MECHTA
International Journal Of Mechanical Engineering Technologies & Applications
V05 N.1
ISSN 2722-3213 articles 2, pp. 12 – 22, 2024

THE IMPACT OF CHAOTIC FLUX REFLECTION FIELD ON HYDROGEN EVOLUTION REACTION OF WATER ELECTROLYSIS

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Abstract

Water electrolysis promises the capability to produce green hydrogen in the future. The efficiency and hydrogen evolution reaction rate (HER) of water electrolysis can be improved through magnetic field assisted electrolysis. External magnetic field exposure improves hydrogen production without requiring complex catalyst synthesis technique. The purpose of this study is to introduce chaos into a magnetic field assisted electrolysis system which disturbs the water molecules stability. The chaos effect was triggered by irregular flux reflection technique. The flux reflection was generated using diamagnetic tourmaline stones which sticked all over the electrolyzer wall. Consequently, the rotational speed of DMF does not reduce the effectiveness of chaotic flux. As a result, the hydrogen bond of the water molecules is destabilized irregularly. In conjuction with that, the bonds are unable to be reformed which make the water molecules continuously in movement. The critical effect of chaotic flux is the shear force that experienced by water molecules. The paramagnetic OH- ion movement is also slowed down so that H+ ion and electrons interaction were occurred in less restrictive manner. Hence, the chaotic magnetic field able to improve HER. The chaotic flux reflection improves hydrogen production in magnetic field assisted water electrolysis through water properties and ion transfer mechanism modification.

Keywords: *Hydrogen Production, Electrolysis, Chaotic Flux Reflection, Magnetic Field.*

1. INTRODUCTION

Green hydrogen production via water electrolysis is currently being pursued. The amount of external energy that required to split a water molecule into OH^- and H^+ is huge. The electrical properties in an electrochemical system is depends on standard potential difference between the anode and cathode which defined by the electrode materials, the acidity of the electrolyte, ion cluster formation of the electrolytes, temperatures of the environment and the solution, the co-solvents, and electrocatalyst [1]. Current materials for hydrogen energy production and storage are largely depend on noble metal due to its efficiency. Most of the time gold, platinum, and palladium are utilized as an electrocatalyst due to their electron stability [2]. Different from such costly approach to improve hydrogen evolution reaction rate (HER), another way to tackle efficiency problem is through the application of magnetic field assistance such as external magnetic fields (EMF) to exploit water diamagnetism [3]. This

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Received on: 2023-12-06
Revised on: 2023-12-06
Accepted on: 2024-01-07

DOI: 10.21776/MECHTA.2024.005.01.2

main objective of this study is to elevate HER on EMF assisted electrolysis by magnetic flux control.

Water diamagnetism allows the H_2O molecules to response magnetic field exposure. As a diamagnetic fluid, water molecules always repel magnetic field in opposite direction [4]. The magnetic properties of a material is depends on its quantum spin order in a certain area which forms a magnetic domain [5]. In a large scale, the grouped domain conforms the polarity of a magnet which in a bipolar magnet denoted by South and North Pole. The direction of a magnetic domain depends on the collection of spin directions which is spin-up (+1/2) or spin-down (-1/2) [6]. Electron's spin allows two electrons to defy Coulomb's law since two electrons can be paired in a same location. The electrons are communicating each other through quantum entanglement which always be in an opposite rotational direction [7]. The quantum entanglement theorem by Albert Einstein and Niels Bohr are mechanically different but state a similar foundation in directional principle which is always entangled in reverse [8]. At the macro-scale, quantum entanglement phenomenon can clearly be seen as water diamagnetism that represents flipping electrons due to the magnetic field response [9]. Hence, in this study the chaotic magnetic flux utilized to force continuous movement of water molecules.

The energetic state of a molecule is identified through its vibrational state. The molecular movement is depended on the kinetic energy which represents itself as a vibration or heat which steer the bounce electron on a molecular orbital [10]. During a movement, the dipole of the water molecule always shifting continuously forms an interchanging pattern [11]. As a result, the dipole elongation is occurred which alter the columbic interaction due to the stronger charge attraction. However, the increase of molecular kinetic energy vibrates the electrons in the orbital which has a collective effect of vibrating molecule [12]. The vibration impact on water molecules is also the displacement of hydrogen bond [13]. The external energy from the vibration reduces the ionization energy to release an electron from the water molecule [14]. The vibration from magnet is different with the vibration due to heat which cannot be directed [15]. Heat induced vibration causes random motion which activates all mode of vibration. As a consequence, the dipoles are inaccessible which slowed down the charge release. The quantum electrodynamic (QED) vibrational response is can be directed which make the electron excitation scheme in an ordered form. Similar with the QED response, the magnetic vibrational response is a directed vibrational response which depend on the directed spin pair entanglement mode of motion [16]. Therefore, the magnetic field exposures in this study it to induce vibrational response.

Directed vibrational response due to EMF can improve hydrogen formation with water electrolysis. The EMF exposure lowers water boiling point which shows the mangnetic field enegizes the water molecule [17]. The intermolecular force of the water molecule is weakened due to the EMF which can be seen from lower surface tension which also indicate weaker cohesion [18]. Weaker cohesion causes water molecule unable to reform the hydrogen bond and dipole [19]. The smaller cohesion indicates higher viscosity and evaporation activation energy. EMF also causes magnetohydrodynamics (MHD) phenomenon which accelerates the charge transfer flow in an electrochemical system [20]. MHD also induces proton conductivity which lead to the reduced flow restriction of the charge transfer [21].

The effectiveness of EMF on HER improvement is surpassed by dymanic magnetic field (DMF) application. DMF exposure rapidly increase HER multiple times compared with static EMF. DMF obtained by rotating the magnetic field force such as rotating a magnetic bar using an electric motor [22]. The alternating frequency of the magnetic field is more significant to increase the HER rate the strength of the magnetic field. This study analyzes the impact of chaos on DMF and static EMF and its effect on the alternating magnetic field frequency. The chaotic molecular movement improves the Brownian motion which also

increases the speed of a reaction [23]. The chaotic magnetic field can be obtained from the flux reflection of an irregular diamagnetic material [24].

Study of EMF and DMF assisted water electrolysis by [3] and [22] controls the HER rate through ordered flux magnets. This study provides an alternative technique to improve the HER rate of water electrolysis through chaotic flux from irregular shaped magnetic reflection. This study results in techniques to improve static EMF and DMF HER rate. The chaotic flux creation procedure and the instrumentation to control the form of the magnetic field is written in the materials and method section. The experimental results of the electrolysis and the magnetic flux visualization in the form of vector phase space are written in the results section. The discussion was built from molecular mechanics point of view in which the effects of the magnet to the water molecules are explained as the molecular displacement and vibration.

2. MATERIALS AND METHODS

The electrolysis test was performed in a chaotic flux area made of a 20x20x20cm acrylic box reactor with brown dravite tourmaline stone that placed all over the reactor wall. Brown dravite tourmaline stone categorizes as a diamagnetic stone [25]. The stones are glued to the acrylic wall of the reactor using G-Glue. The electrodes are carbon electrodes for both cathode and anode. The electrodes were separated with 10 cm gap. The electrodes obtain the electrical power from 12V 25 mAh dry cell battery. The magnets placed besides the cathode and anode outside the electrolysis reactor. The electrolyte was made of 500ml of aquades water with 12 gram sodium chloride (NaCl) salt. The rotational magnetic field was obtained by rotating the magnet beside the cathode using 9V DC motor that connected to an ESP32 microcontroller. The rotational speed for DMF response test was 100 and 1000 RPM.

The HER rate was measured through MQ-8 sensor gas detection. The sensor was attached to the ESP32 microcontroller via analog to digital pin (ADC). The sensor was pre-calibrated using 100ml of pure hydrogen gas that placed in a syringe. The gas was released from the syringe with 1ml sec-1 flow rate. The magnitude and vector direction of the magnetic field flux were measured using QMC5883L sensor that attached to the same microcontroller. The QMC5833L sensor was connected to the microcontroller through inter integrated circuit (I2C) scheme. The ESP-32 microcontroller was connected to Linux personal computer through universal serial bus (USB) port. The firmware of the ESP microcontroller was programed using a Micropython™ programming language. The flux vector phase space was served graphically using python programming language version 3.9.6 with the help of plotting module Matploplib version 3.4.1.

3. RESULTS

The electrolysis test results indicate the order of the magnetic vectors contributes to the HER modification. As shown in figure 1, the chaos order of the magnetic field flux alters the HER rate indicated by the rising cumulative hydrogen concentration. The SMF application increases the HER rate up to 16513 ppm or 773 ppm from the non-magnetic field affect electrolysis which only results in 15420 ppm. Even though the result was insignificant, the presence of the magnetic field shows its effect. Moreover, 100RPM DMF exposure significantly lifts up the HER rate to 21081ppm. Additional rotational speed to 1000RPM increases the hydrogen production to 23902ppm. The chaotic flux significantly improves the HER rate of 100RPM DMF to 23902ppm. Meanwhile, at the higher rotational speed the HER rate insignificantly lifted by 1621ppm from 30404ppm to 32025ppm. The results suggest that DMF is always more significant than SMF in any situation.

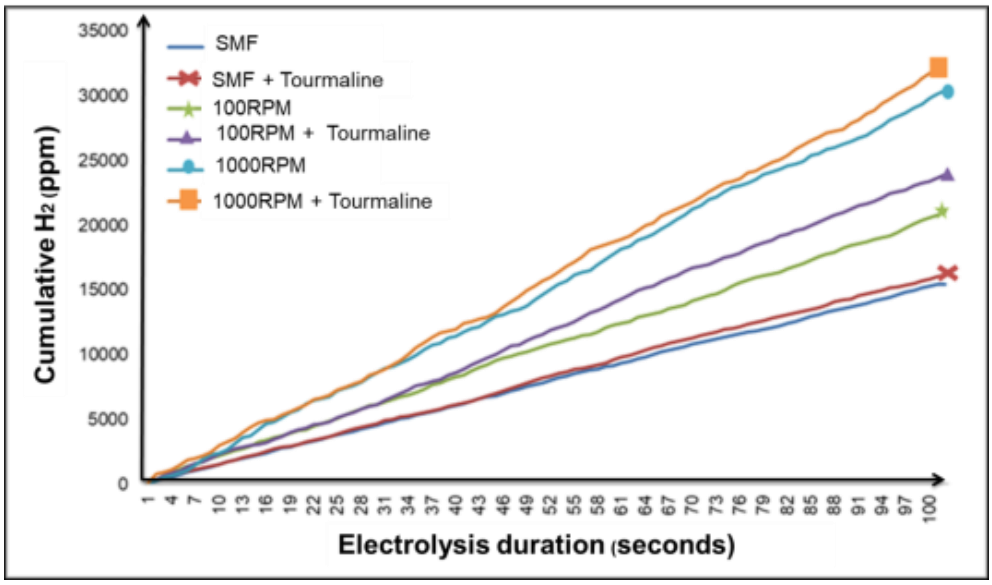
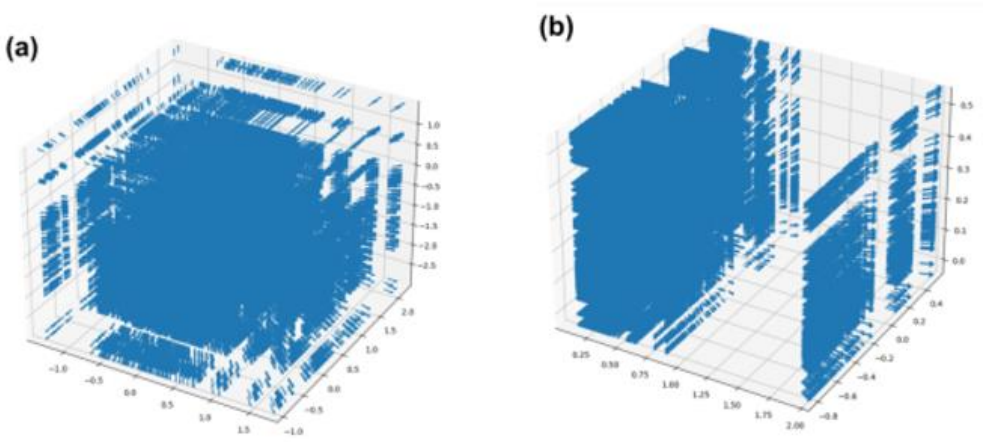


Figure 1. Electrolysis test results

The graphical phase space of the magnetic field indicates the chaotic magnetic flux direction forms alternating magnetic field. The magnetic field direction was changed due to the magnetic field reflection. The changes can be seen in the quiver plot of the magnetic field vector phase space in figure 2. The arrows are the magnetic field trajectory around the water molecules. The fluxes are compresses the water molecule which causes the unbalanced diamagnetic response of the water molecule. The SMF magnetic field vectors direction is shown in figure 2(a) and 2(b). The changes of magnetic field vector direction can clearly be seen since the SMF applied water molecules receive strong magnetic compression (see figure 2(a)). In figure 2(b), the magnetic field vectors are separated from the center magnetic field which flips the direction of the SMF. Therefore, the chaotic flux can be formed on SMF applied magnetic field water.



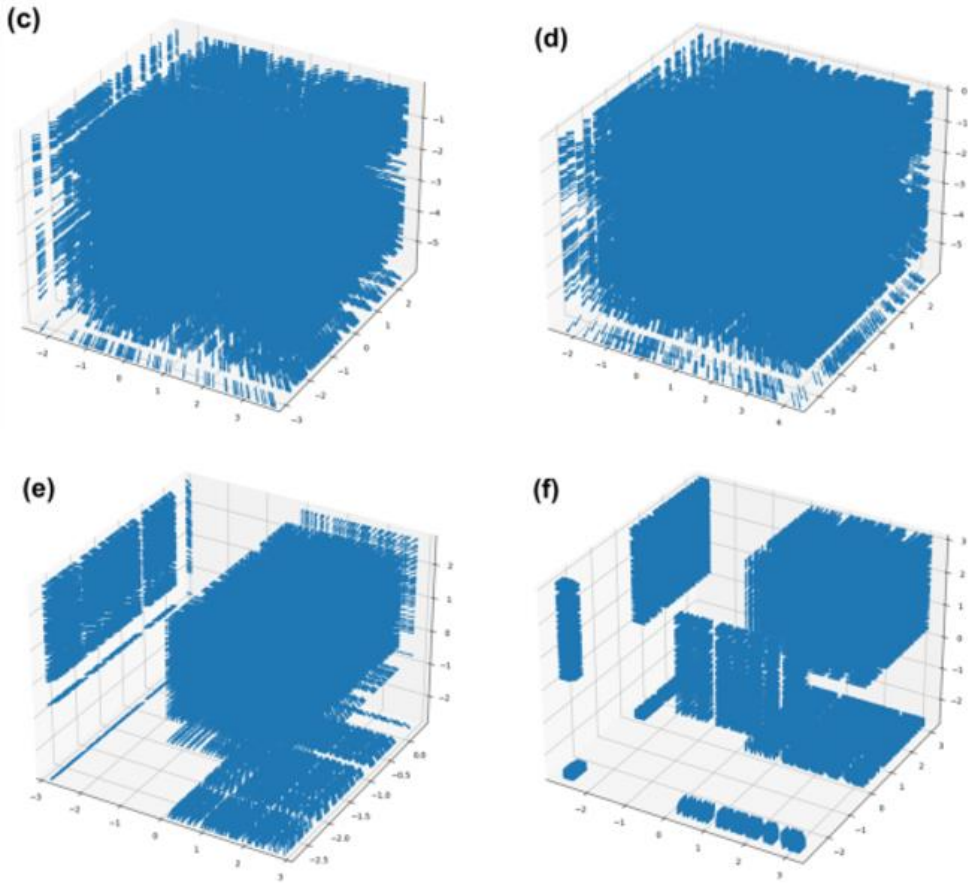


Figure 2. Quiver plot of applied magnetics flux on water molecules: (a) SMF, (b) Chaotic SMF, (c) 100RPM DMF, (d) Chaotic 100RPM DMF, (e) 1000RPM DMF, and (f) Chaotic 1000RPM DMF.

The vector phase space of DMF flux indicates the magnetic field flux direction is controllable through rotational speed control. There is no significant change of magnetic field flux of DMF and chaotic flux of DMF as seen in Figure 2(c) and 2(d). Figure 2(d) shows the central magnetic fields are shifted towards the left direction as the magnetic field lines are remain in their original position. Hence, the tourmaline dravite stone diamagnetism does not add any reflection to the magnetic field vectors in slow rotational speed. At 1000 RPM the DMF shows significant alignment of the magnetic field vectors due to the diamagnetic reflection which forms chaotic flux. Each arrow of the quiver plot which represents the single magnetic field vector are changed from compactly stacked magnetic field lines in figure 2(e) to widely dissected quiver plot as in figure 2(f). In figure 2(f), the vectors are widespread so the spaces are available which show the magnetic compressions to water molecules are unavailable at those regions.

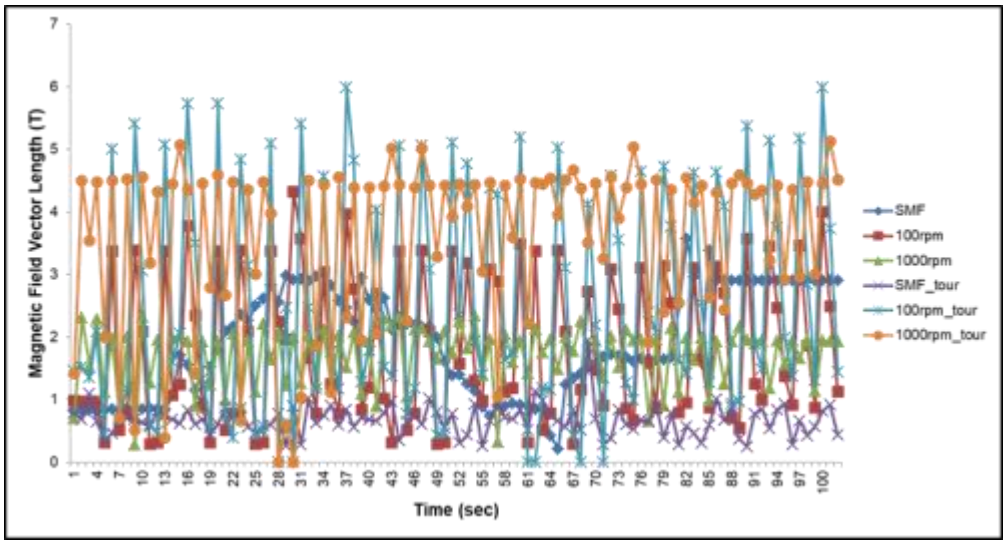


Figure 3. Magnetic flux characteristics from the applied magnetic field

The magnetic field flux reflection is possible to form chaotic flux under the ambience of DMF. The resultant of the magnetic flux is represented by the length of the magnetic field vectors which measures the strength of the compression force applied on the water molecule [26]. The magnetic field reflection enlarges the DMF flux strength at 1000 RPM and also at th100 RPM of DMF which shown in figure 3. The magnetic field magnitude of the 1000 RPM and 100 RPM DMF were increased twice from the initial strength due to the chaotic magnetic field flux formation. Meanwhile, the magnetic field strength of SMF reduced as the chaotic flux formed. The field vector length of SMF was kept around 0 to 0.12 T magnetic field vector length. Without the presence of chaotic flux, the magnetic domains of SMF are self-stabilized started on the 82th seconds in figure 3. The formation of chaotic flux disables the ability of the SMF to reform itself which indicate the increase in magnetic field frequency shift.

4. DISCUSSION

The diamagnetic reflection forms chaotic flux makes the water molecules stay dynamics. The water molecules never remain stable during the magnetic field exposure. The dynamics of the water mole-cules is indicated by the inability of the magnet to rebalancing its domain. Consequently, the kinetic energy of the molecules are increased which makes the water molecules never stop moving due to the diamagnetic response. The continuous exposure of kinetic energy causes perpetual movement of the electrons in the molecular orbital which pops the dipole of a water molecule. The dipoles of the water molecules was popped due to the strained molecular orbital which has a similar effect as a mechanical fatigue in macro-scale solid objects [27]. The vibration mode of a molecule is defined by the energy state which defined by the Hamiltonian of the electrons in the orbital which also include the kinetic energy [28]. The magnetic vibrational response is in the form of directed vibration which is different from the heat induced vibration mode. The pattern of the magnetic induced vibration follows the inter-changing spin pair pattern due to the quantum entanglement phenomenon. As a result, the electrons of the full spin paired molecular orbital always adjust its position one to another [29]. At the molecular level, the entanglement movement is in the form of shaking movement with a directed position as seen in figure 2.

The direction of the magnetic flux vectors follows the direction of the magnetic field that applies compression towards water molecules. Since water is diamagnetic, the direction

of the water molecules response movement is away from the direction of the flux with equal magnitude. The transforms of the direc from figure 2(a) to 2(b) depicts the water molecules are attacked from the left which response with movement to the right. In figure 2(b), the water molecules groups are formed at the left side due to the magnetic response. The realigned water molecules are not back to its original position with a straight trajectory because the continuous interaction among the dipoles. The reflection of the tourma-line stone edges which cause magnetic flux is always unordered. As a result, the shear force was induced which shears the hydrogen bond of the water molecules. The sheared water molecule has weaker hydrogen bonds which make the bonds easier to displaced [30]. In a macro-scale, the phenomenon represented as a lowered surface tension [31]. In consequence, The cohesion among the water mole-cules are weaker so that the intermolecular bond of the water molecule is also weaker [32]. The ununi-formed fluxes of tourmaline reflected magnetic field destabilizes water molecule continuously as shown in figure 3. Hence, the random shaped tourmaline stone edge increases the total Hamiltonian of the water molecules with dominance of kinetic energy due to the inability of the magnetic field line recovery.

The chaotic flux effect on DMF is clearer compared to its effect on SMF. The magnetic flux shift was occurred which shifts the magnetic field vectors such as in figure 2(c) and 2(d). The direction of the DMF is constantly flipped as the magnets stay in rotation. As the magnet rotating, the realignment of the flux is quicker than the SMF and the length of the vectors are shorter. The irregular nature of chaotic flux disturbs the interface between the water and the solid surface. Continuous interaction with the disturbance reduces the surface tension overtime [33]. Consequently, the water molecules intermo-lecular bond is displaced as shown in figure 4. The reflection of the tourmaline stone edges produces magnetic flux that pushes the water molecules in multiple directions. Therefore, the water molecules were teared by the chaotic magnetic field which hinders them to recover their bonding stability. The consequences of such phenomenon are the weakened hydrogen bond and intermolecular bond. Fur-thermore, the ionization energy of the water molecules is always weakened. Conclusively, the impact of the chaotic flux exposure is easier water-splitting reaction.

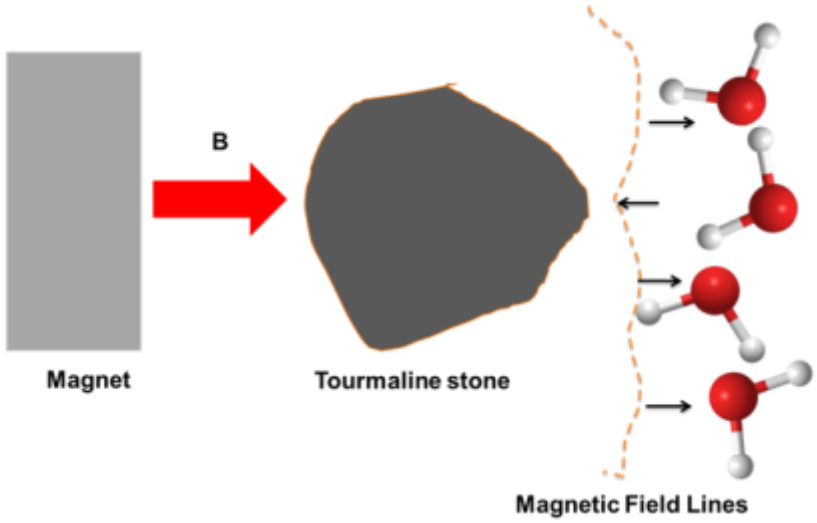


Figure 4. Illustration of Tourmaline reflection which produces chaotic flux

The presence of chaotic magnetic flux modifies the ion transfer mechanism of an electrochemical system. The OH^- and H^+ has a role as the electrochemical products predictor including hydrogen and oxygen production [34]. The exposure of EMF and DMF affects the acceleration of charge transfer during electrolysis. The electron spin configuration in the

valence molecular orbital defines the response of any material to the magnetic field exposure [35]. Therefore, the unpaired molecular orbital of OH^- forms a paramagnetic response due to the free singlet electron [36]. The OH^- ion transfer is held which create more rooms for H^+ ions to react with the electrons. As a result, the hydrogen gas formation occurred in lower restriction. Therefore, the chaotic flux lifts up HER rate through the acceleration of ion transfer and the creation of chaotic water movement.

Table 1. The tradeoff of chaotic flux formation with other magnetic field assisted electrolysis

Technique	H_2 Output	Magnets	Study
EMF	12.1ml in 10min	0.6T	[22]
DMF	25.2ml in 10min	0.6T	
Chaotic Flux	32025 ppm in 10min	0.12T	This study
Foam electrodes EMF	Not reported	0.9T	[37]
Photoelectrochemical EMF	Not reported	0.5T	[38]

This study contributes to provide enhancement in magnetic field assisted electrolysis. The chaotic dynamic magnetic flux have better performance compared to the EMF and DMF by [22] in equal magnitude of magnetic field. The highly sophisticated technique of magnetic field such as foam elec-trode exposed SMF and Photochemical SMF have been developed. However, strong magnets are re-quired to operate foam electrode properly. Meanwhile, photochemical SMF electrocatalytic endurance has never been tested in various electrochemical system [38]. Moreover, foam electrodes and photo-chemical electrode need a certain specialized synthesis techniques which require the involvement of nanotechnology [37]. As a result, this study superior in terms of ease of use and the need of weaker magnets to improve HER rate compared to another studies in table 1. The only tradeoff provided by this study is the need of brown dravide tourmaline stone to create magnetic field reflection.

This study unveils the chaotic flux production by the random sized tourmaline stone magnetic field reflection. Since this study does not consider the uniformity aspect, more studies on processed diamagnetic stone variation such as thickness control, the shape of edges, and, the strength of the mag-nets are required. The phase characterization of the tourmaline stone is also required to assess the magnetic reflectivity through the crystal size and shape analysis. Also, the elemental and morphological studies to view the detail geometry of the produced magnetic flux are needed. Both, characters can be achieved through x-ray diffraction (XRD), scanning electron microscopy (SEM) or atomic force microscopy (AFM), and Energy dispersive x-ray spectroscopy (EDS). The electron density profile analysis will also help to understand the character of the magnetic field reflection by the diamagnetic tourmaline stone.

5. CONCLUSIONS

Chaotic flux improves HER rate of water electrolysis in any condition. The presence of chaotic flux destabilizes water molecule and accelerates Ion transfer. The effect of chaotic flux on static EMF and DMF are different. On static EMF, the chaotic flux prevents the concentration of magnetic field force which compressed the water molecules so that the magnetic field effect spread to any direction. The compressive force traded with shear force which displaces hydrogen bond. As a result, the static EMF experiences similar phenomenon with DMF. On DMF assisted electrolysis, chaotic flux improves HER rate at low RPM and

high RPM magnet rotation. The chaotic magnetic field prevents water molecules to reform which lowers the cohesion. The combination of shear force effect and the cohesion prevention lowers the Ionization energy of water molecule. Moreover, the paramagnetic OH^- ions are trapped by the magnetic field which favors H+- electron interaction. Therefore, the chaotic magnetic flux improves HER through the combination of shear force, Cohesion prevention, and, H^+-electron interaction control. Conclusively, The magnetic field reflection technique shows a great potential to accelerates hydrogen production by magnetic field assisted electrolysis.

ACKNOWLEDGMENTS

The authors would like to express gratitude towards Department of Mechanical Engineering, Faculty of Engineering, Brawijaya University for all supports that have been provided. This study funded through Hibah Doktor Non Lektor Kepala [Fakultas Teknik, Brawijaya University] with grant no.[].

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