Chapter 8

CHAPTER 8

FABRICATION OF ION-CONDUCTING BATTERY USING PREPARED BIO-ELECTROLYTES AND COMPARISON

This chapter gives an insight into the construction of an ion-conducting battery from the bio-electrolyte prepared from the blend of biomass, polyvinyl alcohol, and salt a charge carrier ion. The bio-electrolytes prepared from the Corn silk, Seaweed, and Salmalia gum are sandwiched between the respective anode and cathode for fabricating the respective primary battery. The battery holder setup used for the fabrication of the battery by packing the bio-electrolyte between the anode and cathode pellets for the complete investigation and its characterization has been given in Figure 8.1

8.1 FABRICATION OF ION-CONDUCTING BATTERY

8.1.1 Fabrication of a Magnesium-Ion Conducting battery

The bio-electrolyte film with a maximum conductivity has been confirmed from the obtained AC Impedance analysis and their characterization techniques carried out to investigate their ionic mobility and hence their ion-conducting ability. Thereafter, a magnesium–ion conducting battery has been constructed with the highest conducting biopolymer membrane as the electrolyte. Magnesium metal has been chosen as the anode. The cathode has been prepared by grinding the MnO_2: Graphite: Biopolymer electrolyte in the ratio (3:1:0.5) and pelletized with a 5-ton pressure to form a pellet. Thus, the primary magnesium-ion conducting battery is constructed by sandwiching the anode and cathode with the highest conducting electrolyte membrane.

The anodic and cathodic reactions may take place as given below:

At Anode

$$\mathrm{Mg} + 2(\mathrm{OH}^-) \rightarrow \mathrm{Mg}(\mathrm{OH})_2 + 2e^- \quad (8.1)$$

At Cathode

$$2\mathrm{MnO_2} + \mathrm{H_2O} + 2e^- \rightarrow \mathrm{Mn_2O_3} + 2\mathrm{OH}^- \quad (8.2)$$

Overall Reaction

$$Mg + 2MnO_2 + H_2O \rightarrow Mg\,(OH)_2 + Mn_2O_3 \quad (8.3)$$

The discharge characteristics of the cell at room temperature when connected to an external load of 100 KΩ are analyzed. With a load of 100 KΩ, the variation in the current drawn has been studied. The cell potential is examined until a constant voltage appears for the primary cell and its discharge characteristics with respect to time have also been performed.

8.1.2 Fabrication of a Lithium-Ion Conducting Battery

Primary lithium–ion conducting battery has been fabricated using the respective highest conducting bio-electrolyte prepared from the biomasses. The anode material chosen for the Lithium–ion battery is Zn: $ZnSO_4.7H_2O$: C in the ratio of (3:1:1). They are carefully ground using a mortar and pestle and pelletized using a hydraulic press to form an anode pellet.
The cathode material comprises PbO_2: V_2O_5:C taken in the ratio of 7:2:1 which is also pelletized. Now, the primary battery is constructed by packing the electrolyte between the pelletized anode and cathode. The reactions taking place at the anode and cathode have been provided below which are taken similarly to the proton battery setup.

At Anode:

$$n\,\mathrm{Zn} + \mathrm{ZnSO_4} \cdot 7\mathrm{H_2O} \leftrightarrow \mathrm{Zn}_{n+1}(\mathrm{SO_4}).(7-2\mathrm{n})\mathrm{H_2O}.\,2\mathrm{n}(\mathrm{OH}) + 2\mathrm{nH}^+ + 2ne^- \quad (8.4)$$

At Cathode:

$$\mathrm{PbO_2} + 4\mathrm{H}^+ + 2e^- \quad (8.5)$$

$$\mathrm{V_2O_5} + 6\mathrm{H}^+ + 2\mathrm{e}^- \leftrightarrow 2\mathrm{VO}^{2+} + 3\mathrm{H_2O} \quad (8.6)$$

The protons produced at the anode repel the lithium ions whereas Li^+ ions move from the anode to the cathode site through the bio-electrolyte matrix by hopping mechanism [1].

8.1.3 Fabrication of a Proton Conducting Battery

The primary proton cell has been constructed using the optimized bio-electrolyte with the highest ionic conductivity at room temperature.

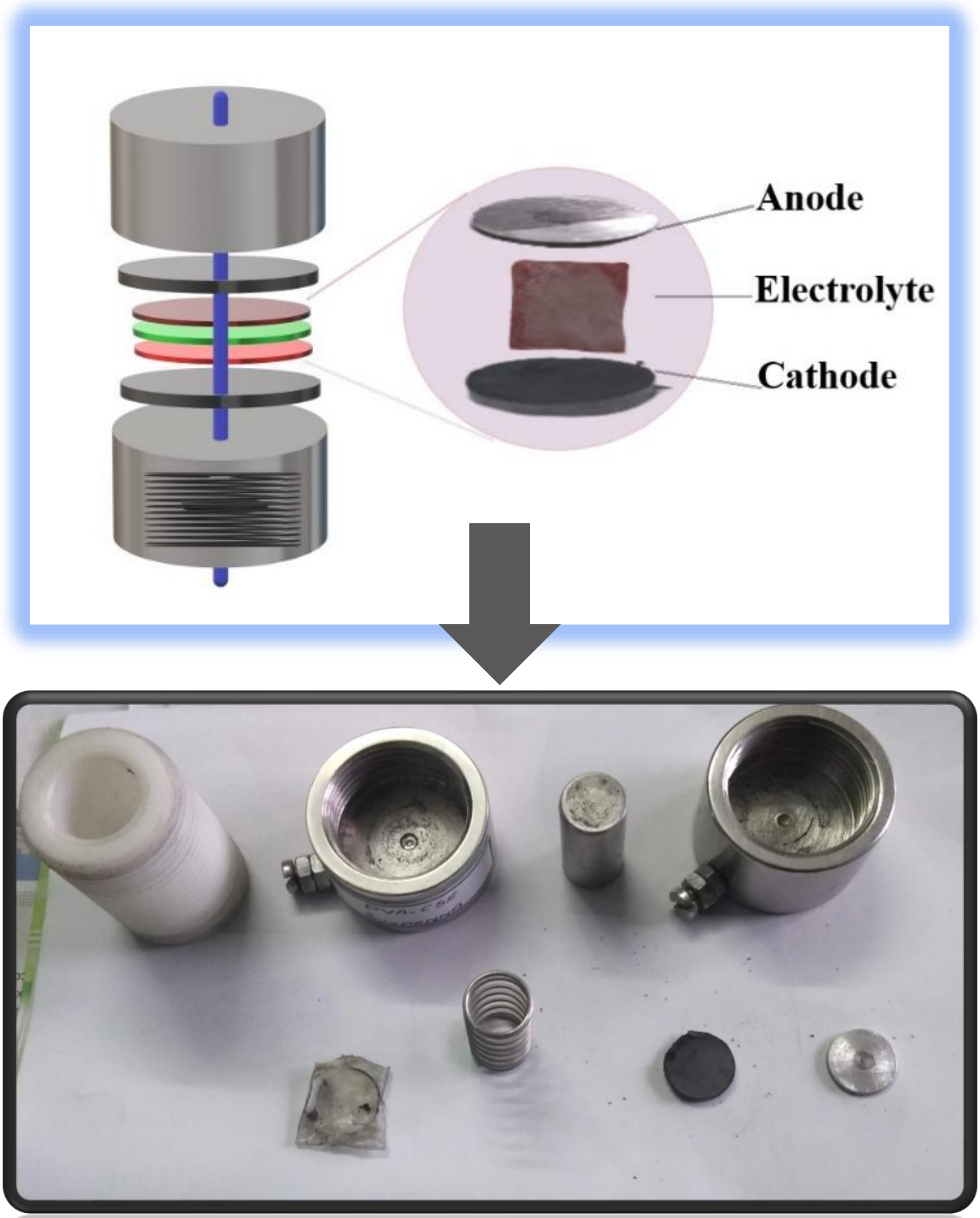

Figure 8.1: Battery holder setup and Battery components

Anode: $Zn + ZnSO_4 \cdot 7H_2O$ (3:1)

Electrolyte: CSAF 0.5

Cathode: $PbO_2 + V_2O_5 + C + bio - electrolyte(CSAF\ 0.5)$ (8:2:1:0.5)

The anode and cathode are made into pellets with the above composition using a hydraulic press. The anodic and cathodic reaction for the primary proton cell is given below

At Anode: $$n\,Zn + ZnSO_4 \cdot 7H_2O \leftrightarrow Zn_{n+1}(SO_4).(7-2n)H_2O.2n(OH) + 2nH^+ + 2ne^- \quad (8.7)$$

At Cathode:

$$PbO_2 + 4H^+ + 2e^- \quad (8.8)$$

$$V_2O_5 + 6H^+ + 2e^- \leftrightarrow 2VO^{2+} + 3H_2O \quad (8.9)$$

The stable open-circuit voltage (OCV) for the primary proton cell obtained by sandwiching the highest conducting bio-electrolyte between the prepared anode and cathode pellets has been tested by the multimeter. The discharge characteristics of the primary proton cell at room temperature are analyzed as a function of time by connecting a load of 100KΩ to the cell.

8.2 Comparison of batteries developed from Corn Silk Biomass/PVA

The Corn Silk extract has been blended with polyvinyl alcohol and the respective magnesium chloride, lithium chloride, and ammonium formate to develop Mg-ion, Li-ion, and proton conducting batteries respectively. After systematic characterization of the bio-electrolyte, three different membranes are optimized for the fabrication of three ion-conducting batteries. The batteries are fabricated with the prepared membranes and tested for their open circuit voltage and discharge characteristics with a load of 100KΩ. This analysis helps in the authentication of the applicability of the developed electrolytes.

The highest conducting bio-electrolyte film of the optimized composition, with a maximum conductivity has been confirmed from the results and an Mg–ion, Li-ion and Proton conducting battery has been constructed with the highest conducting biopolymer membrane as the electrolyte. Here, a magnesium–ion conducting battery has been constructed with the highest conducting biopolymer membrane 0.9g CSE + 1g PVA + 0.45wt% $MgCl_2$ (CSMC 0.45) as the electrolyte. The open-circuit voltage of the battery was found to be 1.95V (Figure 8.3a and 8.3b). The discharge characteristics of the cell at room temperature when connected to an external load of 100 KΩ are depicted in Figure 8.2. With a load of 100 KΩ, the current drawn was 20μA. The discharge capacity of the battery was found to be 1.2mAh. The cell potential dropped from 1.9V and then reduces to 1.88V and later the voltage was constant at 1.87V up to 60Hrs and listed in Table 8.1. This decrease in voltage may be due to the polarization that occurred by the electrochemical reaction at the electrode surface [2]. The studies have been performed with the Corn Biomass for the Li-ion and proton conducting battery. The open-circuit voltage of the battery was studied for all the constructed batteries and tabulated. The discharge characteristics of the battery at room temperature when connected to an external load of 100 KΩ are depicted in Figures 8.3, and 8.4. With a load of 100 KΩ, the current drawn and the discharge capacity of the battery has also been investigated and enlisted for all the constructed battery in Table 8.2 to 8.3.

8.3 Comparison of batteries from seaweed *Sargassum Muticum* Biomass

Similarly, bio-electrolyte membranes have been prepared with *Sargassum Muticum* Biomass/ PVA blend and incorporating magnesium chloride, lithium chloride, and ammonium formate salts as ionic dopants. The respective membranes are then optimized and the highest conducting membrane has been chosen for the fabrication of the battery. The ionic conductivity of the selected membrane composition SMMC 0.7, SMLC 0.6, and SMAF 0.7 has been listed in Table 8.2. These bio-electrolyte membranes are utilized for performing the battery fabrication and discharge characteristic analysis of the battery has also been analyzed and depicted in Figures 8.6 to Figure 8.8 and the results are tabulated in Table 8.2. These studies enunciate the applicability of these seaweed-based bio-electrolyte membranes in battery applications.

Table 8.1: Comparison of the Battery Characteristics for the Magnesium, Lithium and Proton conducting battery obtained from Corn Silk Biomass

S. No	Characteristics analyzed	Corn Silk Biomass		
		CSMC 0.45 (0.9g CSE + 1g PVA + 0.45wt% $MgCl_2$)	CSLC 0.5 (0.9g CSE + 1g PVA + 0.5wt% LiCl)	CSAF 0.5 (0.9g CSE + 1g PVA + 0.5wt% NH_4HCO_2)
1	Ionic conductivity	1.28×10^{-3} Scm^{-1}	2.54×10^{-3} Scm^{-1}	3.30×10^{-3} Scm^{-1}
2	OCV	1.95 V	1.93 V	1.83 V
3	Discharge Time	60 Hours	120 Hours	180 Hours
4	Discharge Current	20 µA	900 µA	14 µA
5	References	Kiruthika et al [3]	Perumal et al [4]	Muthukrishnan et al [5]

8.2.1 Fabrication of Mg-Ion Conducting Battery from Corn Silk Biomass/PVA dopped with Magnesium Chloride

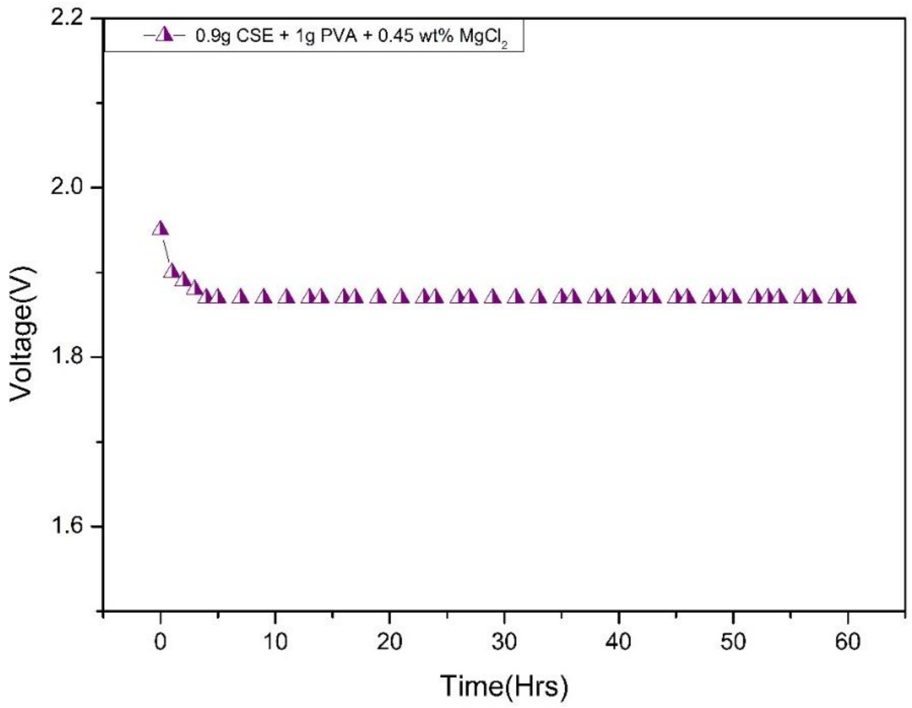

Figure 8.2: Discharge curve for the cell containing the biopolymer electrolyte 0.9g CSE + 1g PVA + 0.45wt% $MgCl_2$ (CSMC 0.45)

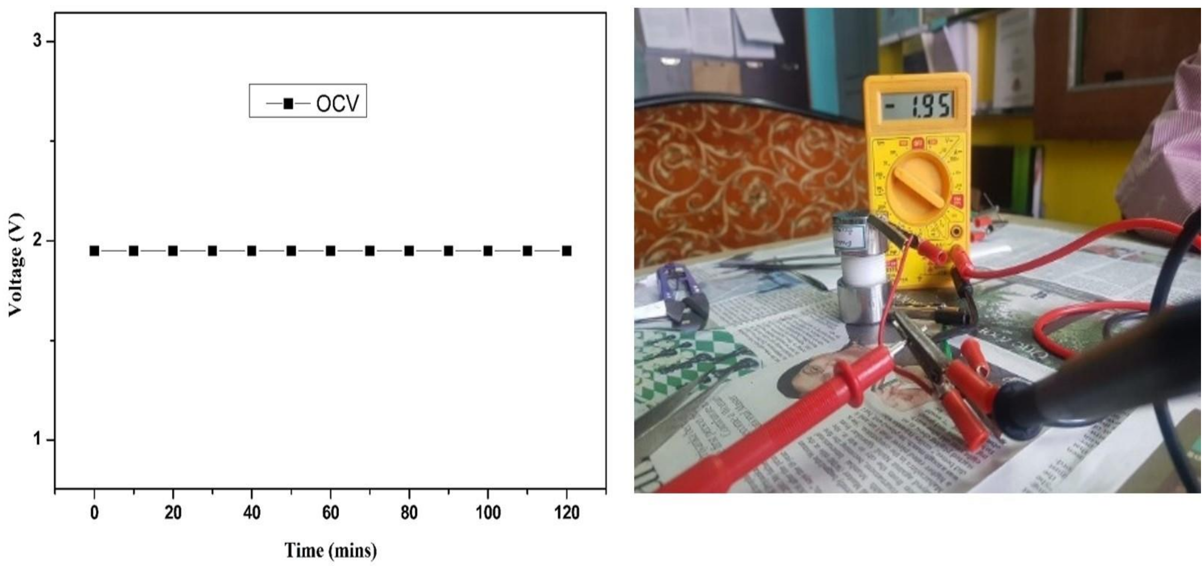

Figure 8.3a and 8.3b: Open Circuit Voltage for 0.9g CSE + 1g PVA + 0.45wt% $MgCl_2$

8.2.2 Fabrication of Li-Ion Conducting Battery from Corn Silk Biomass/PVA dopped with Lithium Chloride

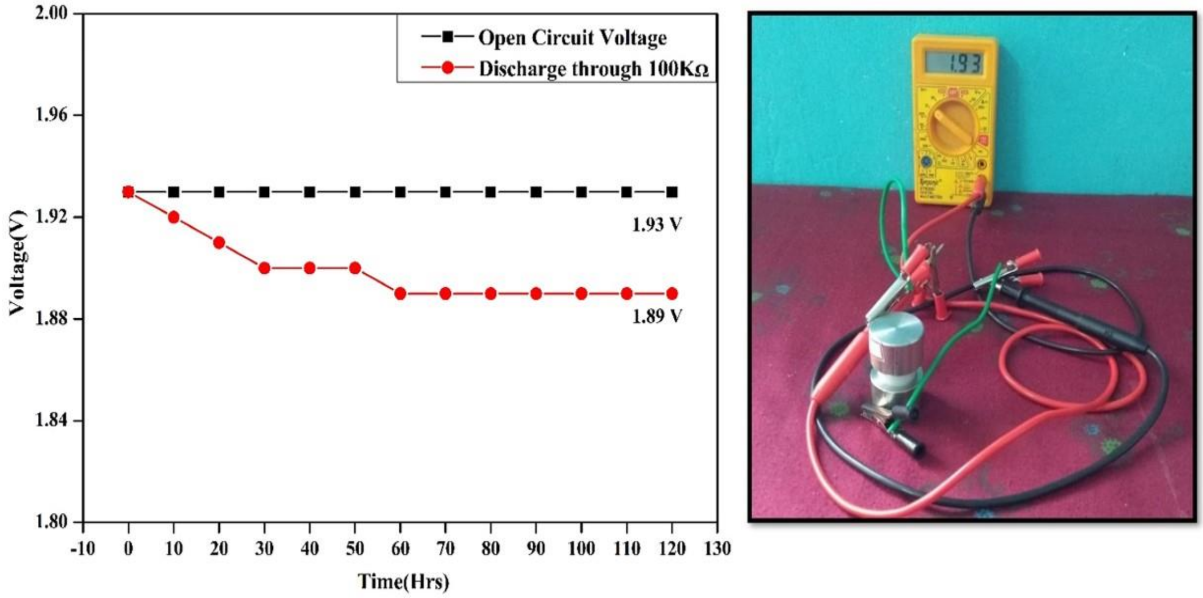

Figure 8.4: Open Circuit Voltage and Discharge curve for the cell containing bio-electrolyte CSLC 0.5 (1g PVA + 0.9g CSE + 0.5wt% LiCl)

8.2.3 Fabrication of Proton Conducting Battery from Corn Silk Biomass/PVA dopped with Ammonium Formate

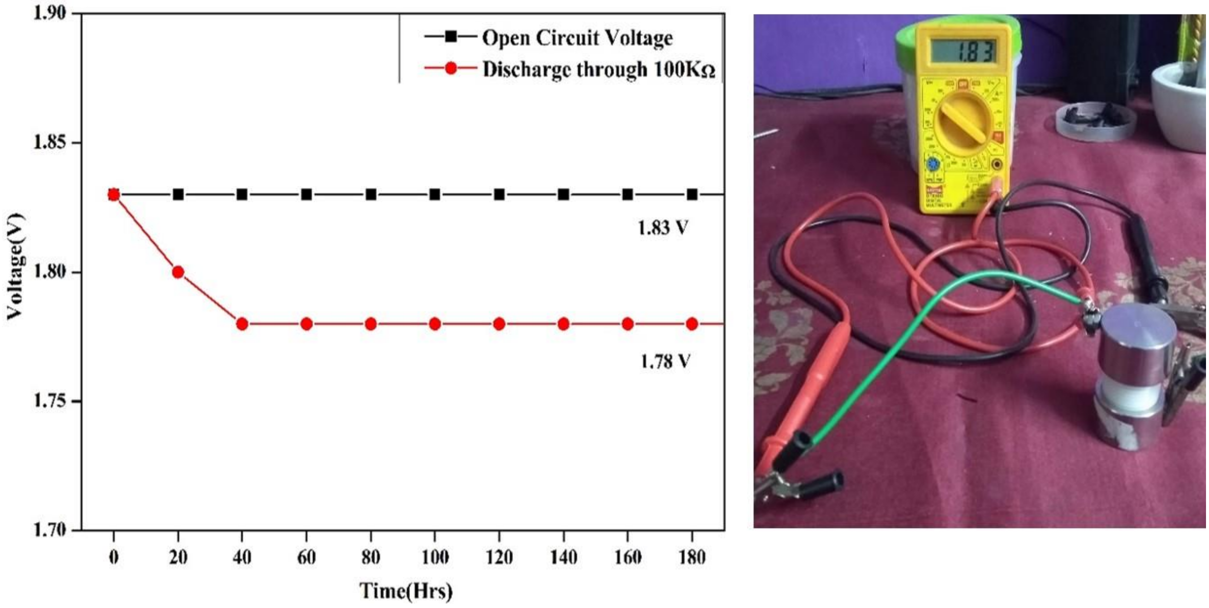

Figure 8.5: Open Circuit Voltage and Discharge curve for the cell containing bio-electrolyte CSAF 0.5 (1g PVA + 0.9g CSE + 0.5wt% NH_4HCO_2)

Table 8.2: Comparison of the Battery Characteristics for the Magnesium, Lithium and Proton conducting battery obtained from *Sargassum Muticum* Biomass

S. No	Characteristics analyzed	***Sargassum Muticum* Biomass**		
		SMMC 0.7 (1g SME + 0.8g PVA + 0.7wt% $MgCl_2$)	**SMLC 0.6** (1g SME + 0.8g PVA + 0.6wt% LiCl)	**SMAF 0.7** (1g SME + 0.8g PVA + 0.7wt% NH_4HCO_2)
1	Ionic conductivity	2.22×10^{-3} Scm^{-1}	4.11×10^{-3} Scm^{-1}	2.83×10^{-3} Scm^{-1}
2	OCV	2.18 V	1.80 V	1.77 V
3	Discharge Time	180 Hours	180 Hours	180 Hours
4	Discharge Current	20 µA	600 µA	50 µA
5	References	Manjula Devi et al [6]	Arockia Mary et al [7]	Selvalakshmi et al [8]

8.3.1 Fabrication of Mg-Ion Conducting Battery from Sargassum Muticum Biomass/PVA dopped with Magnesium Chloride

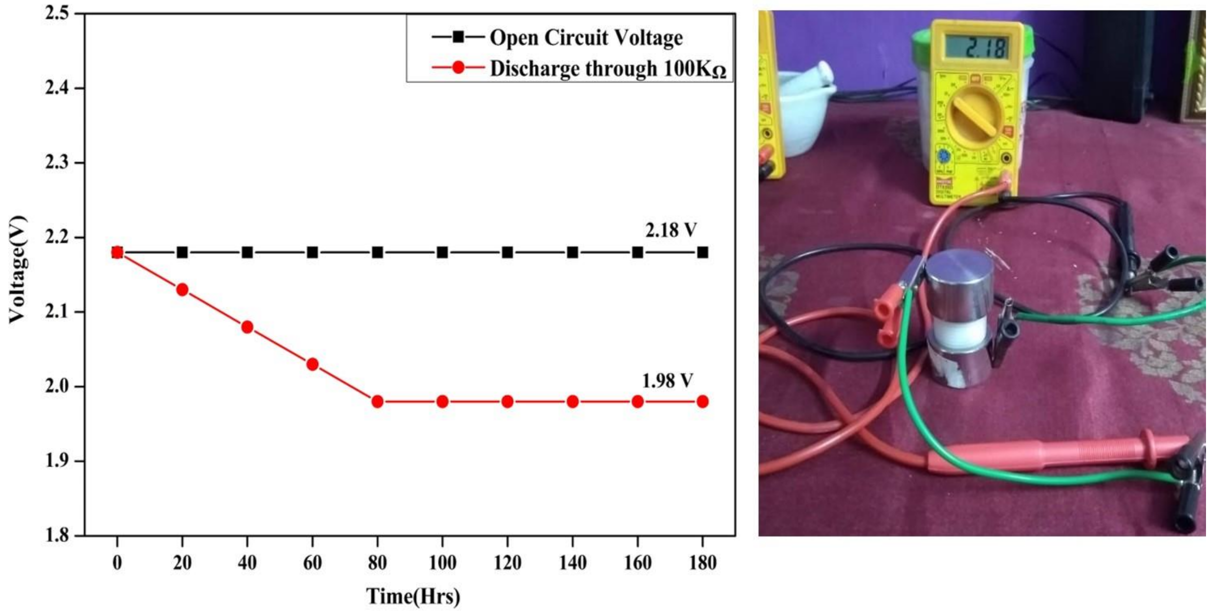

Figure 8.6: Open Circuit Voltage and Discharge curve for the cell containing bio-electrolyte (SMMC 0.7)

8.3.2 Fabrication of Li-Ion Conducting Battery from Sargassum Muticum Biomass/PVA dopped with Lithium Chloride

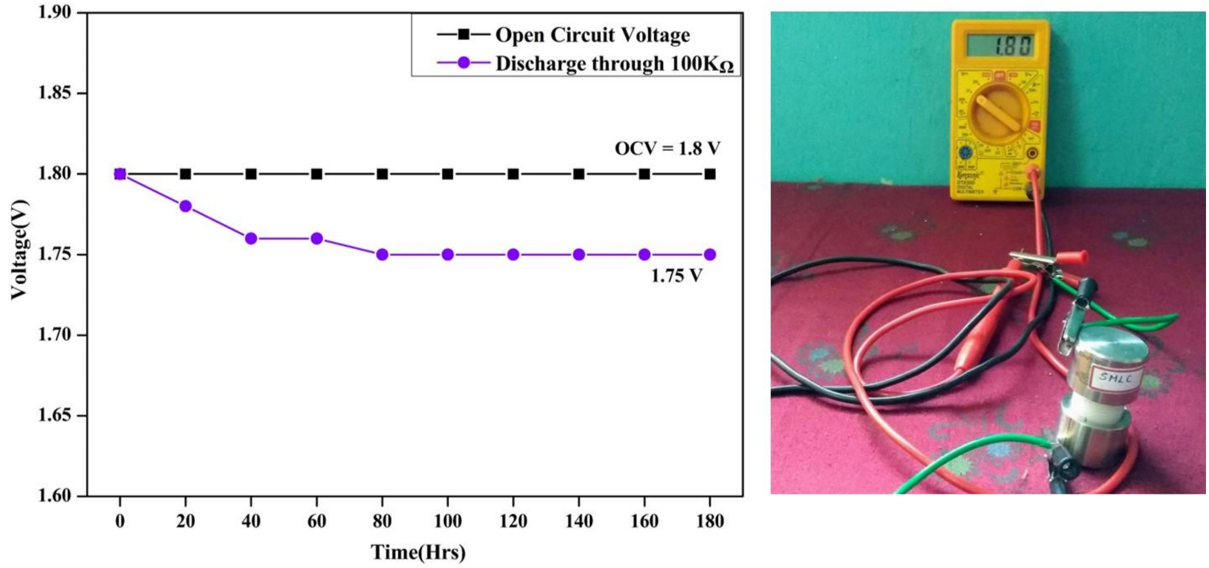

Figure 8.7: Open Circuit Voltage and Discharge curve for the cell containing bio-electrolyte (SMLC 0.6)

8.3.3 Fabrication of Proton Conducting Battery from Sargassum Muticum Biomass/PVA dopped with Ammonium formate

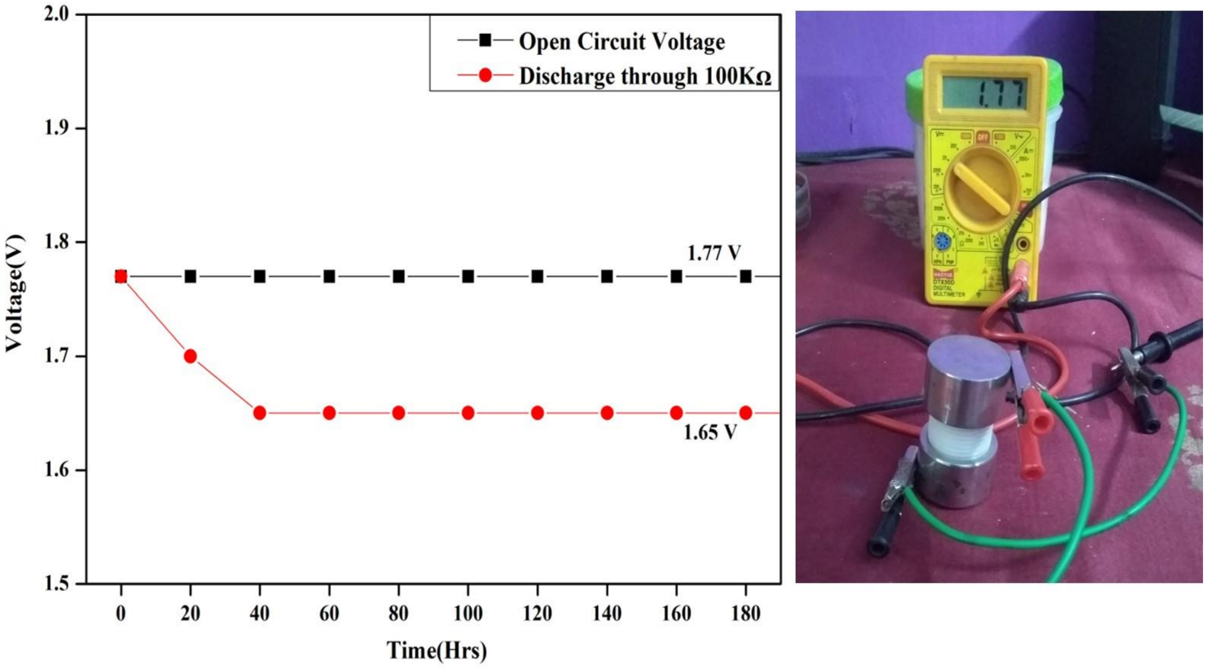

Figure 8.8: Open Circuit Voltage and Discharge curve for the cell containing bio-electrolyte (SMAF 0.7)

8.4 Comparison of batteries from plant gum *Salmalia Malabarica*-Biomass

Another biomaterial Salmalia Malabarica gum has been investigated for the development of bio-membrane by blending them with polyvinyl alcohol. The prepared and optimized composition has been doped with Magnesium. Lithium, and Ammonium salts for the development of bio-electrolyte membranes. The prepared bio-electrolytes doped with the salts are optimized as above mentioned and sandwiched between the anode and cathode as an electrolyte and a separator for the fabrication of Mg-ion, Li-ion, and Proton conducting batteries respectively. The constructed battery in the battery holder is then studied for its output voltage analysis and discharge characteristics with the load as given in Figure 8.9 to Figure 8.11. The results of the studies for all the magnesium, lithium, and ammonium-doped membranes are then tabulated in Table 8.3.

Table 8.3: Comparison of the Battery Characteristics for the Magnesium, Lithium and Proton conducting battery obtained from *Salmalia Malabarica* Biomass

S. No	Characteristics analyzed	*Salmalia Malabarica* Biomass		
		SGMC 0.7 (1g SG + 0.8g PVA + 0.7wt% $MgCl_2$)	**SGLC 0.5 (1g SG + 0.8g PVA + 0.5wt% LiCl)**	**SGAF 0.7 (1g SG + 0.8g PVA + 0.7wt% NH_4HCO_2)**
1	**Ionic conductivity**	7.2×10^{-3} Scm^{-1}	1.39×10^{-3} Scm^{-1}	5.33×10^{-3} Scm^{-1}
2	**OCV**	2.16 V	1.95 V	1.39 V
3	**Discharge Time**	180 Hours	180 Hours	180 Hours
4	**Discharge Current**	16 µA	400 µA	20 µA
5	**References**	Adlin Helen et al [9]	Chitra et al [10]	Sravanthi et al [11]

8.4.1 Fabrication of Mg-Ion Conducting Battery from Salmalia Malabarica Biomass/PVA dopped with Magnesium Chloride

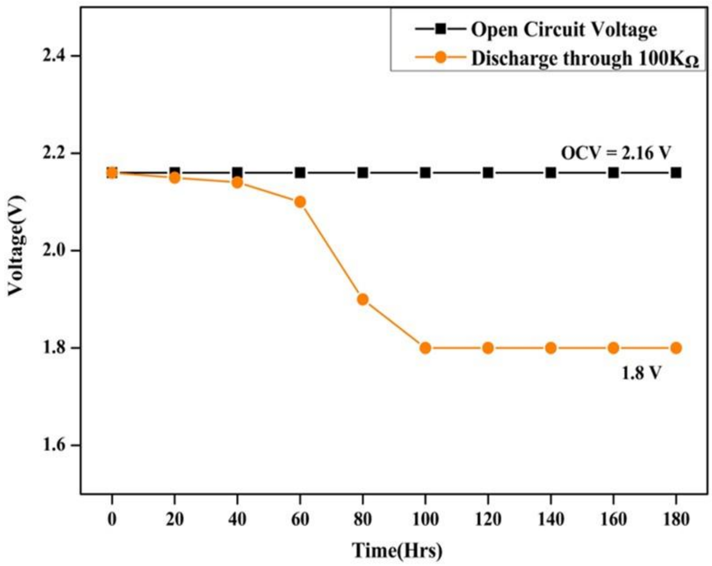

Figure 8.9: Open Circuit Voltage and Discharge curve for the cell containing bio-electrolyte (SGMC 0.7)

8.4.2 Fabrication of Li-Ion Conducting Battery from Salmalia Malabarica Biomass/PVA dopped with Lithium Chloride

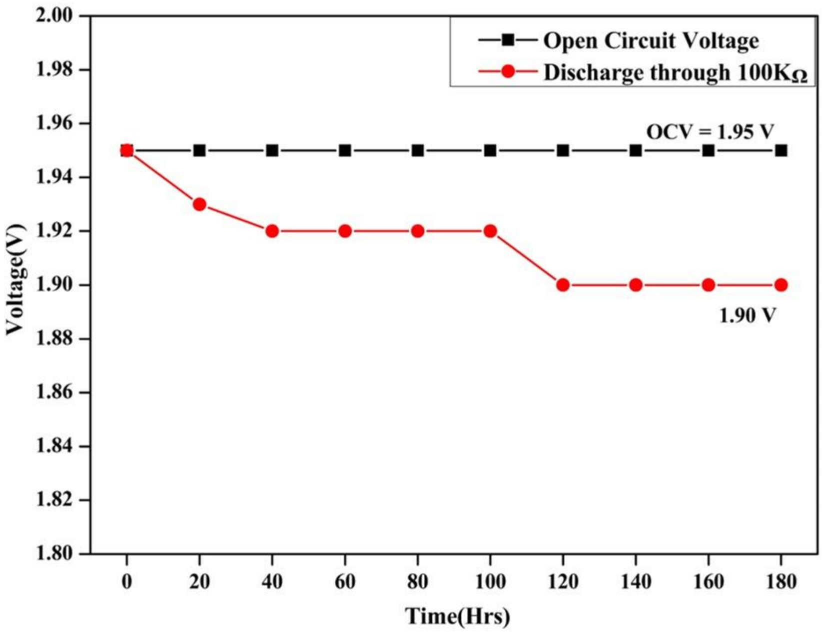

Figure 8.10: Open Circuit Voltage and Discharge curve for the cell containing bio-electrolyte (SGLC 0.5)

8.4.3 Fabrication of Proton Conducting Battery from Salmalia Malabarica Biomass/PVA dopped with Ammonium formate

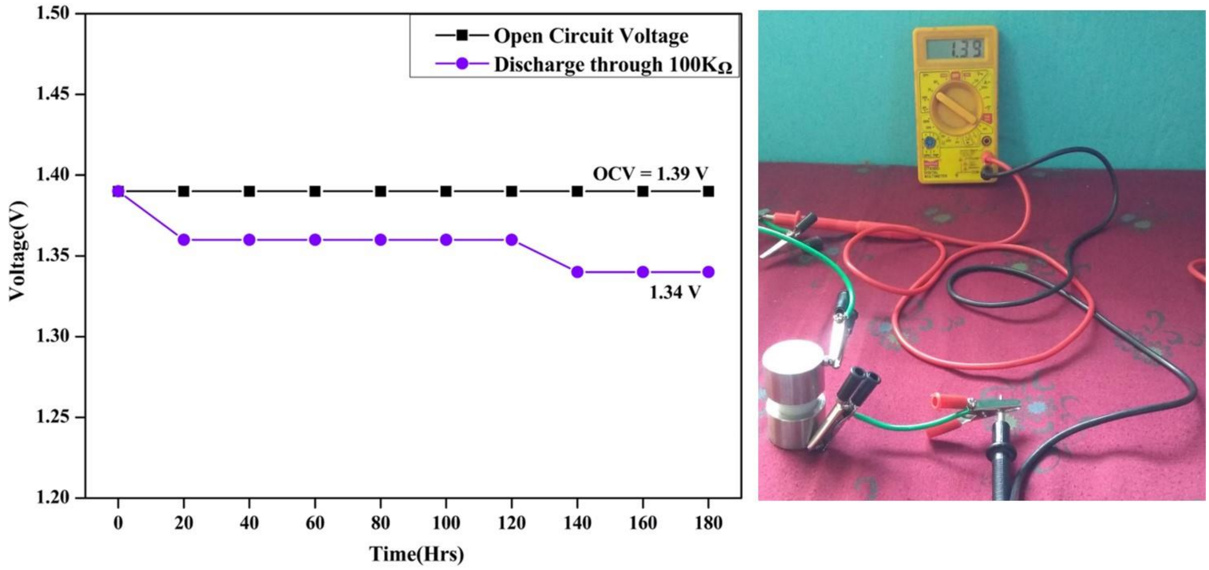

Figure 8.11: Open Circuit Voltage and Discharge curve for the cell containing bio-electrolyte (SGAF 0.7)

8.5 Comparison of Mg-ion conducting Battery of Corn Silk, *Sargassum Muticum*, and *Salmalia Malabarica* - Biomasses

This section of the Chapter deals with the comparison of the magnesium-ion conducting batteries from all the three-biomass selected for this work. In the present investigation, the biomass – Corn Silk, *Sargassum Muticum*, and *Salmalia Malabarica* gum has been used for the three different bio-electrolyte preparation which is further utilized for the fabrication of the Mg-ion, Li-ion, and proton batteries.

Initially, the comparison has been carried out with the ionic conductivity of the bio-electrolyte used for the fabrication of the battery. In magnesium-ion conducting batteries, the ionic conductivity has been maximum for the *Salmalia Malabarica* gum as the biomass (SGMC 0.7) as seen in Figure 8.12. Also, this membrane records the maximum ionic conductivity of all the prepared bio-electrolytes from all three biomasses. Later, with reference to the output circuit voltage (OCV) results also, this membrane SGMC 0.7 is in close proximity to the OCV value of SMMC 0.7 observed in Figure 8.13. This supports the maximum ionic conductivity for the membrane SGMC 0.7.

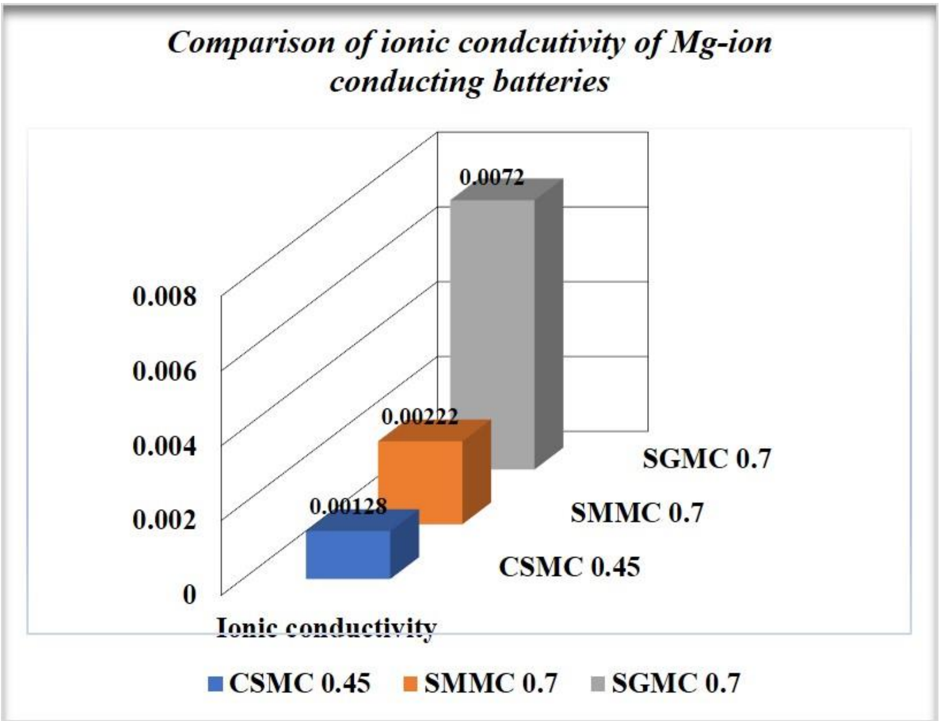

Figure 8.12: Comparison chart of Ionic conductivity of Mg-ion Conducting Batteries CSMC 0.45, SMMC 0.7, and SGMC 0.7

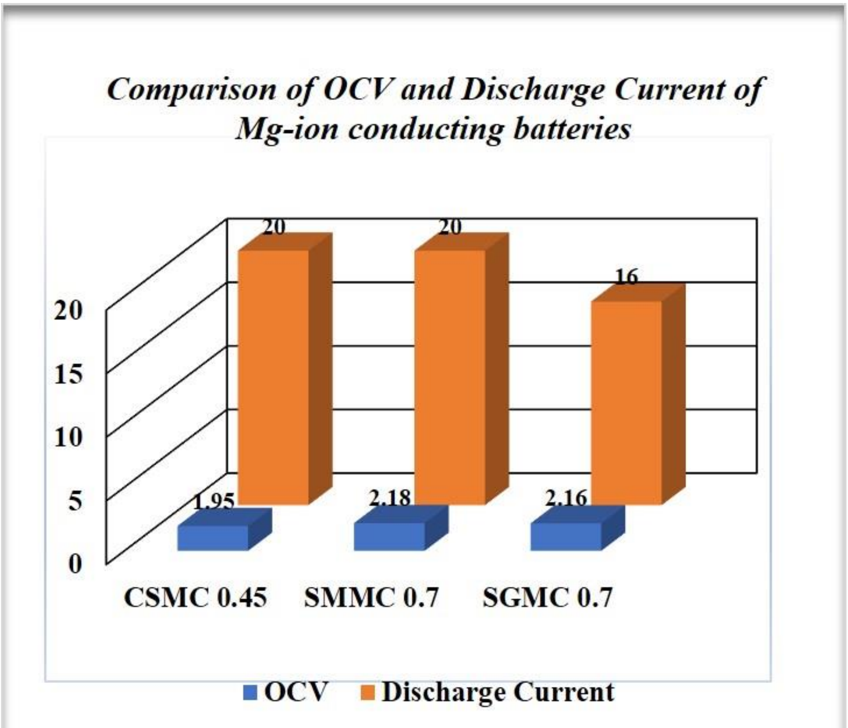

Figure 8.13: Comparison chart of OCV and Discharge Current of Mg-ion Conducting Batteries CSMC 0.45, SMMC 0.7, and SGMC 0.7

8.6 Comparison of Li-ion conducting Battery of Corn Silk, *Sargassum Muticum*, and *Salmalia Malabarica* - Biomasses

On further analysis of the lithium -ion conducting membranes from the three biomasses, depicts the fact that even though SMLC 0.6 (*Sargassum Muticum*) possess high ionic conductivity compared to other two biomaterials, it was SGLC 0.5 (*Salmalia Malabarica*) which has the high OCV of 1.95V as observed in Figure 8.14, 8.15, and Figure 8.16. This results also support the fact that the plant gum has been proved to be a better performer in all the results.

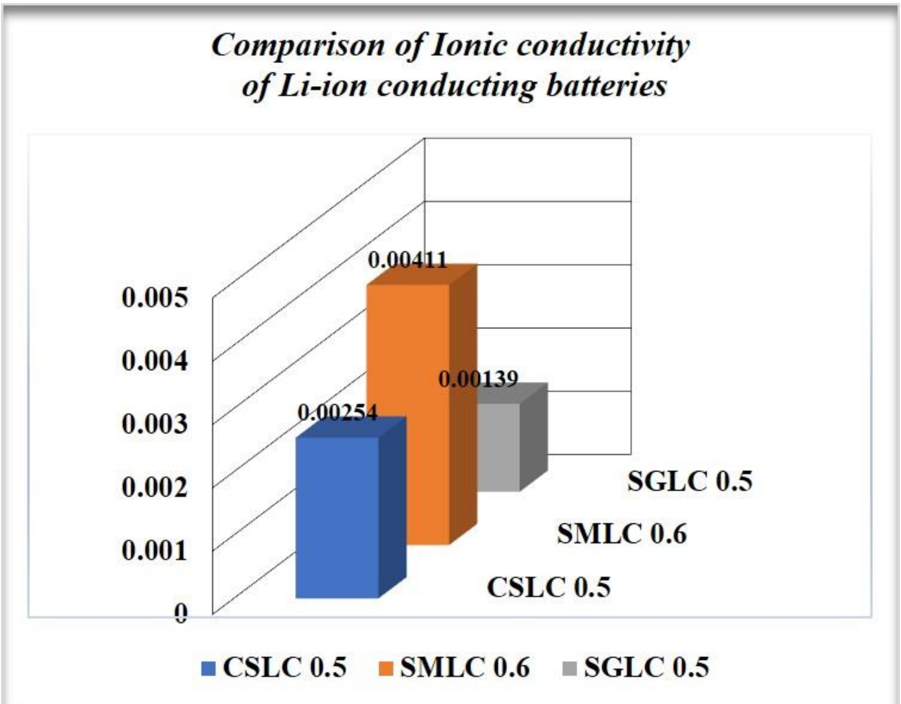

Figure 8.14: Comparison chart of Ionic Conductivity of Li-ion Conducting Batteries CSLC 0.5, SMLC 0.6, and SGLC 0.5

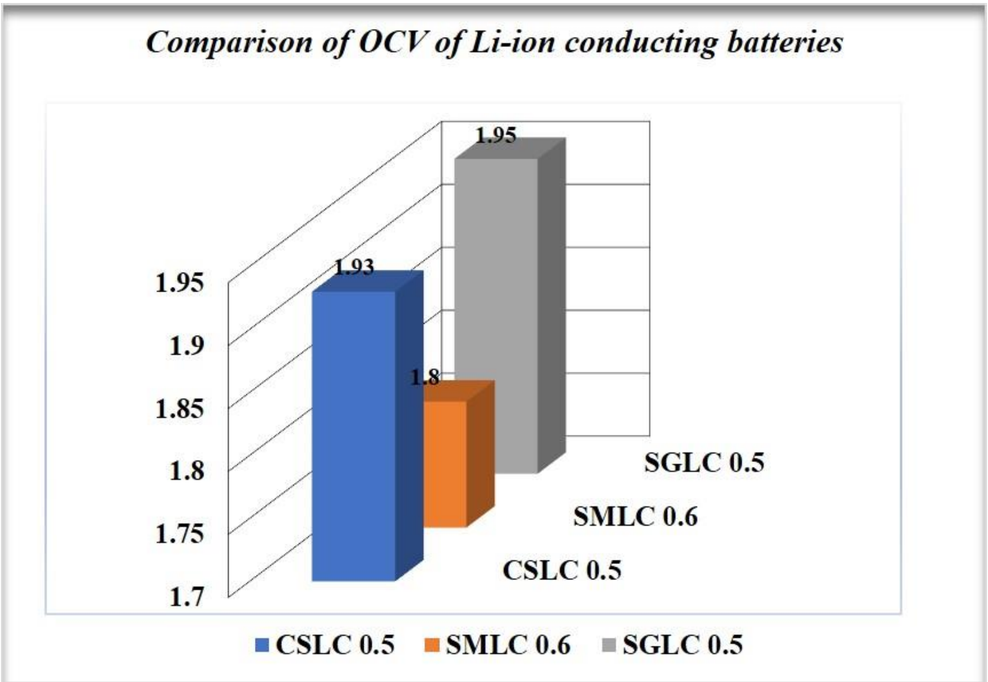

Figure 8.15: Comparison chart of OCV of Li-ion Conducting Batteries CSLC 0.5, SMLC 0.6, and SGLC 0.5

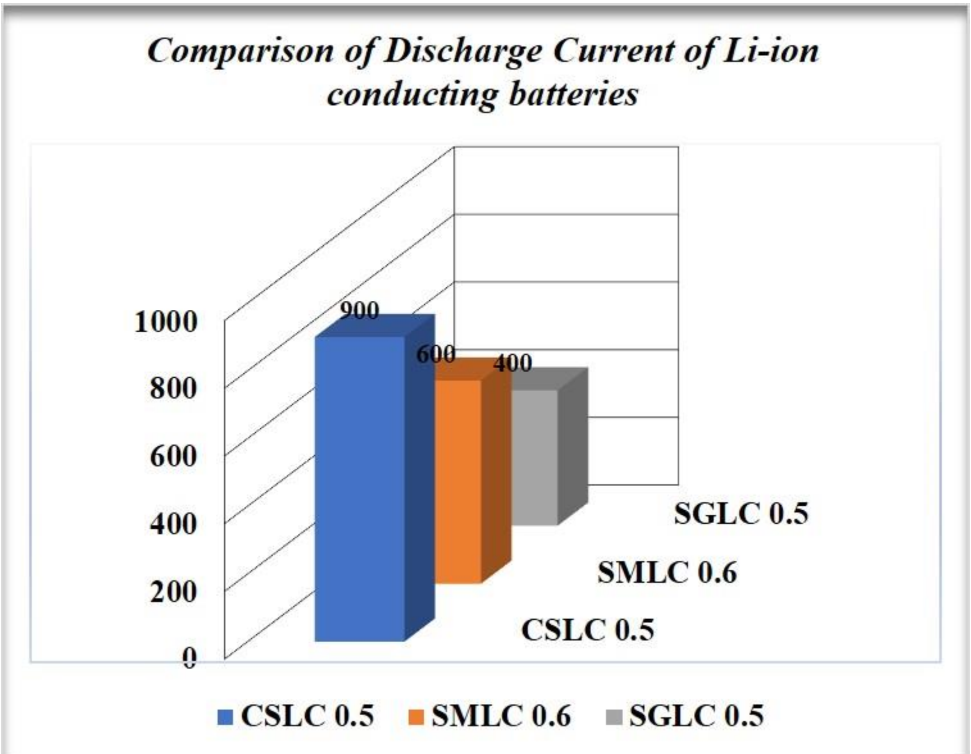

Figure 8.16: Comparison chart of Discharge Current of Li-ion Conducting Batteries CSLC 0.5, SMLC 0.6, and SGLC 0.5

8.7 Comparison of Proton conducting Battery of Corn Silk, *Sargassum Muticum*, and *Salmalia Malabarica* - Biomasses

The evaluation of the results for the proton conducting battery has been performed from Figure 8.17 and Figure 8.18 for all three biomasses. It has been observed again that the bio-electrolyte from plant gum, SGAF 0.7 has the highest ionic conductivity of all the three prepared membranes. Next to the plant gum, was the seaweed which proves to be a better performer for the battery applications.

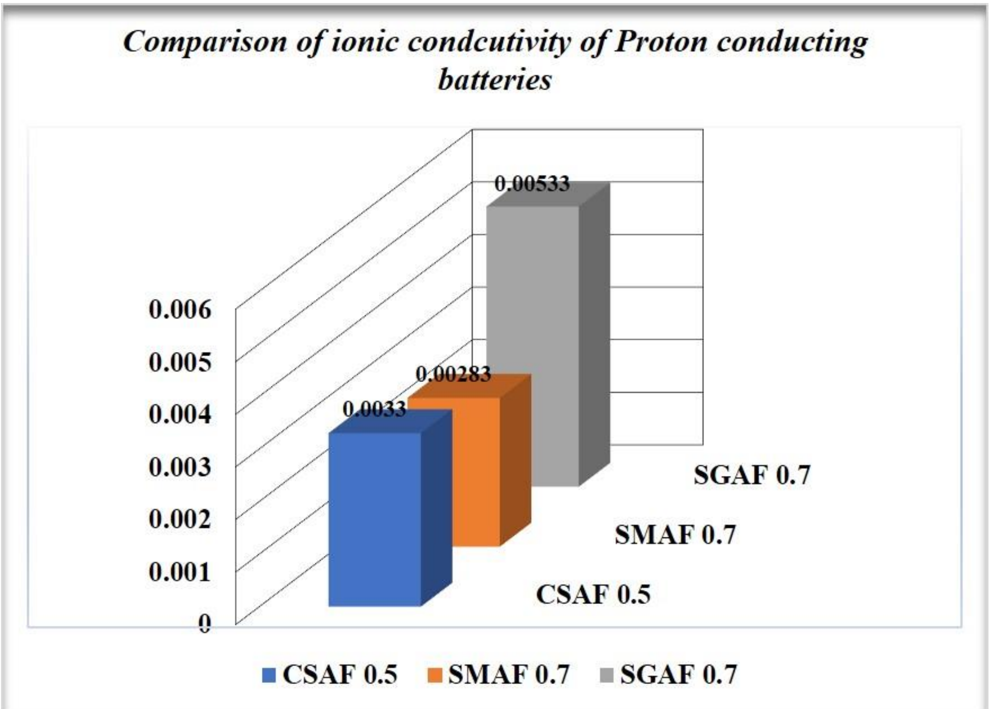

Figure 8.17: Comparison chart of Ionic conductivity of Proton Conducting Batteries CSAF 0.5, SMAF 0.7, and SGAF 0.7

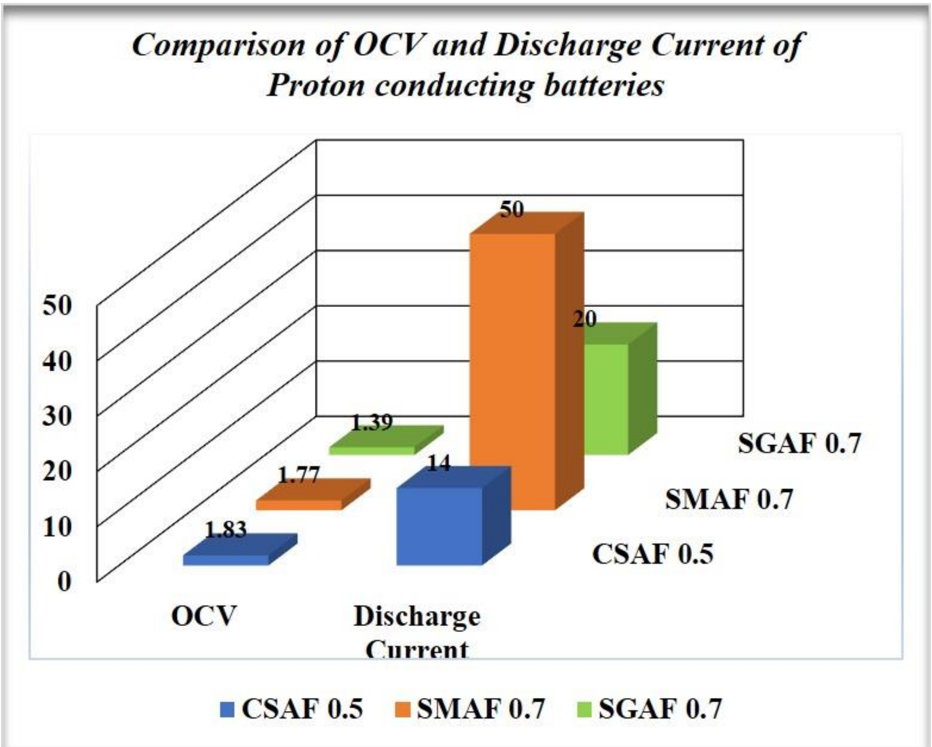

Figure 8.18: Comparison chart of OCV and Discharge Current of Proton Conducting Batteries CSAF 0.5, SMAF 0.7, and SGAF 0.7

References

[1] N.S. Mohamed, R.H.Y. Subban, A.K. Arof, Polymer Batteries Fabricated from Lithium Complexed Acetylated Chitosan, 1995.

[2] R. Manjuladevi, M. Thamilselvan, S. Selvasekarapandian, R. Mangalam, M. Premalatha, S. Monisha, Solid State Ion 308 (2017) 90–100.

[3] S. Kiruthika, M. Malathi, S. Selvasekarapandian, K. Tamilarasan, T. Maheshwari, Polymer Bulletin 77 (2020) 6299–6317.

[4] P. Perumal, P. Christopher Selvin, S. Selvasekarapandian, Ionics (Kiel) 24 (2018) 3259–3270.

[5] M. Muthukrishnan, C. Shanthi, S. Selvasekarapandian, G. Shanthi, L. Sampathkumar, T. Maheshwari, Ionics (Kiel) 27 (2021) 3443–3459.

[6] R. Manjuladevi, M. Thamilselvan, S. Selvasekarapandian, P. Christopher Selvin, R. Mangalam, S. Monisha, Ionics (Kiel) 24 (2018) 1083–1095.

[7] I. Arockia Mary, S. Selvanayagam, S. Selvasekarapandian, R. Chitra, M. v. Leena Chandra, T. Ponraj, Ionics (Kiel) 26 (2020) 4311–4326.

[8] S. Selvalakshmi, N. Vijaya, S. Selvasekarapandian, M. Premalatha, J Appl Polym Sci 134 (2017).

[9] P.A. Helen, K. Ajith, M.I. Diana, D. Lakshmi, P.C. Selvin, Journal of Materials Science: Materials in Electronics 33 (2022) 3925–3937.

[10] R. Chitra, P. Sathya, S. Selvasekarapandian, S. Meyvel, Mater Res Express 7 (2019).

[11] K. Sravanthi, G.S. Sundari, H. Erothu, Optik (Stuttg) 241 (2021).