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TABLE OF CONTENTS

PARALLEL SESSION DISTRIBUTION

Agung Room 1 (Topic : Generation)		
Date : 21 October 2019	Session 1 (13.00 – 16.00)	HYATT REGENCY, YOGYAKARTA
ID PAPER	**TITLE**	**REVIEWER TEAM**
37	HEPAF and IGVM combination tecnology to control the industrial Gas Turbine performance, excess air and CO2 production *Okwaldu Purba and Adhi Eko Apriyanto*	Chairman: Dr. Umar Khayam, S.T., M.T. Co-Chairman: Dr. Zainal Arifin Secretary: Hendi Wijaya, ST, MT
54	Effect of Sodium Chloride Solution Concentration on Hydrogen Gas Production Produced in Water Electrolyzer Prototype *Rusdianasari Rusdianasari, Yohandri Bow, Tresna Dewi and Ahmad Taqwa*	
55	Dry Lay-Up Preservation Using Flue Gases as Preventive Maintenance in Reserved Shutdown Steam Power Plant *Muhammad Muhakkikin, Pronika Lilensi and Supri Arianto*	
101	Determining Optimum Start Priority for Peaker Power Plant with Multiple Gas Turbine *Komang Winadi, Muhammad Ferizqo and Arif Kurniawan*	
150	Optimal Design of Lubricated Journal Bearing Under Surface Roughness Arrangement *Mohammad Tauviqirrahman*	
171	Impact of Sizing and Placement on Energy Storage System in Generation Scheduling Considering Transmission Losses *Imron Imron, Lesnanto Multa Putranto, Sarjiya Sarjiya and Muhammad Yasirroni*	
56	E-Field Measurement for Electromagnetic Risk Identification in Oil and Gas Industry *Hazrul Izwan Hussien, Muhammad Akmal Ayob, Muhammad Akmal Abu Taib, Muhammad Faudzi M Yasir, Indhika Fauzhan Warsito*	

Agung Room 1 (Topic : Generation)		
Date : 21 October 2019	Session 2 (16.00 – 18.00)	HYATT REGENCY, YOGYAKARTA
ID PAPER	**TITLE**	**REVIEWER TEAM**
40	Case Study Of Straightening Methods For Bent Shaft 1.25 Mm On Hip Turbine Rotor Pacitan Steam Power Plant#1 *Yasfi, Muhammad Nasruddin and Hery Artady*	Chairman: Dr. Zainal Arifin Co-Chairman: Sarjiya, S.T., M.T., Ph.D., IPU Secretary: Hendi Wijaya, ST, MT
51	Plastic to Fuel: The Alternative Energy from Plastic Waste in PT PJB UP Paiton Area Using Pyrolysis Plant as Preventive Action Plastic Polluted Sea Water *Muhammad Khoiri Albana, Muhammad Yunus Qomarul Huda and Ramadhani Ramadhani*	
52	Numerical Analysis On The Effect Of Thread Modification On Air Nozzle For Cfb Boiler In PLTU Barru	

	Gede Satya Sarasamucchaya, Mohamad Afin Faisol, Tri Rinanto Mugiharjo, Wawan Hudayana and Muhammad Rai Fadhilah	
112	Learning Vector Quantization Based Vibration Analysis for Steam Power Plant Rotating Equipment Fault Diagnosis	
	Muhammad Insan Al Musthafa	
121	The Development of 35 GW Power Generation for Sustainability of PJB Existing Power Plant: An Assessment and Analysis on Java-Bali System	
	Indratno Pardiansyah and Adrian Untoro	

Agung Room 2 (Topic : Transmission and Distribution)		
Date : 21 October 2019	Session 1 (13.00 – 16.00)	HYATT REGENCY, YOGYAKARTA
ID PAPER	**TITLE**	**REVIEWER TEAM**
2	Determination of Overhead Conductors Curves with Quadratic Approach Based	Chairman: Sarjiya, S.T., M.T., Ph.D., IPU Co-Chairman: Dr. Eng. Ardyono Priyadi, S.T., M.Eng Secretary: Norayati binti Nordin
	Hermagasantos Zein, Sri Utami and Siti Saodah, Conny K. Wachjoe	
32	Lightning Detection Monitoring System For Identification Transmission Line Fault in PLN Trans JBT	
	Eki Farlen	
9	Fuzzy-PID Controller On MPPT PV To Stabilize DC Bus Voltage	
	Adhi Kusmantoro	
75	A Grid-connected Inverter with VAr Support Capability for A Small Scale Solar PV Using A Droop Technique	
	Ferdian Ronilaya, Widamuri Anistia, Ika Noer Syamsiana, Indrazno Siradjuddin, Mochammad Junus and Ariprimarta	
111	Lightning Simulation of Gravel Variant	
	Eko Supriyanto, Indhika Fauzhan Warsito, Muhammad Akmal Abu Taib, Muhammad Faudzi M Yasir and Indhina Reihannisha	
155	Experimental Analysis on Wireless Power Transfer for Continuous Charging of a Mobile Robot	
	Tresna Dewi, Pola Risma, Yurni Oktarina, Ahmad Taqwa, Lin Prasetyani and Ahmad Aman Astra	

Agung Room 2 (Topic : Transmission and Distribution)		
Date : 21 October 2019	Session 2 (16.00 – 18.00)	HYATT REGENCY, YOGYAKARTA
ID PAPER	**TITLE**	**REVIEWER TEAM**
36	The Design of Kalimantan Transmission System Interconnection in Electrical Stability Perspective	Chairman: Dr. Umar Khayam, S.T., M.T. Co-Chairman: Dr. Yulizar Widiatama, M.Eng Secretary: Norayati binti Nordin
	Ardyono Priyadi, Margo Pujiantara, Talitha Puspita Sari, Rahmat Febrianto Wijanarko, Vincentius Raki Mahindara, Adi Priyanto and Ira Savitri	
26	Loss Power Analysis In Transmission And Distribution Channels Of Prototype Wind Turbine Power Plant (PLTB)	
	Mahmuuda Catur and Agus Kiswantono	

35	Analysis of the Implementation of PASTI Energy Meter System in Achieving Operational Cost Efficiency, Case Study in PLN UID Jateng DIY	
	Hardian Sakti Laksana, Ivan Gede Histijanton and R Mirwanto	
38	Special Protection System With Macro Vba-Based Descending Method At PT PLN (Persero) South And Central Kalimantan	
	Ariesa Budi Zakaria, Ratna Nuringtyas and Anang Hardoyo minor revision	
65	An Analysis of Unified Power Flow Controller Placement Effect on Transmission Lines Total Transfer Capability	
	Handika Putra and Irfan Joyokusumo	

PROCEEDING: DOI:

Ballroom 1 (Topic : Policy)		
Date : 21 October 2019	Session 1 (13.00 – 16.00)	HYATT REGENCY, YOGYAKARTA
ID PAPER	**TITLE**	**REVIEWER TEAM**
67	Indonesia Opportunity To Accelerate Energy Transition *Muhammad Arifianto Chairiawan*	Chairman: Dr. Telisa Aulia Falianty Co-Chairman: Dr. Eng. Agus Purwanto, S.T., M.T. Secretary: Nur Faizal bin Kasri
72	Study of AGC in The Sarawak – West Kalimantan Interconnected Power System under Deregulated Scenario *Bagas Maulana Sutardi, M Iqra Orytuasikal and M Fasih Mubarrok*	
80	Execution of Energy Management System in High Rise Office Building (Case Study in SSS Building) *Marsul Siregar, Tajuddin Nur and Firma Purbantoro*	
85	Corporate Strategy Using Strategic Portfolio Analysis in Facing Renewable & Liberalized Electricity Era *Herry Nico Siagian and Fransiscus Adam Perkasa*	
96	Implementation of Risk Analysis using Monte Carlo Simulation on Electricity Investment Decision Making, Case Study: Steam and Combined Cycle Power Plant Development in Indonesia *Herry Nico Siagian and Vernon Sapalatua*	
129	Financial Risk Assessment For Power Plant Investment Under Uncertainty Using Monte Carlo Simulation *Abduh Sayid Albana and Yudha Andrian Saputra*	
163	Smart Grid Initiatives in South East Asian Countries : What Are Being Done in The Early Stage *Revi Aldrian, Daniel Tampubolon and Iman Faskayana*	

<table>
<tr><th colspan="3">Ballroom 1 (Topic : Policy)</th></tr>
<tr><td>Date : 21 October 2019</td><td>Session 2 (16.00 – 18.00)</td><td>HYATT REGENCY, YOGYAKARTA</td></tr>
<tr><td>ID PAPER</td><td>TITLE</td><td>REVIEWER TEAM</td></tr>
<tr><td rowspan="2">78</td><td>Market Survey on the Addition of Cilegon Fuel Gas Compression Capacity as the Sourcing Best Practice of EPC Small Scale Project</td><td rowspan="10">Chairman:
Dr. Matthew Stocks

Co-Chairman:
Dr. Eng. Agus Purwanto, S.T., M.T.

Secretary:
Achmad Alfian Hidayat, S.ST, MT</td></tr>
<tr><td>Muhammad Imaduddin</td></tr>
<tr><td rowspan="2">84</td><td>Digitalization Solution on Customer Services to Leverage the Ease of Getting Electricity</td></tr>
<tr><td>Wisnu Cahyono, Wahyu Haris Kusuma Atmaja and Asteria Palupi Karyuniati</td></tr>
<tr><td rowspan="2">95</td><td>Development Of Predictive Maintenance Methodology Utilizing Machine Learning Technology To Support Plant Health Management</td></tr>
<tr><td>Mochamad Soleh, Aghil Riyadi and Annisa Prima Asnel</td></tr>
<tr><td rowspan="2">120</td><td>PLN Premium Electricity Policy Estimation of Renewable Energy Tariff Using Life Cycle Assessment for Industrial needs in Eco-Friendly Electricity Demand to Accelerate Indonesia Renewable Energy Development</td></tr>
<tr><td>Muhammad Khoiri Albana and Robby Ramadhan</td></tr>
<tr><td rowspan="2">162</td><td>Price Demand Elasticity And Potential Saving Of Electric Subsidies: Empirical Evidence Of Household Socio-Economic Survey</td></tr>
<tr><td>Andri Supriyadi and Telisa Falianty</td></tr>
<tr><th colspan="3">Ballroom 2 (Topic : Smart Grid and Renewable Energy)</th></tr>
</table>

Date : 21 October 2019	Session 1 (13.00 – 16.00)	HYATT REGENCY, YOGYAKARTA
ID PAPER	**TITLE**	**REVIEWER TEAM**
46	Environmentally Friendly Synthesis of LiNi0.80Co0.15Al0.05O2 Cathode Material for Li-ion Batteries and Its Galvanostic Test Using Artificial Graphite Anode	Chairman: Mochammad Facta, S.T., M.T., Ph.D. Co-Chairman: Dr. Yulizar Widiatama, M.Eng Secretary: Achmad Alfian Hidayat, S.ST, MT
	Setia Utaminingtyas, Cornelius Satria Yudha, Muhammad Nur Ikhsanudin, Soraya Ulfa Muzayanha, Agus Purwanto and Hendri Widiyandari	
47	NaCl Doped LiNi0.8Co0.15Al0.05O2 via Solid-State Reaction for Li-Ion Batteries	
	Muhammad Nur Ikhsanudin, Cornelius Satria Yudha, Setia Utaminingtyas, Agus Purwanto, Hendri Widiyandari, Arif Jumari and Endah Retno Dyartanti	
98	Thermal Analysis of PV Module and the Effect on its Efficiency	
	Rivan Muhfidin and Ing-Song Yu	
122	Analysis and Evaluation Performance of MPPT Algorithms: Perturb & Observe (P&O), Firefly, and Flower Pollination (FPA) in Smart Microgrid Solar Panel Systems	
	Suyanto, Luthfansyah Mohammad, Iwan Cony Setiadi and Roekmono	
133	Analysis of Voltage and Power Factor Fluctuation due to Photovoltaic Generation in Distribution System Model	
	Dhandis Rito Jintaka, Aristo Adi Kusuma, Handrea Bernando Tambunan, Muhammad Ridwan and Buyung Sofiarto Munir	
143	Comparative Analysis Between Fixed Tilt And Tracked Pv System In Tropical Climate	
	Rifky Raymond, Aripriantoni - and Dimas Kaharudin Indra Rupawan	
166	Towards 100% renewable electricity for Indonesia: the role for solar and pumped hydro storage	
	Matthew Stocks, Bin Lu, Cheng Cheng and Andrew Blakers	

Ballroom 2 (Topic : Smart Grid and Renewable Energy)

Date : 21 October 2019	Session 2 (16.00 – 18.00)	HYATT REGENCY, YOGYAKARTA
ID PAPER	**TITLE**	**REVIEWER TEAM**
137	Design And Development Of Hardware-Agnostic Solar PV Automated Monitoring System	Chairman: Dr. Noor Akhmad Setiawan Co-Chairman: Mochammad Facta, S.T., M.T., Ph.D. Secretary: Akhmad Dahlan, M.Kom
	Rifky Raymond, Aripriantoni - and Dimas Kaharudin Indra Rupawan	
139	The Aplication Process of the Data Logger Results for Renewable Energy Potential Projection	
	Irwandi Gunanda and Avip Zainhaq	
160	Controlling Energy Consumption of Building with Using An Innovative CLC Brick under Smart Grid Program	
	Marwan Marwan	
168	Predicting Rooftop Photovoltaic Adoption In The Residential Consumers of PLN Using Agent-Based Modeling	

	Fajar Haryadi, Harry Indrawan and Meiri Triani	
172	Electric Vehicle Charging Load Forecasting Model Considering Road Network-Power Grid Information	
	Jun Yang, Xuemei Long, Xueli Pan, Fuzhang Wu, Xiangpeng Zhan and Yangjia Lin	

Agung Room 1 (Topic : Generation)		
Date : 22 October 2019	Session 3 (07.30 – 16.00)	HYATT REGENCY, YOGYAKARTA
ID PAPER	**TITLE**	**REVIEWER TEAM**
29	Investigation the Influence of Height and Length of the Magnet Edge Slotting of Fractional Slot Number in Permanent Magnet Generator on the Cogging Torque Reduction	Chairman: Dr. Zainal Arifin Co-Chairman: Dr. Rachmawan Budiarto, S.T., M.T. Secretary: Hendi Wijaya, ST, MT
	Tajuddin Nur, Liza Evelyn Joe and Karel O. Bachri	
82	Reducing the Cogging Torque of Integral Slot Number in Inset-Permanent Magnet Generator	
	Tajuddin Nur, Sri Mawar and Marsul Siregar	
115	Readiness Index for Indonesian Power Plant toward Industry 4.0	
	Paryanto Paryanto, Harry Indrawan and Nur Cahyo	
134	Water Supply System Based on Renewable Energy in Rawasari Village, Berbak District, Tanjung Jabung Timur Regency, Jambi Province, Indonesia	
	Dwi Novitasari, Dimas Deworo Puruhito, Zakariya Arif Fikriyadi, Rachmawan Budiarto and Fitrotun Aliyah	
141	New and renewable catalyst based on electro-activated carbon for hydrogen generation	
	Deni Shidqi Khaerudini, Hanifah Winarto, Andri Hardiansyah, Sagir Alva, Cecep Rustana, Denawati Junia and Fharuq Dirza Dirgantara	
169	Implementation of Low Speed Horizontal Axis Wind Turbines for Direct Driven Generator	
	Muldi Yuhendri	

Agung Room 1 (Topic : Generation)		
Date : 22 October 2019	Session 4 (10.00 – 12.00)	HYATT REGENCY, YOGYAKARTA
ID PAPER	**TITLE**	**REVIEWER TEAM**
66	Development of Alternative Clean Fuel for Co-firing in Coal Fired Power Plant	Chairman: Dr. Rachmawan Budiarto, S.T., M.T. Co-Chairman: Dr. Zainal Arifin Secretary: Hendi Wijaya, ST, MT
	Mochamad Soleh, Yudi Hidayat and Zaenal Abidin	
77	The estimation of the waste heat recovery in prime cookstove by using Thermoelectric Generators	
	Andrya Muhamad Zuhud, W Widayat and Muhammad Facta	
89	The characteristic of TEG module installed at the wall of the prime stove	
	Widayat Widayat, Facta Mohammad and Andrya Muhammad Zuhud	

119	Modelling Hybrid PV-Generator System Using MATLAB/SIMULINK At Jifak Village, Papua	
	Dwi Handoko Arthanto, Bernardus Galih Dwi Wicaksono, Arga Iman Malakani and Agus Purwadi	
165	Boiler Reliability of 100 MW Power Plant using Reliability Block Diagram (RBD)	
	Ariyana Dwiputra, M. Iqbal Felani and Nurcahyo Nurcahyo	

Agung Room 1 (Topic : Generation)		
Date : 22 October 2019	Session 5 (13.00 – 15.30)	HYATT REGENCY, YOGYAKARTA
ID PAPER	**TITLE**	**REVIEWER TEAM**
7	Numerical Study Characteristic of Non-Premixed Combustion in the HRSG Supplementary Firing	Chairman: Dr. Rachmawan Budiarto, S.T., M.T. Co-Chairman: Dr. Zainal Arifin Secretary: Hendi Wijaya, ST, MT
	Muhammad Fakhri, Arrad Safitra and Teguh Ariwibowo	
22	Process Control and Instrumentation Design of Biogas Treatment by using Labview	
	Winaldha Erza Nur Hafizah and Nugroho Adi Sasongko	
31	Evaluation Of Improvement Balancing Procedure As Proactive Maintenance Activity At Induced Draft Fan (Idf) Of Coal Fired Power Plant (CFPP) Lontar	
	Andi Rinaldi Hasan and Abdul Rokhim Al Apit	
33	Flyback Transformer As A Generator High Voltage In Frequency 3 - 10 Khz	
	Yuli Hermanto and Agus Kiswantono	
157	Energy Losses Analysis using Value Stream Mapping (VSM) Method: Power Plant Case Study	
	Wahyu Isa Arifin and Iwan Vanany	
170	Excessive Water Content Identifying Approach Using Sweep Frequency Response Analysist and Electrical Individual Test for Power Transformer	
	Muhammad Helmi Prakoso and Rizky Fajar Maulana	

Agung Room 2 (Topic : Transmission and Distribution)		
Date : 22 October 2019	Session 3 (07.30 – 10.00)	HYATT REGENCY, YOGYAKARTA
ID PAPER	**TITLE**	**REVIEWER TEAM**
13	Optimization Of Distance Relays Fault Locator With The Impedance Difference Method	Chairman: Dr. Eng. Ardyono Priyadi, S.T., M.Eng.
	Alfi Yulianta	

18	Current Transformer Challenges : Respond and Improvement for detecting Saturated CT and Reliability Line Current Differential Relay's outside zone fault experience *Reza Widya Hutama*	Co-Chairman: Dr. Umar Khayam, S.T., M.T. Secretary: Aji Hanggoro, ST, MT
86	Impact of Plug In Electric Vehicle on Uniformly Distributed System Model *Kevin Gausultan Hadith Mangunkusumo, Dhandis R Jintaka, Joko Hartono, Aristo Adi Kusuma and Buyung Sofiarto Munir*	
92	Modeling the Temperature of the Distribution Transformer Oil Using Transformer Body Temperature and Power Quality Parameters Based on Artificial Neural Network *Anang Tjahjono, Septian Wahyu Arjunady, Rosmaliati Rosmaliati, Rika Novita W and Taufik Taufik*	
145	Placement and Capacity Optimization of Unified Power Flow Controller using Imperialist Competitive Algorithm *Rini-Nur Hasanah, Rionaldi Wika Yuniatmoko and Hadi Suyono*	
153	Comparison Of Static Var Compensator (Svc) And Unified Power Flow Controller (Upfc) For Static Voltage Stability Based On Sensitivity Analysis : A Case Study Of 500 Kv Java-Bali Electrical Power System *Chico Hermanu Brillianto Apribowo and Oktavian Listiyanto*	

Agung Room 2 (Topic : Transmission and Distribution)

Date : 22 October 2019	Session 4 (10.00 – 12.00)	HYATT REGENCY, YOGYAKARTA
ID PAPER	**TITLE**	**REVIEWER TEAM**
10	On Digital Power Transmission Systems *Dodi Garinto*	Chairman: Dr. Umar Khayam, S.T., M.T. Co-Chairman: Dr. Eng. Ardyono Priyadi, S.T., M.Eng. Secretary: Aji Hanggoro, ST, MT
20	Re-Engineering GIS Salak Lama *Muhammad Alamin, Ammar Syahid Rabbani, Chairun Nisa Qory and Fajar Andy Setyawan*	
109	Corona Discharge in Cloud Voltage Variation *Eko Supriyanto, Indhika Fauzhan Warsito, Muhammad Akmal Abu Taib, Muhammad Faudzi M Yasir and Indhina Reihannisha*	
138	Protection Scheme 150 Kv Overhead Transmission Line Of T-Connection Configuration Siantan – Tayan – Sei Raya Substation *Andreas Simanjuntak, M. Ariansyah Putra and M Sabli*	
146	Optimal Tuning of PID Control on Single Machine Infinite Bus Using Ant Colony Optimization *A. M. Shiddiq Yunus and Muhammad Ruswandi Djalal*	
152	Optimization of Economic Dispatch of 150 kV Sulselrabar System using Lagrange Approach *A. M. Shiddiq Yunus and Muhammad Ruswandi Djalal*	

Agung Room 2 (Topic : Transmission and Distribution)

Date : 22 October 2019	Session 5 (13.00 – 15.30)	HYATT REGENCY, YOGYAKARTA
ID PAPER	**TITLE**	**REVIEWER TEAM**
23	Implementation Of Fault Current Limiter In West Java 150 Kv Transmission System *Johanno Wibowo, Abdur Rouf, Erliansyah Nur Muhammad and Syah Jahan Al Achmad*	Chairman: Dr. Umar Khayam, S.T., M.T. Co-Chairman: Dr. Eng. Ardyono Priyadi, S.T., M.Eng. Secretary: Aji Hanggoro, ST, MT
49	The Effect of Variations in Aging Time and Cooling Media of Artificial Aging and Natural Aging of Alumunium 6061 Alloy on Microstructures, Tensile Strength, Hardness, and Electrical Conductivity *Dian Mughni*	
71	Double Side Down Conductor As Lightning Safety For 150 KV Transmission Tower *Jamrotin Armansyah, Ervin Saputra and Azharizal Fajar Amruryad*	
73	IOT For Data Communication of Energy Meter at amr PT. PLN (Persero) *Widi Kristiawan, Heru Kismanto, Rijal Islami, Arief Budiman and Ozy Akbar*	
83	Automation Of Electricity System PLN UPDL Banjarbaru Using Passive Infrared Sensors *Soni Asmaul Fuadi and Ario Dwi Prabowo*	
107	Voltage Deviation Minimization Using GA (Genetic Algorithm) to obtain the Optimal Placement of the DG (Distributed Generation) and Capacitor on the three-phase Radial Distribution Network *Gama Dwi Nefanda, Wildan Arif Febrianto, Ontoseno Penangsang and Rony Seto Wibowo*	

Ballroom 1 (Topic : Policy)

Date : 22 October 2019	Session 3 (07.30 – 10.00)	HYATT REGENCY, YOGYAKARTA
ID PAPER	**TITLE**	**REVIEWER TEAM**
45	Electricity Demand Forecasting Using a Simple-E Expanded Approach at PT PLN (Persero) of Kotamobagu Area From 2018 to 2022 *Zakki Mubarok*	Chairman: Dr Matthew Stocks. Co-Chairman: Dr. Telisa Aulia Falianty. Secretary: Norayati binti Nordin
81	Demand Response Based on MIQP Method for Reducing Generation Cost *Fikriyan Fajar Al Farobi, Sarjiya Sarjiya, Lesnanto Multa Putranto and Muhammad Yasirroni*	
100	Study of Determining Cost Compensation of Power Wheeling Transaction on Composite System Reliability by Optimal Power Flow	

	Rifqi Fatchurrahman and Ariesa Budi Zakaria	
105	Opportunity Cost Allocation for Wheeling Using Power Flow Tracing	
	Yusuf Susilo Wijoyo, Sasongko Pramonohadi and Sarjiya	
123	Coal-Fired Steam Power Plant Source of Pollution, Government Policy on Energy Needs to be Revised	
	Ryan Perdana Putra and Oslo Simanjuntak	
154	Household Welfare and Targeted Subsidy Policy: Has the Rationalization of Electricity Tariffs Helped?	
	Andri Yudhi Supriadi, Mohamad Ikhsan, Benedictus Raksaka Mahi and Montty Girianna	

Ballroom 1 (Topic : Generation)		
Date : 22 October 2019	Session 4 (10.00 – 12.00)	HYATT REGENCY, YOGYAKARTA
ID PAPER	**TITLE**	**REVIEWER TEAM**
30	Optimize the Cogging Torque Reduction of Integral Slot Number in Permanent Magnet Machine	Chairman: Dr. Telisa Aulia Falianty. Co-Chairman: Dr Matthew Stocks. Secretary: Norayati binti Nordin
	Marsul Siregar, Tajuddin Nur and Dolly Ramly Wohon	
42	Construction of Waste-to-Energy (WTE) Power Plant in Balikpapan to cover waste and marine-waste treatment in Indonesia	
	Mirza Prasetya Kurniawan, Jhibril Marshall, Hafidz Nufi Hartanto and Anrizal Rizal	
50	Visibility study of Optimized Hybrid Energy System Implementation on Indonesia's Telecommunication Base Station	
	Mochamad Mardi Marta Dinata and Joko Slamet Saputro	
61	Installation Of Lithium-Bromide (Li-Br) Absorption Chiller System In Cilegon Power Plant Utilizing Waste Heat From HRSG For Gas Turbine Compressor Air Intake Cooling	
	Fandi Setia, Jon Tohom Johannes Silitonga and Sayuti Warganegara	
161	Design and Analysis of Toothed Log Periodic Antenna as Partial Discharge Sensor in Power Apparatus	
	Umar Khayam, Miftahul Husna and Rachmawati Rachmawati	

Ballroom 1 (Topic : Policy)		
Date : 22 October 2019	Session 5 (13.00 – 15.30)	HYATT REGENCY, YOGYAKARTA
ID PAPER	**TITLE**	**REVIEWER TEAM**
4	Battery Asset Sharing as a New Business Model for Business Sustainability of Indonesia's Electricity Industry	Chairman: Dr Matthew Stocks.
	Bustani Hadi Wijaya and Muhammad Rakhmat Setiawan	

44	The Influence Of Primary Energy (Fuel) Price And Levelized Cost Of Electricity (LCOE) On Optimal Portfolio Of Power Generation In Indonesia *Lutfiari Erlianto and Lutfiari Erlianto*	Co-Chairman: Dr. Telisa Aulia Falianty. Secretary: Norayati binti Nordin
76	Losses Management of PT. PLN (Persero) Rayon Siak by Using Rumus Susut Jogja Calculation Method *Ainur Rohmah and Edy Ervianto*	
113	Regulatory and Bankability for Mid-sized Coal Mine Mouth Power Plant Development for Technology, Coal Specification and Tariff Economy Issues *Ahmad Romadun*	
130	Feasibility Study on Installation of Solar Cell Renewable Energy Generators *Husein Mubarok and Bsyu Prastowo*	
131	Partner Selection Methods for IPP Development by PLN Subsidiaries as an Implementation of Presidential Regulation 4 (2016) *Nyoman Ngurah Widiyatnya, M. Aulia Akbar Muzakki and Amir Wahyu Al Karim*	

Ballroom 2 (Topic : Smart Grid and Renewable Energy)		
Date : 22 October 2019	Session 3 (07.30 – 10.00)	HYATT REGENCY, YOGYAKARTA
ID PAPER	**TITLE**	**REVIEWER TEAM**
3	Inverter Position Placement Method In PV Farm Using The String PV Cluster On Normal/Partial Shaded Conditions *Antonius Rajagukguk*	Chairman: Mochammad Facta, S.T., M.T., Ph.D. Co-Chairman: Dr. Noor Akhmad Setiawan Secretary: Aji Hanggoro, ST, MT
62	Optimization Technique of Unit Commitment Implementation in Microgrid Electricity System With Renewable Energy Sources – A Review *Ignatius Rendroyoko, Ngapuli Irmea Sinisuka and Deddy P Koesrindartoto*	
97	Hybrid Energy For Insulated Island From Peoples Independent Power Producers *Muhamad Hami Pradipta, Peri Indriyanto and Herda Dwi Cahyanova*	
106	Deaerator Exhaust Waste Heat Recovery Using TEG *Wildan Arif Febrianto and Agung Rahardian Puntaran*	
149	A Robust MPPT Control For PV Panel Using Adaptive Proportional Integral Controller Based On Fuzzy Logic *Slamet Kasbi, Estiko Rijanto and Asep Nugroho*	
159	Implementation of Optimization Techniques for Unit Commitment Schemes for Variable RES Power Plant Integration in Microgrid Systems *Ignatius Rendroyoko, Ngapuli Irmea Sinisuka and Deddy P Koesrindartoto*	

Ballroom 2 (Topic : Generation)

Date : 22 October 2019	Session 4 (10.00 – 12.00)	HYATT REGENCY, YOGYAKARTA
ID PAPER	**TITLE**	**REVIEWER TEAM**
28	Improvement of Cogging Torque Reduction by Combining the Gradually Inclined Surface End and Dummy Slot in Armature Core of Fractional Slot Number in Permanent Magnet Machine	Chairman: Dr. Noor Akhmad Setiawan Co-Chairman: Mochammad Facta, S.T., M.T., Ph.D. Secretary: Aji Hanggoro, ST, MT
	Tajuddin Tajuddin Nur Tajuddin Nur, Feri Yusivar, Liza Evelyn Joe and Marsul Siregar	
43	Design Microhydro Power Plant Utilize Discharge Channel Teluk Balikpapan 2x110 MW Coal Fired Power Plant by Finite Element Method Analysis	
	Hafidz Nufi Hartanto, Mirza Prasetya Kurniawan, Muhammad Hanif Salim and Anrizal	
59	Numerical Study of the Characteristics of Flow and Heat Transfer Design of USC 1000 MW Superheater Boiler	
	Ronny Sirait	
64	Arc Flash Calculation Study Based on IEEE 1584-2002 Standard on 6 kV GT 4.3 Switchgear for the Application of Personal Protective Equipment (PPE) Based on NFPA 70E on PT. Pembangkitan Jawa Bali UP Muara Tawar	
	Arief Rahman, Akhmad Habibi and Riswandha Prasdiatmaja	
68	Development of Fly Ash and Bottom Ash Utilization As Hazardous Waste Absorption on Coal Fired Power Plant	
	Mochamad Soleh, Yudi Hidayat and Zaenal Abidin	
70	Overview Turbine's Rotor Repair Methodology in 55 MW Geothermal Powerplant	
	Dwi Handoyo, Sugeng Triyono and Cayhono Soesetyo	

Ballroom 2 (Topic : Smart Grid and Renewable Energy; Generation; Policy)

Date : 22 October 2019	Session 5 (13.00 – 15.30)	HYATT REGENCY, YOGYAKARTA
ID PAPER	**TITLE**	**REVIEWER TEAM**
8	A Study of Reducing Waste Heat Rejected by Condenser Using Thermoelectric Heat Pumps to Decrease Net Plant Heat Rate of Coal Fired Power Plant (Generation)	Chairman: Mochammad Facta, S.T., M.T., Ph.D. Co-Chairman: Dr. Noor Akhmad Setiawan Secretary: Aji Hanggoro, ST, MT
	I Gde Agung Chandra Satriya Wibawa, Muhammad Yunus Qomarul Huda and Muhammad Kamal Wisyaldin	
48	Risk Analysis of Changes in Coal Quality in Coal Fired Power Plant for Energy Policy (Policy)	
	Septian Surya Pradana and Ashari Didik Hardianto	
126	Characteristics of Temperature Changes Measurement on photovoltaic Surfaces, Against Quality of Output Flow at Solar Power Plants (Smart Grid and Renewable Energy)	
	Andi Makkulau, Christiono Christiono and Samsurizal Samsulrizal	
147	Smart grid technology for energy conservation in street lights: Lesson learnt from six years' operation in Indonesia (Smart Grid and Renewable Energy)	

Effect of Sodium Chloride Solution Concentration on Hydrogen Gas Production in Water Electrolyzer Prototype

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***Abstract*— Energy is an essential component of human life because all human activities require energy. The current consumed energy comes from fossil fuels that are not renewable in a short time; therefore, they are decreasing over time. The current research shows the possibility of producing energy source from water in which Indonesia as an archipelago country has an abundant source of water. Therefore, Indonesia has a high possibility of developing renewable energy sourced from water. The process of getting hydrogen from water is called the electrolysis process of water. In this study, a water electrolyzer prototype was designed, and an experiment in producing hydrogen was conducted. The water used in this study is 6 liters with a variable that changes the concentration of sodium chloride solution (NaCl) starting from 10, 20, 30, 40, and 50%. The optimal production of hydrogen gas is at the concentration of 50% NaCl solution with the amount of gas produced at 11.29 liters and the mol percent of hydrogen in the product which is 78.45%.**

Keywords—electrolysis, hydrogen, sodium chloride solution, water electrolyzer

I. Introduction

Some solutions are offered in facing energy deficiency by researching and developing renewable energy such as nuclear, solar, wind, and tidal power. Those emerging renewable energies come with advantages and disadvantages in their applications. One of the new energies that have sound potential is hydrogen [1, 11].

Hydrogen fuel is energy composed of a single element called hydrogen H_2. This energy is environment-friendly energy whose emission is water. With the right developing technology, this energy has great potential and economically beneficial with almost zero pollution [4].

Hydrogen gas is formed by electrolyzing water using metal electrodes. Indonesia is an archipelago country whose 2/3 territory is the ocean; therefore, Indonesia has a great potential in developing hydrogen fuel to solve energy deficiency in Indonesia [11].

It is predicted that hydrogen becomes the primary energy supply for electricity generation known as hydrogen fuel. This hydrogen fuel can be used for transportation and domestic due to its environmentally friendly nature and easiness to produce.

During the electrolysis process, hydrogen will be produced in cathode; the electrode connected to negative pole and oxygen will be in anode; the electrode connected to the positive pole. The amount of hydrogen produced is twice as the amount of the produced oxygen, and both produced elements are proportional with electric power used in generating them. The electrolysis of water takes a long time to complete [5].

The rate of water electrolysis in producing hydrogen and oxygen can be increased by adding electrolyte material such as salt, base, acid. Those electrolytes are added to the water to increase the solution conductivity. The most used salt is Sodium Chloride due to its low price and easiness to solute in water. The electrolysis chemical reaction is: [6]

$$\text{Energy (Electricity)} + 2H_2O \longrightarrow O_2 + 2H_2 \quad (1)$$

Electric pressure is applied to the negative electrode (cathode) pushing electrons to the water, and in the anode (positive electrode) in absorbing electron. The water molecule in cathode consists of positive hydrogen ion (H^+) and hydroxide (OH^-).

$$H_2O \longrightarrow H^+ + OH^- \quad (2)$$

H^+ is an open proton, free to capture electrons from the cathode, then into ordinary and neutral hydrogen.

$$H^+ + e^- \longrightarrow H \quad (3)$$

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The hydrogen atom is assembled with other hydrogen atoms and make molecules in the gas to bubble and then rise to the surface.

$$H + H \longrightarrow H_2 \quad (4)$$

Positive electrodes have caused hydroxide ions (OH^-) to move to the anode. When it reaches the anode, the anode releases excess electrons taken by the hydroxide from the previous hydrogen atom, then the hydroxide ion joins with another hydroxide molecule and forms 1 molecule of oxygen and 2 molecules of water:

$$4\,OH^- \longrightarrow O_2 + 2H_2O + 4e^- \quad (5)$$

This oxygen molecule is very stable, and then the bubble rises to the surface, and the process is repeating. The reactions at the cathode (reduction) depend only on the type of cation in the solution. If the cation comes from metal with a lower electrode potential, then the water will be reduced [7].

In the process of electrolysis, electrodes are electrified (by DC current) so that the compounds in the electrolyte break down to form ions, and the oxidation-reduction process occurs to produce gas. The electrolysis process requires a high electric current to ensure the chemical reaction process becomes effective and efficient [8].

If both electrode poles (cathodes and anodes) are electrified by electric current, the electrodes will be interconnected since the electrolyte solution becomes a conductor that causes gas bubbles to emerge in electrodes. The electrolysis process states that oxygen atoms form a negatively charged ion (OH^-) and a hydrogen atom forms a positively charged ion (H^+). At the positive pole, the H^+ ions are attracted to the negatively charged cathode pole; therefore, the H^+ ion converges to the cathode. Hydrogen atoms will form hydrogen gas shown as gas bubbles at the cathode which floats upward. The same thing happens to OH^- ions which fuse at the anode then form oxygen gas in the form of gas bubbles. In the Electrolyzer Water Prototype, various concentrations of NaCl solution are used to be the starters and function to increase the number of ions in the feed solution to produce more hydrogen gas [9, 10].

II. Experimental Design

In general, the design of the prototype is divided into three parts; container feed water reservoir, H_2, and O_2 gas storage tube, and electrode pipe. The feed water container has a length of 27 cm, a width of 13 cm, and a height of 17 cm. The container for feed water is made of plastic with the form of a beam. The bottom of the feed container consists of two outputs. The first is the output for the feed stream to the electrode pipe, and the second one is the output to the product storage tube. This second output hole is made slightly upward because the feed must first come out through the first output hole. The flow leading to the electrode pipes is connected to a pipe with 100 cm vertically and 85 cm horizontally as the entry point for feed water.

Electrodes are 40 cm stainless steel with 40 cm for the cathode and 8 cm for the anode. Cathodes and anodes are connected using a tee. This tee connection is installed parallel with another pipe as a pathway for the produced hydrogen and oxygen gas that comes out from the top of the anode. The pipe is connected to each storage tube. The electrodes used are 5 pairs and arranged in parallel. The cables are connected between the anode and cathode and then to the regulator. At the bottom of the electrode pipe, an outlet is placed to remove the remaining water after the electrolysis process and as a place for cleaning/draining tools.

For H_2 and O_2 gas storage tubes, two expenditure streams are made. The first flow is located at the bottom of the tube and connected directly to the container of water (the raw material). The second flow is on the top of the tube, which is given a pressure gauge and a check valve as a safety valve. The H_2 and O_2 gas storage tubes are 27 cm in height and 9 cm in diameter. At the end of the pipe, a nozzle is installed to ensure the gas can be burned directly.

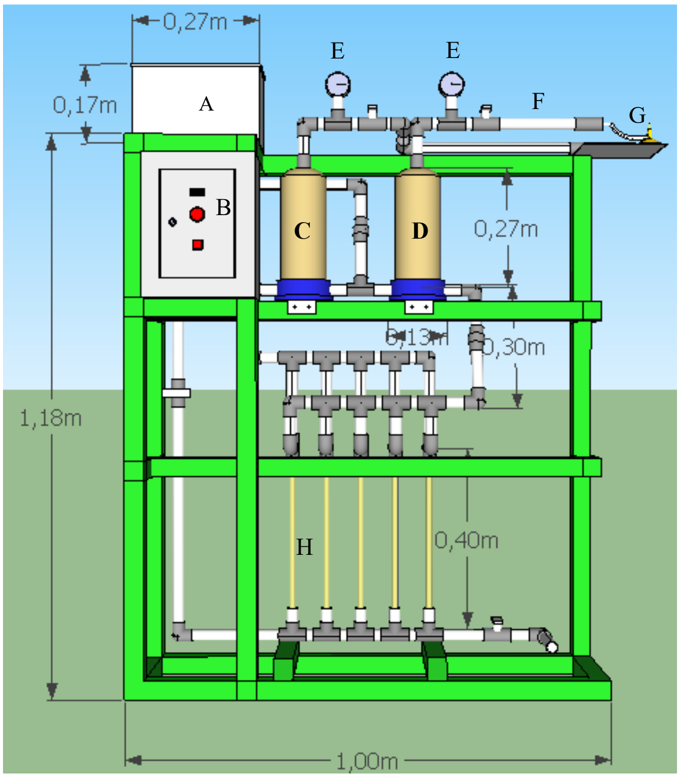

Fig. 1.Water electrolyzer design

Where:

A: Water storange
B: Panel Box
C: O_2 gas storage
D: H_2 gas storage
E: Pressure Gauge
F: Arestor Flashback
G: Nozzle Burner
H: Electrodes (Stainless Steel)
I: Drain

III. Result and Discussion

A. Literature study on Effect of NaCl Electrolyte Solution Concentration to the Volume of Hydrogen Gas Produced

The relationship of the concentration of NaCl electrolyte solution to the volume of electrolyzed hydrogen gas for 20 minutes can be seen in Fig 2. It shows that hydrogen gas production has a linear increase in the concentration of sodium chloride solution. This condition shows the greater the concentration of NaCl electrolyte solution, the more significant electrons formed and denser to facilitate the transfer of electrons from the solution to the electrode [2].

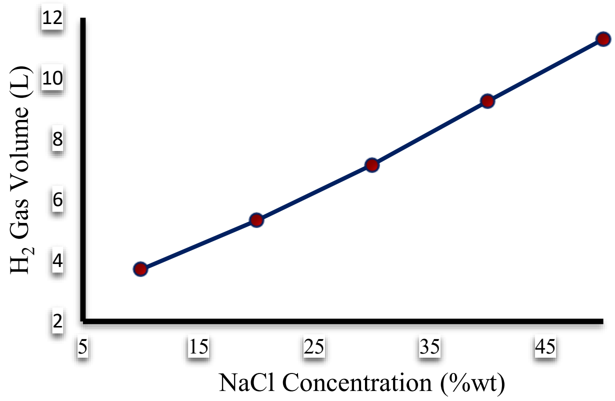

Fig. 2. Literature study on Effect of NaCl Electrolyte Solution Concentration to the Volume of Hydrogen Gas Produced

The increment of NaCl concentration is proportional to the increase in hydrogen gas volume. The more sodium chloride is used, the more Na^+ and Cl^- ions have formed that increase the conductivity of the water. With the increase in conductivity, this makes the electric current also produced primarily. Thus, the process of decomposing water into hydrogen and oxygen becomes faster.

Electrolysis proses in this study used stainless steel electrodes. A direct electric voltage is applied to the electrode to create a potential difference between the two electrodes. This potential difference creates ions in the electrolyte solution migrate towards the electrode opposite the charge with the ion. In this research, the ions in solution come from the dissociation of NaCl. The dissociation that occurs in the NaCl solution produces Na^+ and Cl^- ions. Positively charged ions such as sodium ions (Na^+) and hydrogen ions (H^+) in electrolyte solutions migrate towards the cathode. Negatively charged ions such as chloride ions (Cl^-) and hydroxyl ions (OH^-) migrate to the anode. Migration of these ions creates an electric current in the solution, giving rise to a redox reaction on the electrode.

Theoretically, the volume of hydrogen gas is obtained by calculating using the equation of the reaction of water with sodium chloride. The amount of water as the raw material used in this process is 6 liters. By knowing the temperature, molecular weight, and density data, the moles of water can be determined to calculate the moles of reactants reacting and the moles of the product produced. This mole data is used to calculate the volume of hydrogen.

Based on the results of the calculation, the higher the concentration of the NaCl electrolyte solution used, the greater the volume of hydrogen gas produced. Fig. 2 shows the tendency increment. This trend is caused by the variation in the concentration of NaCl solution is in a short rance, which is only 10 grams difference; therefore, the difference in the increment in yield of hydrogen volume produced is not too significant; ± 2 liters.

B. Experiment results on Effect of NaCl Electrolyte Solution Concentration on Hydrogen

Hydrogen gas production increases proportionally with the difference in NaCl concentration used in the electrolysis process of water. When the electrolysis process takes place, water fills the hydrogen and oxygen gas storage tubes. After the electrolysis time is reached, which is 20 minutes, the gas fills the gas storage tube. Based on observations made during the process, hydrogen gas is formed quickly enough that it starts to appear at around the 20th second. The increment of hydrogen gas level indicates the decrease in water level. From the gas height data in this tube, the volume of gas formed can be calculated using the cylinder volume equation (cylindrical reservoir tube)

In line with the literature study, the formation of hydrogen gas in the experiment is affected by the concentration of NaCl. The effect of NaCl solution concentration on the produced hydrogen gas is shown in Fig. 3.

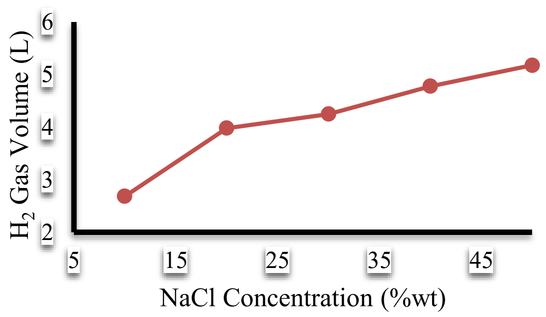

Fig. 3. Effect of NaCl Solution Concentration on the Volume of Hydrogen Gas Produced in Experiment

The data collection process was carried out five times according to variations in the concentration of NaCl solution used; 10, 20, 30, 40, and 50%. From the experiment data, it can be seen that the higher the concentration of NaCl solution is used, the more hydrogen gas is produced. In the first round (the concentration of 10% NaCl solution) the hydrogen gas volume is 2.68 liters, while in the second round the volume of hydrogen is around 3.98 liters. This increase in hydrogen volume is quite high, which is around 1.3 liters. Unlike the next round, the increase in hydrogen gas is only about 0.3 liters. Hydrogen gas production is still increasing from the previous round, but the increase is less than before. The function of NaCl solution as an electrolyte solution in this process is still quite optimal, but based on experiments that have been carried out, the use of electrolytes containing sodium (Na) will lead to crystallization of sodium salt in the electrode pipeline where reaction and decomposition of water molecules into hydrogen and oxygen [2].

The formation of sodium salt in the electrode pipe results in the production of hydrogen gas gradually decreasing. This condition can be observed in Fig. 3. On the next process, the produced hydrogen gas is only about ± 0.5 Liter increment for different NaCl concentration solution. This condition is very different from the first round because the tool still has not accumulated sodium salt.

At the specific application time of electrolysis, the performance of the prototype water electrolyzer tool is reduced due to the accumulation of sodium salt in the electrode pipe. This accumulation can be identified by changing the color of the water in the hydrogen gas and oxygen storage tubes becoming red brick color due to the nature of sodium when dissolved in water, and it will change color. The deposition of sodium salt can result in reduced work function and electrode reactivity; therefore, hydrogen production will tend to decrease.

The volume of the produced hydrogen gas achieved from the experiment is compared to literature study. In the literature study, the increment is linear and constant, while in the experiment, there is a tendency of decreasing the production of hydrogen gas. Fig. 3 shows that the highest hydrogen volume is 5.17 Liter, while in literature study, the highest hydrogen volume produced is 11.29 Liters.

The difference that occurs is quite apparent, at the concentration of 10% NaCl solution. Theoretically, the hydrogen volume is 3.71 Liter, while in the experiment, the hydrogen volume is 2.68 Liter. This difference is not so far in the first use of experiment tools that the electrode pipe used is clean. In the results of the second experiment, at a concentration of 20% NaCl, the difference began to occur a little bigger; 5.32 Liter in theory and 3.98 Liter in the experiment. This difference is increasing until the concentration of NaCl solution used is 50%. The highest difference is at the 5^{th} round, which is 11.29 Liter in theory and 5.17 Liter in the experiment; the difference is around 6 liters. The loss of the volume of hydrogen is as much as 6 liters in the experiment. This loss is due to a decrease in the performance of the electrode, which is increasingly saturated. This condition occurs because more sodium salt is formed and heaps on the tool components. This inhibition if no corrective action is taken or repairs on the part of the contaminated equipment, will make hydrogen production increasingly inefficient and not maximum.

C. Effect of NaCl Concentration on Hydrogen Gas Composition

Fig. 4 shows the result of chromatography gas to show the effect of the concentration of NaCl solution on the composition of hydrogen gas and impurity gases.

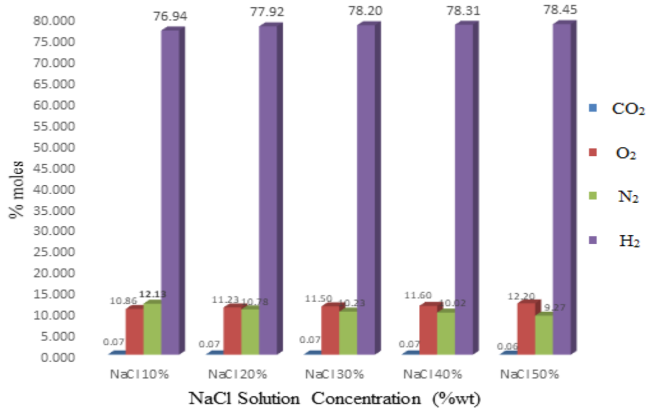

Fig.4. Effect of NaCl Concentration on Hydrogen Gas in Gas Chromatography Analysis

The analysis of gas products using gas chromatography is carried out by the principle of separating the mixture into its components. This analysis is conducted by using gas as a moving phase that passes through a layer of absorption (sorbent) that is stationary. The results of the analysis show that not only hydrogen gas is contained in the gas product, but also other gases are formed; therefore, the hydrogen produced is not 100% pure. Other components include carbon dioxide, oxygen, and nitrogen.

The presence of other gases causes hydrogen gas to become impure. Other gas contaminants in the form of carbon dioxide, nitrogen, and oxygen can come from the air that enters during the product storage process in the sample bag. Air is a mechanical mixture of various gases. Average air composition consists of nitrogen gas 78.1%, oxygen 20.93%, and carbon dioxide 0.03%, while the rest is argon, neon, krypton, xenon, and helium [12].

At the time of the product, the shelter process has been carried out and endeavored as much as possible, to ensure no direct contact with air. The problem in tool design is an absence of a vacuum system to eliminate the air content in a room. When the process takes place, the hydrogen gas storage tube is filled with water but is not 100% full, leaving a residual space filled with air. When hydrogen gas begins to fill the reservoir tube, then a little air is mixed with hydrogen. When the gas product valve is opened, some of the gas is discharged into the air but does not rule out the possibility that there is still homogenized air with hydrogen. Therefore, by using gas chromatography, the existences of other gasses are still detected.

D. Effect of% Heat Loss, Electric Efficiency and SFC (specific fuel consume) on hydrogen produced

The heat loss in the water electrolyzer water prototype is not influenced by electric current, electric voltage, and the number of electrodes because those three components are fixed variables in this study. The value of efficiency can influence heat loss in this process, the higher the efficiency of the gas produced, the lower the heat loss that occurs since the heat loss is inversely proportional to efficiency. In this process, the heat loss value tends to be constant, which is around 17.91%, and this condition can be stated for each rotation since all rounds use the same operating conditions. In the literature study, the electric power used in the process is around 79.8 W with a 13.3 V voltage setting, 6 A electric current, and 20 minutes, while the actual conditions that occur are the power used is 65.5 W, 13, 1 V voltage, 5 A electric current, and 20 minutes. With this difference, the heat loss can occur due to the difference in operating conditions during the device setting, referring to the actual conditions.

By reviewing the differences in operating conditions, electrical efficiency can also be calculated. Based on the results of the calculation of electrical efficiency in this water electrolyzer is 82.08%. This is still said to be good because in general, electrolysis efficiency is theoretically 80%. This value only refers to the efficiency of converting electrical energy into hydrogen chemical energy [3, 12].

Electrical efficiency can be calculated by using the differences in operating condition, and in this research, the electrical efficiency achieved is 82.08%. This efficiency is sufficient, more than the standard of 80%. This value only refers to the efficiency of converting electrical energy into hydrogen chemical energy [3].

Energy requirements in the electrolysis process of water are determined by calculating the amount of energy needed in electrolysis per number of moles of H_2 gas produced. Based on the literature study, the higher the concentration of electrolytes, the conductivity will increase; therefore, the energy requirements per gas volume of H_2 produced will be smaller.

Water electrolysis requires a minimum of 286 kJ of electrical energy input to separate each mole [3]. Water electrolysis does not convert 100% of electrical energy into hydrogen chemical energy. This process requires more extreme potential than what is expected based on the reversible cell number reduction potential.

In this electrolysis process, SFC is needed, which varies in the concentration of NaCl solution. This SFC value is directly proportional to the volume of hydrogen gas produced both theoretically and in the experiment. It should be noted that the results of this SFC calculation are that the SFC value tends to decrease with the increasing volume of hydrogen gas produced. The condition is the same as the electrode performance described in the previous section. This decrease in SFC value is due to the function or performance of the electrode pipe which begins to experience saturation, where even though the volume of hydrogen produced is still increasing, the SFC given is decreasing. Information on gas volume comparison data in theory and practice versus SFC can be seen in Fig. 5 Fig. 5 indicates that there was a significant decrease which occurs due to the energy needed to produce hydrogen gas in the second and subsequent rounds is not as much as in the first round; therefore, this process requires energy that is not as much as the first round.

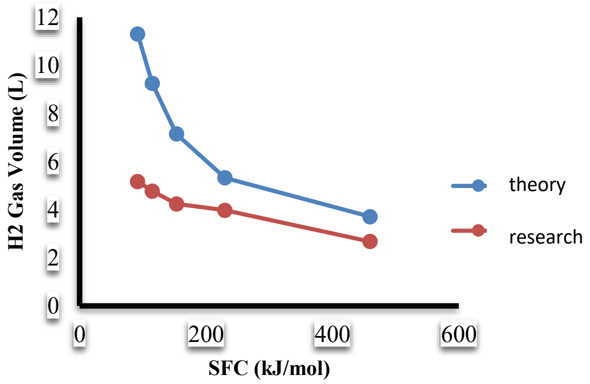

Fig. 5. Graph of SFC (Specific Fuel Consume) Relationship to Hydrogen Gas Volume Generated in Theory and Experiment

IV. Conclusion

The water electrolyzer prototype designed in this study has a capacity of 6 liters of raw material, each hydrogen and oxygen gas canister is 3.58 liters, into hydrogen and oxygen gas with various NaCl concentrations. In this process, hydrogen gas produced with the highest volume produced in the electrolysis process is 11.29 liters, so the optimum NaCl concentration in this study is 50%. The results of gas chromatography analysis show that on average for 5 samples of hydrogen content in the product is 77.96%; oxygen 11.48%, nitrogen 10.49%; and carbon dioxide 0.07%.

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