PKL electrochemical cell and battery-The influence of equilibrium constant

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Abstract

Galvanic cell is an electrochemical cell. It was discovered by Luigi Galvani in1780. He discovered that when two different metals (say Copper and Zinc) touched at the same time to two different parts of a nerve of a frog leg then the leg contracts. He named it animal electricity. A Galvanic cell derives electrical energy from spontaneous redox reaction taking place within the cell. In 1800 Alessandro Volta presented his Voltaic cell which was entirely out of non-biological material to challenge Galvanie's animal electricity theory in favour of his own metal-metal contract electricity theory. The cell invented by Volta was the first electrical battery. In common usages, the word "battery" has come to include a single Galvanic cell, but a battery properly consists of multiple cells. To keep it in mind it has been designed and fabricated PKL electrochemical cell. It is found that the PKL cell and battery potential depends on equilibrium constant. The variation of PKL electrochemical cell and battery has been tabulated graphically discussed.

Key Words: PKL electrochemical cell, PKL electrochemical battery, Equilibrium constant, PKL extract, Secondary salt

I. Introduction

A cell is a single arrangement of two electrodes and an electrolytic solution capable of yielding electricity due to chemical action within the cell or of producing chemical action due to passage of electricity through the cell. Each cell is made of two electrodes, one liberates electrons and is called oxidizing electrode (i.e at which oxidation occurs), while the other absorbs electrons and is called reducing electrode (i.e,at which reduction occurs). Examples are Deniell cell, Voltanic cell etc. A battery is a combination of two or more cells arranged in series or parallel. For example, the ordinary 6 volt lead storage battery is a combination of three 2 volt cells connected in series. In this research work, PKL has been used as a biomass source. After finishing the oil, gas and coal renewable energy source will face the energy crisis. PKL source is one of the renewable energy sources. It can provide the electricity in the un electrified areas of Bangladesh. It may be alternative sources like solar energy all over the world.

II. Methods and Materials

The materials used for PKL electrochemical cell has been gin by the following:

II A. Theory

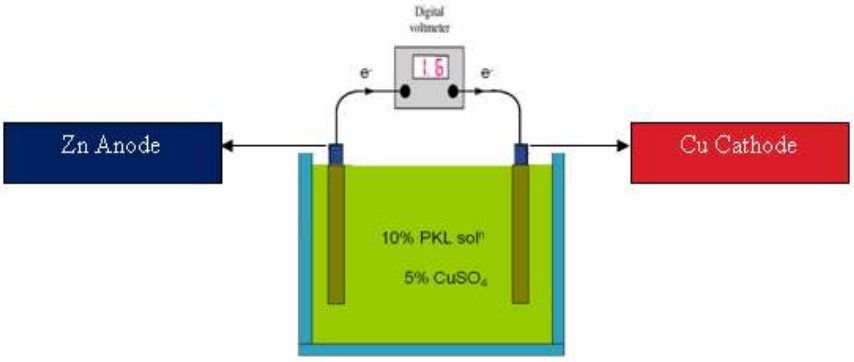

Fig.1 PKL electrochemical Cell

The readings from the voltmeter give the reaction's cell voltage or potential difference between its two half-cells. Cell voltage is also known as cell potential or electromotive force (e.m.f) and it is shown as the symbol E_{cell}. The total cell reaction which produces electricity can be represented as follow:

$$2Zn+Cu^{2+}+2H^{+} \longrightarrow 2Zn^{2+}+Cu+H_2\uparrow$$

The anode half cell reaction is,

$$2Zn \longrightarrow 2Zn^{2+} + 4e^{-}$$

The cathode half cell reactions,

$$Cu^{2+}+2e^{-} \longrightarrow Cu$$
$$2H^{+}+2e^{-} \longrightarrow H_2\uparrow$$

So the cell representation is,

$$Zn|Zn^{2+}|H^{+}|Cu^{2+}|Cu$$

II B. PKL Cell Potential

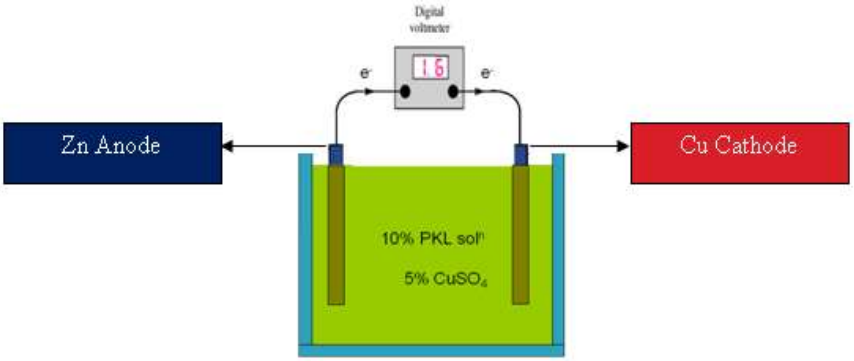

Fig.2 PKL electrochemical Cell

The Cell potential is : $E_{Cell} = E_{right\ (cathode)} - E_{left\ (anode)}$.

So that, $E_{Cell} = E_{Cu^{2+}|Cu} + E_{2H^{+}|H_2} - 2E_{Zn^{2+}|Zn}$ …… …. (1)

If E_{cell} is positive the reaction is spontaneous and it is a voltaic cell. If the E^{o}_{cell} is negative, the reaction is non-spontaneous and it is referred to as an electrolytic cell.

Here,

$$E_{Cu^{2+}|Cu} = E^{0}_{Cu^{2+}|Cu} - \frac{0.0591}{n}\log\frac{1}{[Cu^{2+}]} \quad \text{..... (2)}$$

$$E_{2H^{+}|H_2} = E^{0}_{2H^{+}|H_2} - \frac{0.0591}{n}\log\frac{1}{[H^{+}]^2} \quad \text{..... (3)}$$

$$E_{Zn^{2+}|Zn} = E^{0}_{Zn^{2+}|Zn} - \frac{0.0591}{n}\log\frac{1}{[Zn^{2+}]^2} \quad \text{..... (4)}$$

Where, n= number of moles of electrons transferred in cell reactions,$[Zn^{2+}]$ = Concentration of Zinc in molarity,

$[Cu^{2+}]$ = Concentration of Copper in molarity,

$E^{0}_{Zn^{2+}|Zn}$ = -0.76Volt

$E^{0}_{Cu^{2+}|Cu}$ = 0.34Volt

$E^{0}_{H^{+}|H_2}$ = 0.0 Volt

So that, PKL Cell potential = $E^{0}_{Cu^{2+}|Cu} - \frac{0.0591}{n}\log\frac{1}{[Cu^{2+}]} - [E^{0}_{Zn^{2+}|Zn} - \frac{0.0591}{n}\log\frac{1}{[Zn^{2+}]}]$

$+ E^{0}_{2H^{+}|H_2} - \frac{0.0591}{n}\log\frac{1}{[H^{+}]^2} - [E^{0}_{Zn^{2+}|Zn} - \frac{0.0591}{n}\log\frac{1}{[Zn^{2+}]}]$

$= E^{0}_{Cu^{2+}|Cu} + E^{0}_{2H^{+}|H_2} - 2E^{0}_{Zn^{2+}|Zn} + \frac{0.0591}{2}[\log\frac{1}{[Zn^{2+}]^2} - (\log\frac{1}{[Cu^{2+}]} + \log\frac{1}{[H^{+}]^2})]$

$= 0.34 + 0 - 2(-0.76) + \frac{0.0591}{2}\log\frac{[Cu^{2+}][H^{+}]^2}{[Zn^{2+}]^2}$

$= 1.86 + \frac{0.0591}{2}\log\frac{[Cu^{2+}][H^{+}]}{[Zn^{2+}]}$ ..... (5)

II C. Calculation of PKL Cell Potential

The equation (5) represents the equation for the calculation of PKL cell potential. For cell-8 the cell potential is calculated below: Here, the initial concentration of Zn^{2+} in molarity is = 0.0334 M.The initial concentration of Cu^{2+} in molarity is = 0.3330 M. The pH of the solution is = 3.5.The concentration of H^{+} in molarity is = antilog (-3.5) = 3.16×10^{-4} M. Now putting the values in equation (5) we get,

PKL cell potential at temperature 25^0C and 1 atm = $1.86 + \frac{0.0591}{2} \log \frac{[0.333][3.16\times10^{-4}]}{[0.0334]}$ = 1.85 V.

Thus the theoretical value of PKL cell potential at temperature 25^0C and 1 atm is 1.85 for one unit cell. And thus the potential for a battery with six compartment is = 6 × 1.85 V =11.1 V

III. Results and Discussion

The theoretical value of PKL cell potential at temperature 25^0C and 1 atm is 1.85 for one unit cell. And thus the potential for a battery with six compartment is = 6 × 1.85 V =11.1 V. But practically the potential is only 6.4 V. Thus it is seen that practically the cell potential doesn't depend on the acidity of PKL juice. Though the current flow can varies with the % of PKL juice. Where each of the electrodes was connected in parallel but when they were connected in series then we get the potential almost 11V.

IV. Determination of equilibrium constant of cell reaction

IV A. Equilibrium constant (K)

Equilibrium constant is the ratio of the equilibrium concentrations of the products raised to the power of their stoichiometric coefficients to the equilibrium concentrations of the reactants raised to the power of their stoichiometric coefficients. For a reversible reaction:

$aA + bB \leftrightarrow cC + dD$ and $K = [C]^c \cdot [D]^d / [A]^a \cdot [B]^b$, Where,

[A] = equilibrium concentration of A in Molerity (M)
[B] = equilibrium concentration of B in Molerity (M)
[C] = equilibrium concentration of C in Molerity (M)
[D] = equilibrium concentration of D in Molerity (M)
And a, b, c and d are the number of moles of A, B, C and D respectively.

IV B. Theory

When a cell produces a current, the current can be used to do work – to run a motor, for instance. Thermo dynamical principal can be employed to derive a reaction between electrical energy and the maximum amount of work W_{max} obtainable from the cell. The maximum amount of work obtainable from the cell is the product charge flowing per mole and maximum potential difference, E through which the is transferred, $W_{max} = -nFE_{max}$ ..... (1)

Where n is the number of moles of electrons transferred and is equal to the valence of the ion participating in the cell reaction. F stands for Faraday and is equal to 96500 coulombs and E is the e.m.f. (electromotive force)of the cell.

The input work, $W_{max} = -nFE_{max}$ ..... (2)

The output work, $W = -nFE$ ..... (3)

According to thermodynamics, the maximum work that can be derived from a chemical reaction is equal to the free energy (ΔG) for the reaction, $W_{max} = \Delta G$ ..... (4)

Therefore, from (2) and (4) we can write, $\Delta G = -nFE_{max}$ ..... (5)

Again at equilibrium the Gibbs free energy, $\Delta G = -RT\ln K$ ..... (6)

$= -2.303RT\log K$ ..... (7)

From (5) and (7) we get, $-nFE_{max} = -2.303RT\log K$

$$\text{or, } \log K = \frac{-nFEmax}{-2.303RT}$$

$$\text{or, } \log K = \frac{nFEmax}{2.303RT}$$

$$\therefore K = \text{antilog}\frac{nFEmax}{2.303RT} \quad \text{..... (8)}$$

Table 1: Calculation of the equilibrium constant

Cell No.	Temperature, T (K)	Maximum potential of PKL battery, E'_{max}	Maximum potential of PKL cell $E_{max} = E'_{max}/6$	Number of electron transferred, n	Equilibrium constant $K = \text{antilog}\frac{nFEmax}{2.303RT}$	Comments
1	301	5.89	0.982	4	5.88×10^{65}	
2	,,	6.12	1.020	4	2.09×10^{68}	
3	,,	4.93	0.822	2	3.39×10^{27}	The PKL Cell was fuelled with only PKL juice/extract
4	,,	6.25	1.042	2	7.76×10^{34}	The Cell was fuelled with only secondary salt
5	,,	6.34	1.057	4	6.16×10^{70}	
6	,,	5.31	0.885	4	1.86×10^{59}	
10		6.16	1.027	4	6.03×10^{68}	

Here, F = 96500C; [Faraday constant], R = 8.314 $JK^{-1}mol^{-1}$; [the molar gas constant],n = Number of electron transferred. For cell-3 and 4 number of electron transferred were 2 and for rest of the cells that were 4, T = 25^0C = 301K; [Room temperature]

IV C. Calculation

The known equation is: $K = \text{antilog}\frac{nFEmax}{2.303RT}$ ..... (9)

Where, n= number of moles of electrons transferred in cell reactions, F= 96500C = Faraday Constant,

$E_{max} = \frac{E^0_{cell}}{6} V = X$ Volt (Consider), Where, E^0_{cell} is the standard potential of the PKL module.

R= 8.314 $JK^{-1}mol^{-1}$, T = Room temperature at Kelvin scale. By putting the value of the above quantities in equation (9) we can calculate the value of equilibrium constant K of PKL cell.

For cell-8: $K = \text{antilog}\frac{nFEmax}{2.303RT} = \text{antilog}\frac{4\times96500\times1.027}{2.303\times8.314\times301} = 6.03\times10^{68}$

V. Results and Discussion

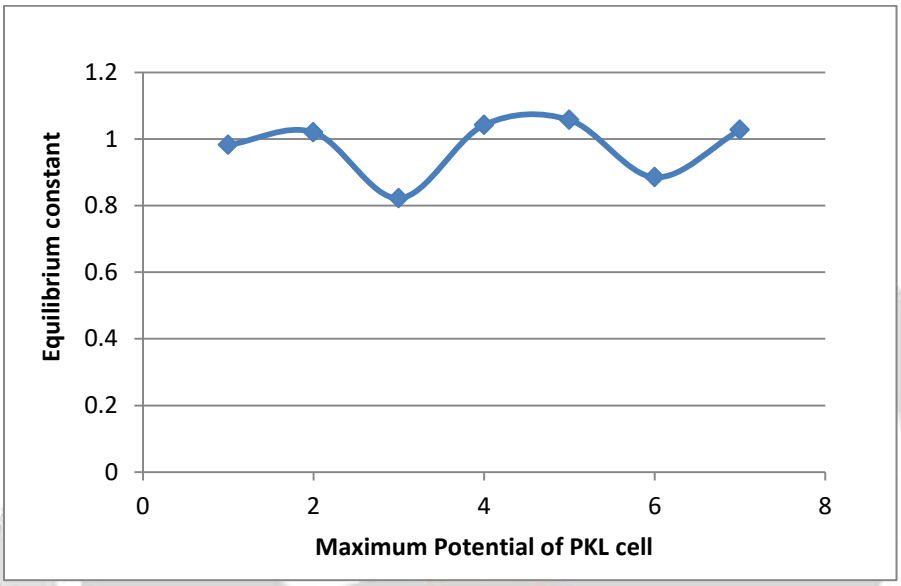

Fig.3 Equilibrium constant versus Maximum Potential of PKL cell

Fig.3 shows the Equilibrium constant versus Maximum Potential of PKL cell. It is shown that the variation of Equilibrium constant with time is fluctuated in sinusoidal form.

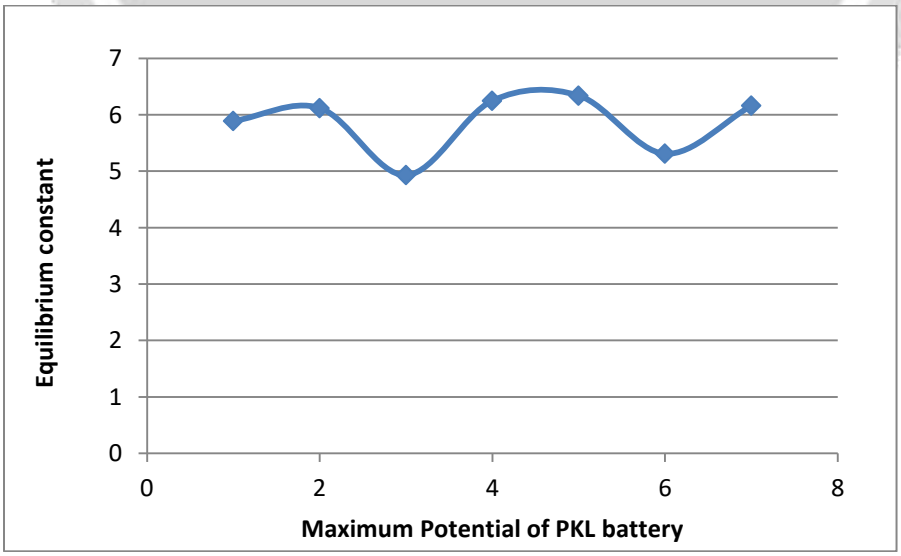

Fig.4 Equilibrium constant versus Maximum Potential of PKL battery

Fig.3 shows the Equilibrium constant versus Maximum Potential of PKL battery. It is shown that the Variation of Equilibrium constant with time is fluctuated in sinusoidal form.

The reaction taking place is the ionic reaction where the charged species may produce and consume simultaneously. The concentration of product ions increases very fast and similarly the concentration of reactant ions decrease simultaneously. The equilibrium constant was calculated from the maximum potential which was observed at initial point. In Cell-3 & -4 there was only one type of ionic species demonstrated at Table 1 but for the other three cells there were both reactant species (H^+ & Cu^{2+}). From this we can decide that the forward reaction is higher for the reaction at which both the ionic species presence. This is because both Cu^{2+} & H^+ ions simultaneously reduce to give solid copper and hydrogen gas and for this zinc plate undergoes oxidation very much rapidly. Again $CuSO_4.5H_2O$ acts as a secondary salt and hence the presence of this salt increases the ionization of weak organic acids presence in PKL extract/juice.

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