 050009 (2023); https://doi.org/10.1063/5.0112356

SHOW ABSTRACT

The Input Voltage and Reaction Time from Dielectric Barrier Discharge Treatment Affect the Biogas Production and the Reduction of Pollutants in Palm Oil Mill Effluent

Reni Desmiarti[1, a)], Nola Tri Utami[1, b)], Muhammad Adios[1, c)], Ofta Bima Sakti[1, d)], Dharma Raka Saputra[1, e)], Ariadi Hazmi[2, f)], Maulana Yusup Rosadi[3, g)]

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Abstract. The performance of dielectric barrier discharge (DBD) treatment was investigated to demonstrate the potential use for palm oil mill effluent (POME) treatment in terms of biogas production and chemical oxygen demand (COD) and total solids (TS) reduction. The treatment was undergone by applying the different input voltage of 15, 20 and 25 kV for 3 hours of reaction time with a frequency of 50 Hz in a DBD glass reactor. The experiment was carried out at room temperature and under normal air pressure. The results showed that the biogas concentration increased with the increase of input voltage. The concentration of hydrogen, methane, carbon monoxide and carbon dioxide increased from the initial values by 85%, 10%, 33% and 99%, respectively, for the input voltage of 15 kV. Biogas concentration also increased with the prolonged reaction time, indicated that more energy was supplied to convert the organic pollutants to form biogas. The high reduction of pollutants in POME was achieved to 48% for COD and 42% for TS when the applied voltage increased to 25 kV. The low reduction of COD and TS was probably caused by the high pH value of POME used in this study, resulting a poor degradation and agglomeration of COD and TS.

INTRODUCTION

Indonesia is the world's top producer and exporter of palm oil with the production of the commodity amounted to around 48.4 million metric tons (Badan Pusat Statistik, 2020). In recent years, the production of palm oil had come under increased global scrutiny and criticism, due to detrimental effects on the environment. Along with the production of palm oil, palm oil mills generate large volumes of effluent from palm fruit extraction, in hereafter refers as palm oil mill effluent (POME). POME is considered as a high strength industrial wastewater which can be 100 times more polluting than municipal sewage (Wu et al., 2009). POME contains about 95–96% of water, 4–5% total solids (TS) and was also reported to have high biological oxygen demand (BOD), chemical oxygen demand (COD) and the presence of organic acids with unpleasant odor (Anuar et al., 2021). Furthermore, Mao et al. (2018) reported that 28 m^3 of methane was produced per ton of POME. POME is a prospective source for biogas production as an alternative renewable energy source (Desmiarti et al., 2021). Thus, sustainable treatment for POME produced from oil palm mills is required for safe disposal to the environment.

Numerous conventional treatments have addressed to be used for POME treatment, such as biological treatment (Rahman et al., 2018), coagulation and flocculation (Zahrim et al., 2017) and electrocoagulation (Ibrahim et al., 2018; Moussa et al., 2017). Pond treatment is widely used for POME treatment that consists of anaerobic, facultative, and aerobic systems. However, pond treatment is incapable to achieve satisfactory effluent quality due to ineffective pollutant degradation, high operating on aeration energy and pond desludging, polluting the receiving watercourses, as well as the emissions of gases (Show et al., 2021). Advanced treatments appear to be most favorable for degradation of highly concentrated organic pollutants in POME. For lab-scale, the use of dielectric barrier discharge (DBD) had demonstrated that organic pollutant could be removed as well as the successful production of biogas from POME (Desmiarti et al., 2021). DBD generates the oxidant agent, such as hydroxyl radicals (•OH-), hydrogen peroxide (H_2O_2) and ozone (O_3), which have a high oxidation potential to decompose organic compounds in water (Budiman and Wu, 2016; Hazmi et al., 2017). With different input energy and the presence of oxidant agents, the higher conversion, and the degradation of organic pollutants to form biogas in POME could be achieved through DBD treatment. To improve treatment efficacy, this study investigates the feasibility of DBD system to produce gas from POME by reducing the reaction time.

In this study, DBD reactor was equipped with the real time gas sensor with high sensitivity and detection limit to record the biogas produced from POME. The input voltage of 15, 20 and 25 kV and reaction time for 3 hours were identified for the experiment. This work can be used to diagnose the optimum conditions for biogas formation from POME in lab-scale. The aim of this study is to investigate the performance of DBD treatment by varying the input voltage and reaction time for biogas production from POME as well as the reduction potential for pollutants in POME assessed by COD and TS values.

MATERIALS AND METHODS

POME

The POME used in this study was purchased from Tranco Energi Utama Incasi Raya Group, a palm oil company located in Indrapura, West Sumatra, Indonesia. The POME was collected from the initial sedimentation tank, and the filtration was performed to remove dirt, plant cell debris, fibers, and other solids. The initial COD, TS and pH were 2866.2 mg/L, 456.9 mg/L, and 5.5, respectively. The proximate compositions of POME are shown in Table 1 (Salihu and Alam, 2012).

TABLE 1. The proximate compositions of POME

Components	Composition (%)
Moisture	6.99 ± 0.14
Crude protein	12.8 ± 1.30
Crude lipid	10.2 ± 1.24
Ash	14.9 ± 1.35
Carbohydrate	29.6 ± 2.44
Nitrogen free extract	26.4 ± 2.33
Total carotene	0.02 ± 0.00

DBD Treatment

A 3,500 mL glass was used as a DBD reactor and the working volume of POME was 800 mL. The system was operated at room temperature (25°C) and atmospheric pressure (1 atm) following by Desmiarti et., al, 2021. DBD system was equipped with a needle-plane electrode, with the needle electrodes was connected to a high voltage alternating current with a frequency of 50 Hz, while the plane electrode was connected to the ground. The input voltages used in this study were 15, 20 and 25 kV, were supplied to the AC source with the reaction time of 3 hours, and were recorded with a P6014A Tektronix high-voltage probe. The discharge currents were recorded using a TDS5104 oscilloscope through a P6021A current probe. A diaphragm pump was used to flow the gas from DBD reactor to an acrylic gas storage with the volume of 800 mL.

The degradation of organic pollutants in POME will create biogas, where carbohydrates are used as substrates for the following reactions.

$$(C_6H_{12}O_6)_{8\,(aq)} \rightarrow 8C_4H_8O_{2\,(aq)} + 16CO_{2\,(g)} + 16H_{2\,(g)} \qquad \Delta H = -7{,}855.5 \text{ kJ/mol} \qquad (1)$$

$$8C_4H_8O_{2\,(aq)} \rightarrow 16H_2O_{(g)} + 8CH_{4\,(g)} + 24C_{(s)} \qquad \Delta H = -2{,}344.7 \text{ kJ/mol} \qquad (2)$$

Analysis

A TGS 821, TGS 816, and CDM 7160 manufactured by Figaro Ltd., Japan was used to record the concentration of H_2, CH_4, and CO and CO_2 gas, respectively. A Pico ADC24 data logger was used to record the gas concentration for 3 hours reaction and transfer the electrical output signals to a personal computer. The pH, COD and TS were measured with the procedures described in the APHA standard methods.

RESULTS AND DISCUSSION

Biogas Production under Different Input Voltage

Fig. 1 shows the amount of biogas produced from POME with the variation of input voltage. DBD treatment generates the oxidant agents when the high voltage was applied and react with organic molecules in POME to form H_2, CH_4, CO, and CO_2. When the input voltage was increased to 25 kV, H_2 and CO concentration increased by 82% and 8%, respectively. The applied voltage could facilitate the energy abosorption by C═O in CO_2 to form CO. The high concentration of H_2 was thought that DBD treatment accelerated the formation of •O from C═O that will react with CH_4 and form H_2 (Mao et al. 2018). The increase of biogas production with the increase of input voltage indicates a high reaction of biodegradable substances in POME with oxidant agents produced from DBD treatment. Supplying a higher input voltage will enhance the concentration of oxidant agents and electron density, thus promote high conversion of CH_4 and CO_2.

The formation of biogas generally increased with the increase of reaction time. H_2 and CO concentrations are show the increase trend for applied voltage of 15 kV up to 86% and 10% at 15 kV, respectively. CO_2 and CH_4 show a stable trend of concentration with the prolonged reaction time. This indicates that the formation of CO_2 and CH_4 for higher applied voltage reached a maximum conversion due to limitation of energy density. Generally, prolonged reaction time can supply more energy consumption for biogas in DBD reactor, thus increasing the biogas production (Mao et al., 2018).

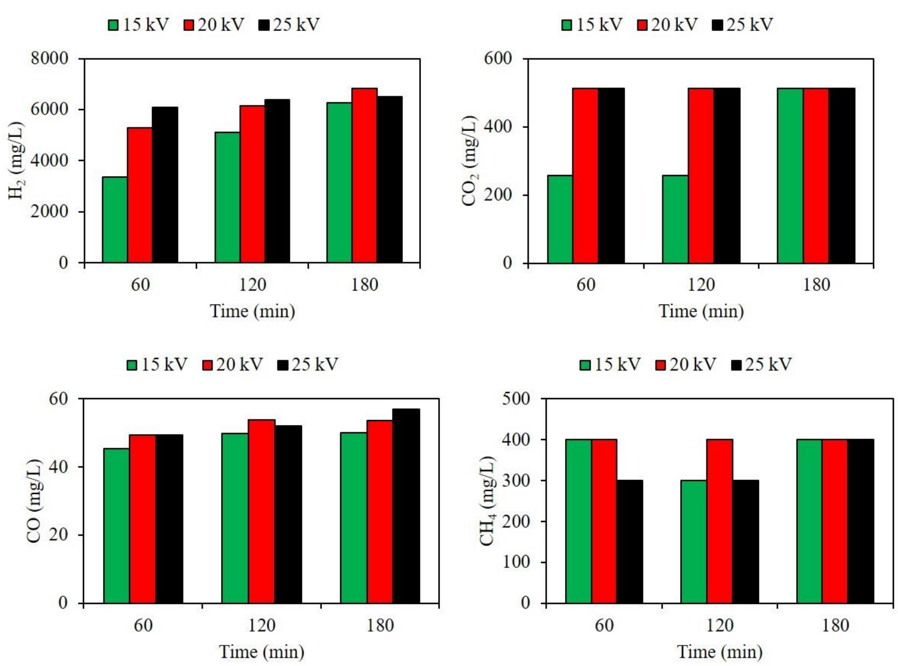

FIGURE 1. The amount of biogas produced from POME with different input voltage.

Effect of Input Voltage on the Reduction of COD and TS

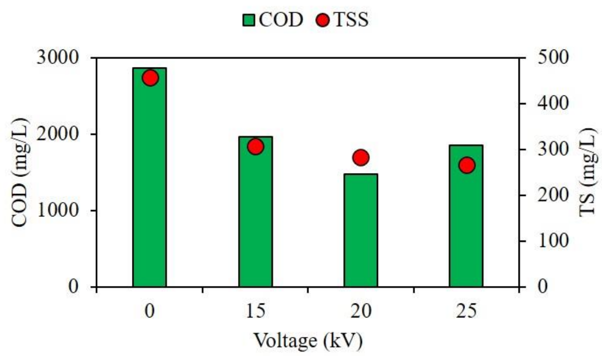

FIGURE 2. The amount of (a) H_2, (b) CO_2, (c) CO and (d) CH_4 produced from POME with different input voltage.

Besides enhance the production of biogas, DBD treatment can facilitate the biodegradation of POME by the reduction value of COD and TS. Fig. 2 shows the reduction amounts of COD and TS by adopting a different input voltage. The greatest percentage reduction of COD was observed at 20 kV, which corresponded to 49%, while TS reduction was observed higher for up to 42% at 25 kV. The lesser reduction of COD at 25 kV was probably due to the presence of high recalcitrant organic substances in POME that was not be able to react with oxidant agents during DBD treatment. However, the reduction of COD and TS in this study are generally lower to that corresponding study by Liew et al. (2021), where COD and TS removal was achieved for 88.9% and 61.5%, respectively. This may be due to the lower settle-ability and biodegradability of the POME used in this study.

The DBD treatment demonstrates the COD and TS reduction in POME by adopting a higher input voltage and electricity (Desmiarti et al., 2021). During DBD treatment, $\bullet OH^-$ generated and attacked the organic substances in POME and initiated the oxidation destruction through radical addition and directly reduced COD content (Taha and Ibrahim, 2014). DBD treatment also can precipitate the lignin content in POME and reduced the pH value, resulting a reduction in TS and pH dropped from 5.5 to 5. As the pH recorded as 5 at 25 kV, the result shows that lower pH can cause the agglomeration of lignin particles to form bigger and denser flocs, thus resulting lower TS value. This finding is concordant with a study by Taha and Ibrahim (2014) which showed that pH 2 accelerated the agglomeration of particles in POME, resulting lowest turbidity.

CONCLUSION

The input voltage and reaction time applied in DBD treatment were investigated to observe the potential production of biogas from POME as well as the reduction of COD and TS. Increasing the input voltage enhanced the conversion of POME to form H_2, CH_4, CO and CO_2 gas by DBD treatment for up to 86%, 33%, 10% and 99%, respectively. Reaction time also affects the production of biogas from POME. Increasing the reaction time when the voltage was 25 kV, biogas concentration increased to 7%, 33% and 16% for H_2, CH_4 and CO. COD and TS decreased with the increased of input voltage. The high reduction number of COD observed at 20 kV which corresponded to 49%, while TS reduction was observed 42% at 25 kV. The low reduction of pollutants in this study were likely to be caused by the high pH value of POME that could not facilitate a good performance of degradation of COD and agglomeration of TS. However, the current operational performance of this study needs further investigation (i.e., pH adjustment as pretreatment process). Decreasing pH value can accelerate the degradation process as well agglomeration process, resulting high reduction of COD and TS. This work provides the important information on understanding the DBD treatment system to the wastewater conservation and treatment, POME in particularly.

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CERTIFICATE

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