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CHARACTERISTICS OF ELECTRIC CURRENT IN THE ELECTROLYSIS OF ACID AND ALKALINE WATER PRODUCTION FOR HEALTH

EKKI KURNIAWAN[1,3]*, JANKUNG RAHARJO[1,3], YULINDA[1], AND RINTIS MANFAATI[2]

1Department of Electrical and Energy System Engineering, FTE, Telkom University, Bandung, Indonesia

2Department of Chemical Engineering, Polytechnic of Bandung, Bandung, Indonesia

3Center of Excellence of Sustainable Energy and Climate Change, Telkom University, Bandung 40257, Indonesia

*Corresponding Author email: ekkikurniawan@telkomuniversity.ac.id

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Abstract

Acidic and alkaline water with potential health benefits can be produced through the process of electrolysis. In addition to the applied voltage, electric current is a crucial parameter in the electrolysis process. The energy consumed during electrolysis can be determined by measuring the voltage, electric current, and duration of operation. This study aims to investigate the characteristics of electric current during the electrolysis of mineral water to produce Electrolyzed Reduced Water (ERW) and Electrolyzed Oxidized Water (EOW), commonly referred to as alkaline and acidic water, respectively. The electrolysis current is monitored at specific time intervals (0, t_1, and t_2) throughout the process. In the initial stage (from 0 to t_1), the current increases exponentially, similar to the charging current behaviour of an inductor (L). In the second stage (from t_1 to t_2), the current decreases exponentially, resembling the discharge of a capacitor (C). In the final stage (after t_2), the current stabilizes and remains nearly constant, analogous to current flow through a resistor (R). A novel aspect of this study is the introduction of an equivalent RLC transient circuit model to describe the dynamic behaviour of electrolysis current. In this model, the electrolysis process is represented by a series RLC circuit with a switch operating sequentially at 0 (inductor charging), t_1 (capacitor discharging), and t_2 (resistive steady state). To the best of our knowledge, this RLC-based interpretation of electrolysis current behaviour in the context of ERW and EOW production has not been previously reported.

INTRODUCTION

Electrolyzed water is produced through the process of water electrolysis, which separates water into two distinct streams i.e. Electrolyzed Reduced Water (ERW) at the cathode and Electrolyzed Oxidized Water (EOW) at the anode. This process occurs in an electrolytic cell equipped with a membrane that separates the anode and cathode chambers, allowing ions exchange. When a voltage is applied, it generates an electric field that drives the flow of electrons and the movement of ions in the solution. Positively charged ions such as Ca^{2+}, Mg^{2+}, Na^{+}, and K^{+} migrate toward the cathode, where they react with OH^{-} ions to produce ERW (alkaline water). Conversely, negatively charged ions such as SO_4^{2-}, NO_3^{-}, CO_3^{2-}, Cl^{-}, and F^{-} move toward the anode, where they combine with H_3O^{+} ions to produce EOW (acidic water). The effectiveness of electrolysis depends on various parameters, including the applied voltage, current, electrolysis time, and the mineral content (Total Dissolved Solids, TDS), with a minimum recommended TDS of approximately 50 mg/L to ensure sufficient ionic conductivity [1].

At the cathode, a reduction reaction occurs, producing ERW (alkaline water) with a pH > 7 and a negative Oxidation-Reduction Potential (ORP), typically ranging from -300 mV to -800 mV. The reaction is as follows [2]-[3]:

$$2H_2O_{(l)} + 2e^{-} \rightarrow H_{2(g)} + 2OH^{-}_{(aq)} \quad (1)$$

This alkaline water contains an increased concentration of hydroxide ions (OH^{-}), which can combine with positively charged mineral ions such as Na^{+}, K^{+}, Ca^{2+}, and Mg^{2+}. The presence of dissolved hydrogen gas (H_2) is believed to contribute to antioxidant properties; however, its health benefits remain under ongoing scientific investigation and should be interpreted with caution [4].Conversely, at the **anode**, an oxidation reaction produces **EOW** (acidic water), with a pH < 7 and a high ORP typically ranging from +600 mV to over +1200 mV. EOW contains a mixture of oxidizing agents such as hypochlorous acid (HOCl), chlorine gas (Cl_2), and dissolved oxygen (O_2), which contribute to its antimicrobial activity [5]–[7]. The anodic reactions include [8], [9]:

$$2H_2O_{(l)} \rightarrow O_{2(g)} + 4H^+_{(aq)} + 4e^- \quad (2)$$

$$2Cl^-_{(aq)} \rightarrow Cl_{2(g)} \quad (3)$$

$$Cl_{2(g)} + H_2O_{(l)} \rightarrow HOCl_{(l)} + HCl_{(l)} \quad (4)$$

Due to its oxidizing nature, EOW is commonly used as a disinfectant or antiseptic, particularly in medical and food-processing applications [6].

While the chemical properties of ERW and EOW have been widely studied, the dynamic electrical characteristics during electrolysis—specifically the behavior of the electrolysis current—have received less attention. Understanding the current profile is important for optimizing system design, energy efficiency, and product consistency. It is hypothesized that the current follows a transient behavior that can be modeled using an equivalent RLC circuit, where changes over time are associated with the buildup and stabilization of ion transport within the electrolyte.

This study aims to investigate the time-dependent behaviour of electrolysis current during the production of ERW and EOW from mineral water. Develop and validate an equivalent RLC transient circuit model to represent the electrochemical behaviour observed during the electrolysis process. Provide insights into the energy profile and system dynamics that could support improved control and efficiency in electrolyzed water production.

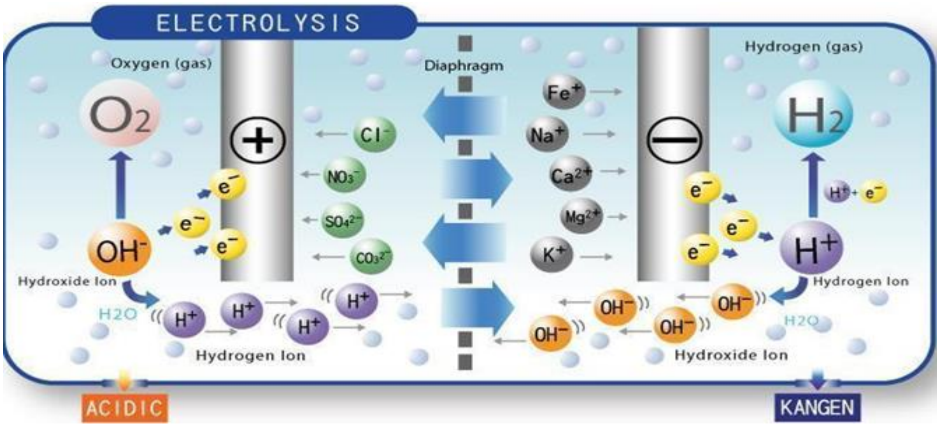


Figure 1. The mineral water electrolysis process produces oxygen gas and acidic water on the anode side and hydrogen gas and alkaline water on the cathode side [1].

Further research on the benefits of alkaline and acidic water has been carried out by medical experts. Shirahata (2012) has explained that electrolysis of mineral water can produce alkaline water which can prevent diseases such as stroke, diabetes, cancer, etc. [6], [10]

Alkaline water produced from the cathode of an electrolysis machine can provide good benefits for the body, namely increasing serum sodium levels in human blood [11]. Alkaline water therapy with a pH of 9.5 can reduce Lactate Dehydrogenase (LDH) levels in lymph node cancer sufferers. Non-pharmacological therapy was provided over a period of two months. Each respondent consumed 1.5 liters of alkaline water/day.[12]

Consuming alkaline water improves acid-base balance and can avoid dehydration. Regular consumption of alkaline water is a valuable nutritional factor that influences acid-base balance and hydration status in healthy active adults [13], [14]. Alkaline water with a combination of pH 9.5 and 11.5 for a period of 14 days is effective in reducing Random Blood Sugar (RBS) in people with type 2 diabetes mellitus.[15]

Drinking alkaline pH-9 can inhibit physical fatigue, recover fatigue more quickly, and does not increase cardiac endurance in high-intensity anaerobic interval training in soccer players.[16]

Resistance Inductor and Capacitor

Resistors, inductors, and capacitors (RLC) are fundamental load elements in electrical circuits and are classified as passive components, meaning they cannot independently generate electrical energy. Instead, they rely on external voltage or current sources to function. The characteristic relationships and ideal impedance values for these components are presented in **Table 1**.

Electrical resistance (R) is defined as the ratio between the voltage (V) applied across a component and the resulting electric current (I) flowing through it. Ohm's Law, expressed as I=V/R.

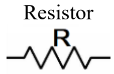
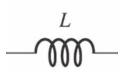
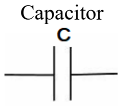
An inductor (L) is a passive device typically made of a coiled wire, with or without a magnetic core such as iron or ferrite. The inductance of an inductor determines how it resists changes in current. The voltage across an inductor is given by the formula V=L di/dt, while the current can be calculated using i=1/L∫v dt.

An inductor stores energy in a magnetic field, and when a DC voltage source is applied, the current through it gradually increases and eventually reaches a maximum value determined by the circuit.

A **capacitor (C)** is an electrical device used to store electrical charge. It consists of two conductive plates separated by an insulating material known as a dielectric. Capacitors store energy in the form of an electric field, functioning similarly to small rechargeable batteries that can absorb and release electrical energy. When uncharged, a capacitor has zero voltage across its terminals, and when charged, it maintains a steady voltage, much like a battery.

In circuits with voltage sources, capacitors draw energy from these sources. If q is the amount of charge transferred over time ttt, the resulting current is i = dq(t)/dt, or i(t) = C dV(t)/dt.

Table 1. RLC component symbol and its formula for voltage and current.

Component Symbol	Formula	
	Voltage	Current
Resistor 	V= IR	I=V/R
Inductor 	V = L di/dt, V(t)= Vo $e^{-tR/L}$	I=V/R (1-$e^{-tR/L}$)
Capacitor 	V=(1/C)∫idt V(t)= Vo $e^{t/RC}$	I= V/R $e^{-t/RC}$

When a DC voltage is applied to an inductor or capacitor, there is a change in current and therefore the current changes exponentially slowly. In the inductor the current will go to a value that will reach the peak value, the current will no longer change, while in the capacitor the current will reach its lowest point. This deceleration rate is characterized by the τ =L/R or RC time constant, as shown in **Figure 2**.

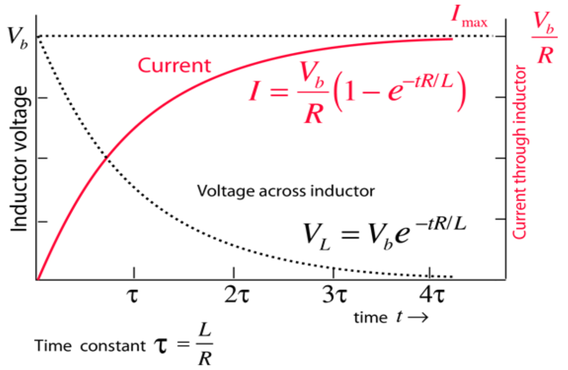


Figure 2. Graph of transient current and voltage across an inductor.

Equivalent Electrical Circuit

Previous research regarding the equivalent electrical circuit of the electrolysis process. None of the four equivalent circuits that follow list inductance L as one of the characteristics of electrolyzed water:

The equivalent circuit for the charge transfer resistance (Rct) and constant phase element (CPE) in an electrochemical cell is depicted in **Figure 3.** The Cint double electrical layer capacitance is the result of combining the capacitive qualities. Geometric cell capacitance is denoted by Cgeom. The resistance of charge transfer reactions at the electrode/electrolyte interface is modeled by the Rct parameter. (Cint–interface capacitance, Cgeom–cell capacitance, Rct–charge transfer resistance at the electrode/electrolyte interface, and Rel–bulk electrolyte resistance (solution or solution + membrane).[19]

The PEMEL electrical equivalent circuit that takes impedance Warburg into account is shown in **Figure 4.** The activation resistance (Ract) and electrical double-layer capacitor (Cdl) connected to activation losses, Warburg impedance (ZW) connected to mass transfer, and membrane resistance (Rohm) related to ohmic losses make up the electrical equivalent circuit parameters. Moreover, Rtot is the total equivalent resistance of the cell, and Vrev is the value that results from deducting the voltage, Ecell, needed for cell activation from the applied voltage, VEL[21].

Figure 5. The equivalent circuit model incorporates key elements such as inductors, resistors, and constant phase elements (CPEs). Among these, resistors play a central role, representing ionic conduction and electron transfer pathways. The resistance values reflect the material's opposition to interfacial charge transport—either electron transport in conductors or ion transport in electrolytes—as well as charge transfer at the electrode interfaces. Capacitors and inductors represent space-charge polarization effects, including adsorption/desorption dynamics and the electrochemical double layer. The inductive response typically arises from measurement wiring and connections. These elements are configured in both series and parallel to reflect the system's complex electrochemical behavior. The CPEs specifically account for surface roughness of electrodes and are indicative of the anodic OER and cathodic HER charge transfer processes, along with associated mass transport effects [22].

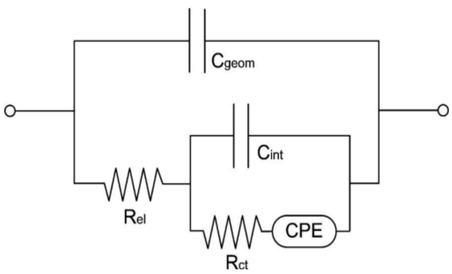


Figure 3. Equivalent circuit of electrochemical cell.

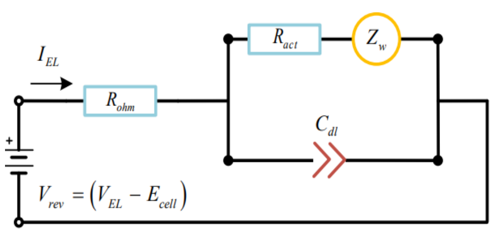


Figure 4. PEMEL electrical equivalent circuit.

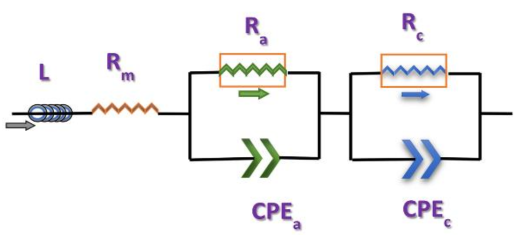


Figure 5. Equivalent circuit of Anion Electrolyzer Membrane (AEM).

EXPERIMENT

Material

Materials used consist of distilled water, Bandung City PDAM water, and sea water taken around Ancol beach, Jakarta City.

Instrumentation

The instrumentation consists of an assembled Portable Water Ionizer (PWI), Taff Ware KWE-PM01 Brand of Digital Energy Meter (DEM), AC voltage source PLN 220V, pH,TDS and ORP meter brand CT8022. The Measuring Instrument DEM, pH, TDS, and ORP meter can be seen **in Figure 6**.

Figure 7 shows the complete electrolysis device, known as a PWI, which has a maximum fixed volume of 1400 ml. The anode side of the container is split by a membrane into two sections: the cathode, which is a plastic kettle cathode, and the anode, which is a plastic bottle with a volume of 200 ml and 1200 ml.

The bottle's anode side is punctured multiple times, each with a hole area of about 1 cm^2, so that cotton membrane can be inserted. The teapot lid is fastened to the carbon graphite and stainless steel (SS306) electrodes, which are 12 cm long and 1 mm in diameter. There is a gap of 7 cm between each electrode.

Even though this equipment uses an inert type electrode, there is still erosion damage on the anode due to the oxidation process. To overcome this, an electrode exchange switch is used, so that one electrode can function as an anode or cathode, depending on the direction of the switch.

Figure 6. Measuring Instrument DEM , pH, TDS, and ORP meter.

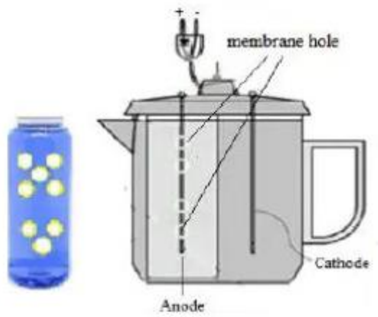


Figure 7. PWI schematic design.

Figure 8 shows a schematic of the electrolysis circuit which produces acidic water on the anode side and alkaline water on the cathode side. The voltage source comes from AC PLN source of 220 volts, rectified by a diode producing a DC voltage of approximately 105 volts. The electric current measurement is set on the button on the DEM measuring instrument.

Procedure

There were three electrolysis experiments for three different types of water that were put into the PWI, the bottles and teapots were filled completely with the water, as follows:

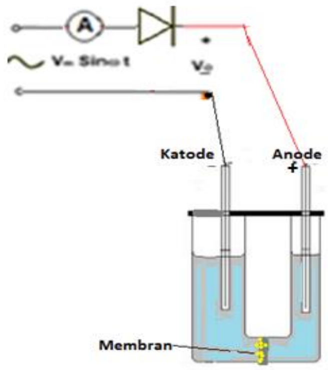
Experiment 1: 700 mL of distilled water mixed with 700 mL of PDAM water, the TDS was measured at 63 ppm, pH= 7.1, temperature = 24.6 °C, ORP = 245 mV.

Experiment 2: 1400 mL of PDAM water, the TDS was measured at 111 ppm, pH= 7.1, temperature = 25.2 °C, ORP = 185 mV

Experiment 3: 1400 mL of PDAM water mixed with 1 drop of sea water, the TDS was measured at 203 ppm, pH= 7.1, temperature = 26.1 °C , ORP = 140 mV.

In each experiment, the electrolysis current was measured every 10 minutes, 18 times, for up to 180 minutes. After completing the experiment, the acidic and alkaline water were separated and the ORP, temperature, pH, and TDS values were measured.

(a)



(b)

Figure 8. (a). PWI dan DEM meter, and (b). the schematic of the experimental series and electrolysis process that produces acidic and alkaline water.

RESULT AND DISCUSSION

Results of Temperature, ORP, TDS and pH Measurements

Measurements of pH and TDS of type 1, 2 and 3 electrolysis water with TDS 63, 111 and 203 ppm were carried out at the beginning and end of the experiment. The results can be seen in **Table 2**. From this table it can be seen that the higher the TDS value, the higher the pH change.

Table 2. The measurement results of TDS and pH

TDS Initial (ppm)	pH inital	TDS result		pH result	
		Acid	Base	Acid	Base
63	7.1	388	72	3.8	8.4
111	7.1	777	131	3.3	9.0
203	7.8	191	122	2.6	10

Tabel 3. The measurement results Temperature & ORP.

Temp. Initial (° C)	ORP Inital (mV)	Temp. Result (° C)		ORP result (mV)	
		Acid	Base	Acid	Base
24.6	245	30.2	30.7	703	-367
25.2	185	35.1	35.6	857	-475
26.1	140	40.1	40.9	1100	-784

From **Table 3.** it can be seen that the temperature increased by 9-15 degrees Celsius. Meanwhile, the ORP value on the anode side is positive and on the cathode side it is negative. **Figure 9** is a graph of electric current measured for three types of electrolyzed mineral water, each for 3 hours (180 minutes)

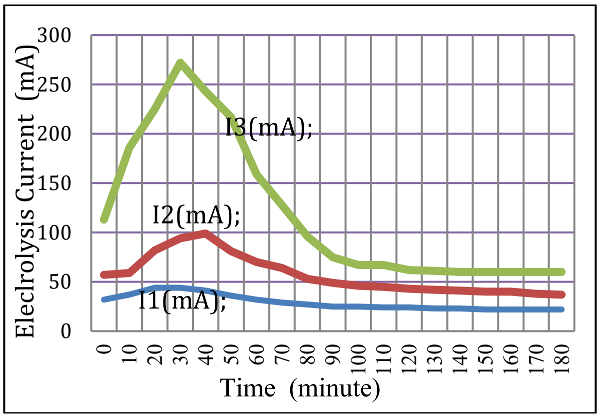
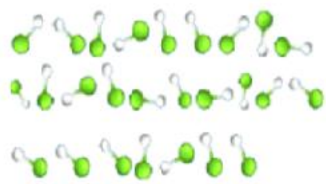
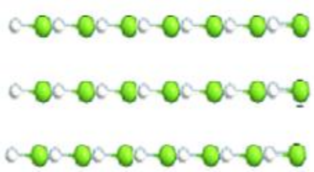


Figure 9. Graph of electrolysis current for 180 minutes.

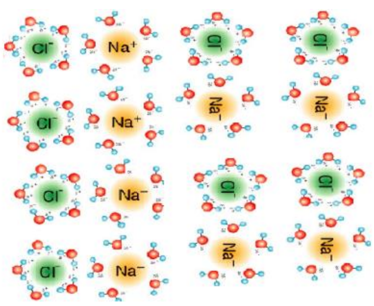
From the **figure 9**, it can be seen that in the first time stage the electrolysis current increases exponentially until it reaches its peak. The characteristics of the current are similar to the charging current of an inductor (L), then in the second time stage the electrolysis current decreases exponentially, at this stage the characteristics are like the charging current of a capacitor (C) and in the third time stage the electrolysis current tends to be constant, just like the current flowing in the resistor (R) although at the end there is a decrease, this occurs because of the increase in temperature of the solution which causes an increase in the resistance value.



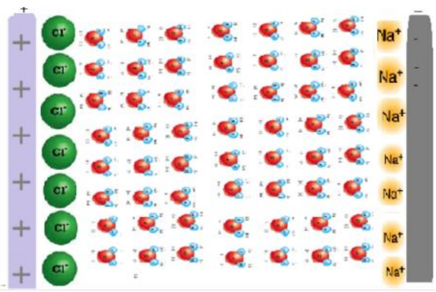
(a) Dipole orientation before electrolysis, the inductance properties L begin to appear



(b) Dipole orientation during electrolysis until, the capacitancy properties C begin to appear



c. Dipole orientation Na^+ and Cl^- in water before electrolysis



d. Dipole orientation Na^+ and Cl^- in water after electrolysis

Figure 10. Changes in the direction and position of the ions and molecules during the electrolysis process illustration (a) before electrolysis the direction is random, the position of the molecule is not random (b) after the electrolysis process, the direction is regular, so the ions are released attracted by the electrode, (c) NaCl molecules around the water before electrolysis still random (d) after electrolysis Na^+ ions will stick to the cathode side (-) and become Na metal, while Cl- ions are attracted to the anode side (-) and will eventually turn into Cl_2 gas.

The change in the orientation of the dipole ions and molecules in the electrolyte can be seen in **Figure 10,** initially random, when there is an electric field, causes a gradual regular orientation towards which the current increases to a peak point, this is in accordance with the nature of inductance L, after everything is regular in one direction, at that time the current begins to decrease, the capacitance property C appears, until all ions are attracted to the electrode, both anode and cathode, if it has been achieved, then only the resistance property, R from water appears.

Thus the equivalent circuit can be depicted as in **Figure 11.** The equivalent circuit model can be described as an RLC transient circuit with a switch with the switching time being 0 for L, t1 for C, and t2 for R Sequentially.

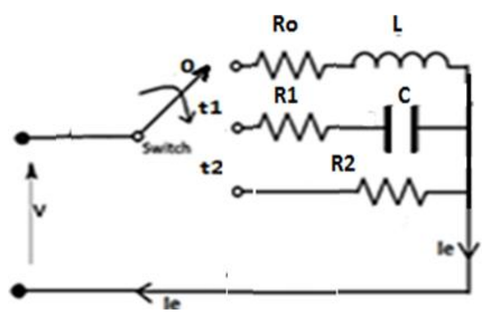


Figure 11 . The equivalent circuit of electrolylis producing alkaline and acid water.

The Equation (7), (8) and (9) are the electrolysis current equation I1, I2, and I3 is the electrolysis current in amperes unit that flows in water types 1, 2 and 3. with TDS values of 63, 111, and 203 ppm respectively. The current equation that occurs during electrolysis can be written as follows :

$$I1\ (t) = \{0{,}052(1 - e^{-0{,}113t});\ t < t1\ 0{,}04e^{-0.067t};\ t1 < t < t2\ 0.022;\ \ t > t2\ \ \}A \quad (7)$$

t1 = 1800 s ; t2 = 7200 s

$$I2\ (t) = \{0{,}113(1 - e^{-0{,}183t});\ t < t1\ 0{,}099e^{-0{,}103t};\ t1 < t < t2\ 0.040;\ \ t > t2\ \ \}A \quad (8)$$

t1 = 2400 s ; t2 = 7200 s

$$I1\ (t) = \{0{,}384(1 - e^{-0{,}283t});\ t < t1\ 0{,}278e^{-0{,}188t};\ t1 < t < t2\ 0.063;\ \ t > t2\ \ \}A \quad (9)$$

t1 = 2400 s ; t2 = 7200 s

In each equation there are three time events, namely 0, t1 and t2. The amount of energy during the electrolysis process can be calculated from the area of the integral graph of the equation for each current multiplied by the DC voltage installed i.e 0.102, 0.201 and 0.4247 Kkal/mole. With the help of MS Excel software, the R, L and C values can be calculated, the results can be seen in **Table 4.** Ro in unit ohms (Ω) is connected in series with L in unit Henry(H), R1 in unit ohms (Ω) is connected in series with C in unit Farad (F) and R2 in unit ohms (Ω) is the resistance at the last moment of the electrolysis process.

Table 4. Calculation Results of R, L, and C Values.

TDS (ppm)	Ro (Ω)	R1 (Ω)	R2 (Ω)	L (H)	C (F)
63	2035	2450	4773	18011	15
111	932	961	2625	5089	10
203	273	313	1667	967	5.3

From all the table above it can be seen that TDS is one of the important parameters of mineral water or drinking water. The TDS value is directly proportional to the electrical conductivity value. The high electrical conductivity value of water indicates the high TDS contained. Each water has its own TDS value, which is different from one another, depending on the concentration of dissolved ions in it.

The TDS value depends on the content of mineral salt ions, which can form alkaline water and acid water in the electrolysis process. TDS is the amount of alkaline/alkaline earth ions (Na^+, K^+, Ca^{2+}, Mg^{2+}), acid ions (Cl^-, NO_3^-, SO_4^{2-}, F^-) contained in mineral water. The TDS value can be approximated by equation (10) [23]:

$$TDS = Cl^- + NO_3^- + SO_4^{2-} + F^- + Na^+ + K^+ + Ca^{2+} + Mg^{2+} + 0.6\ Alkalinity \quad (10)$$

CONCLUSION

Mineral water is an electrolyte solution that can be separated into alkaline and acidic water through electrolysis using a membrane separator. The total dissolved solids (TDS) concentration in the mineral water determines the magnitude of the electrolysis current; higher TDS results in a higher current. Variations in the electrolysis current are influenced by the orientation of molecular dipole moments, ion reduction in the electrolyte, and changes in electrolyte temperature.

The electrolysis current of mineral water exhibits three distinct behavioral phases. In the initial phase, the water exhibits inductive characteristics, where the current increases exponentially until reaching a peak value. In the second phase, the current decreases exponentially, indicating capacitive behavior. In the final phase, the current becomes nearly constant, which reflects resistive characteristics.

Therefore, mineral water electrolysis can be modeled as a transient electrical circuit consisting of a parallel combination of R–L, R–C, and R elements, representing its inductive, capacitive, and resistive behavior over time.

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