Reinforced PSEBS based ion exchange membranes with PVP as catalyst layer in a BPM for desalination application

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Abstract

Functionalized poly (styrene ethylene butylene polystyrene) polymer based resin-fiber reinforced monopolar and bipolar with polyvinyl pyrrollidone (PVP) intermediate ion exchange membranes (IEM) was prepared for the desalting technique using electrodialysis process. The performance was conducted using 5 g/L to 25 g/L concentration of NaCl solution for 8 h and the parameters results were compared between prepared and commercial based IEM systems. The current efficiency and energy consumption obtained during the process were 53.6 % and 0.56 Wh for prepared IEM system and 53.61 % and 1.39 Wh for commercial IEM system respectively. In addition, efficiency of IEM towards acid-base production, sodium-chloride ion concentration, salinity and electrical conductivity of ions were also analyzed for all the final feed solutions. The reproducibility performance was also analyzed.

Keywords: *Desalination; Water treatment; Reinforced IEM; Water splitting technology; BPM with PVP intermediate; Reproducibility performance.*

1. Introduction

The interest in water production has been dramatically increased in the recent years due to the shortage of water supplies in many areas and continuous diminishing of natural resources. The increase in using metals and chemicals in various process industries has resulted in generation of large quantities of effluents containing high level of toxic heavy metals and their presence results in environmental-disposal problems due to their non-degradable and persistence nature. Conventional methods for treatment of water and waste water effluents including removal of metals from aqueous solutions involve various technologies such as chemical precipitation, chemical oxidation or reduction, ion exchange, filtration, electrochemical treatment, reverse osmosis, membrane technologies and evaporation recovery [1].

Among all, ion exchange method and its associated electrochemical applications have been used successfully in many industries for more than fifty years for the removal of heavy metals from waste effluents of various characteristics [2]. For this purpose, a special type of ion exchange membranes (IEM) called bipolar membranes (BPM) was synthesized for the first time in the 1950's [3]. The selection of the membrane materials influences mainly the chemical and mechanical stability, the transport properties of the membrane layers and the strength and topology of the intermediate region. To improve the water splitting effect of a BPM, a thin interface layer/contact region of thickness in the order of 1 - 10 nm, containing an immobilized water dissociation catalyst, is generally introduced between the charged layers where the desired water dissociation occurs [4]. The anion and cation permeable layers of the BPM

consist of materials similar to standard anion and cation permeable membranes and should allow the selective transport of the water splitting products.

The present study highlights the work designed to evaluate the desalination efficiency of laboratory functionalized, resin and glass fiber reinforced Poly (styrene ethylene butylene polystyrene) (PSEBS) polymer based monopolar (cation exchange and anion exchange) and bipolar (with PVP as the intermediate layer (IL)) ion exchange membranes. The study was conducted for five different synthetic salt water concentrations ranging from 5 g/L to 25 g/L of NaCl solution (used in feed compartment (FC)) in terms of conductivity, solution pH, transport number of ions (T. No.), feed concentration, current efficiency (CE), energy consumption, water dissociation efficiency (WDE), water dissociation flux and acid-alkali production in the acid and base compartments (AC and BC) with increasing time up to 8h. The experimental results were compared with results of commercially available polystyrene divinylbenzene based (PSDVB) membranes under similar experimental conditions. In addition, for all the obtained final feed solutions after the performance, sodium-chloride ion concentration, salinity and electrical conductivity of ions were determined and the reproducibility test for the system with highest CE was conducted.

2. Experimental methods

2.1 Materials

Commercial strong acid cation exchange membrane (CMI – 7000S) and commercial strong base anion exchange membrane (AMI - 7001S) were procured from Membranes International INC, New Jersey, USA. While BPM made up of PSDVB were procured from Arun Electro chemicals, Chennai. Glass fiber was purchased from Meena glass fiber industry. Seralite (Cation Exchange resin (CER) - equivalent to Amberlite IRC - 120, 20-50 mesh standard grade) and Seralite (Anionic exchange resin (AER) - equivalent to Amberlite IRA - 400, 20-50 mesh standard grade) were obtained from Sisco Research Laboratory Pvt. Ltd. (SRL). Polyvinyl Pyrrollidone (PVP) [Mw ~ 130000] was purchased from Sigma-Aldrich (USA).

2.2 Reinforced IEM preparation

Anionic and cationic functionalized PSEBS based ionomers were obtained as reported earlier [5,6]. It should be noted that surface modification was one of the way to minimize undesired properties or to introduce additional functions like higher IEC with firmness and durability for a polymer separation membrane. Reinforced cationic exchange membrane (RCEM) and reinforced anionic exchange membrane (RAEM) based on PSEBS polymer was prepared by first dispersing a specific quantity (various percentages loading ranging from 10 % to 70 %) of dried and crushed CER/AER (60 °C for 24 h in an oven) in either sulfonated PSEBS-tetra hydro furan (THF) solution or Quaternized PSEBS-THF solution respectively for 12 h using a magnetic stirrer at room temperature. And then for uniform dispersion of particles and breaking up their aggregates, the solution was sonicated using an ultrasonic instrument and finally stirred again with a magnetic stirrer for another 30 min. Then the mixture containing resin and ionomer solution was cast onto a clean and dry petridish over which the glass fiber was placed to get immersed in the solution after sometime. The petridish containing solution of ionomer with resin particles and glass fiber was dried in the oven for 24 hours at 45 °C.

The obtained membranes with various resin content were subjected to conductivity studies and from Table 1, it was observed that the conductivity of the prepared membranes increases with

increase in resin loadings. Once the resin content increased above 50 % of polymer content, the nature of the prepared membranes changed from soft to brittle. So, in order to avoid the breakage and brittleness, various resin loadings in polymer membranes was optimized to be 40 % for both kinds of resins [7]. Reinforced bipolar membrane (RBPM represented as RPSEBS-PVP) was prepared in the similar way as reported earlier [8] by using approximately 0.13 g of PVP based conducting polymer in 6 mL of ethanol solvent as IL solution for each membrane layer.

Table 1. Optimization of resin loadings in PSEBS polymer using its conductivity

% of resin added	CER Conductivity (S/cm)	AER Conductivity (S/cm)
10	5.2×10^{-5}	1.17×10^{-7}
20	7.1×10^{-5}	3.2×10^{-5}
30	2×10^{-4}	3.7×10^{-5}
40	7.1×10^{-4}	5.0×10^{-5}
50	6.6×10^{-4}	2.5×10^{-5}
60	7.1×10^{-5}	1.0×10^{-5}
70	4.8×10^{-5}	1.8×10^{-6}

2.3. Design and working principle of BPMED unit

The bipolar membrane electrodialysis (BPMED) unit used in the study was supplied by Arun Electrochemical, Chennai. The construction and description of the BPMED instrument used for determination of desalination process efficiency was similar to one reported earlier [9]. The electrodes used were cathode (made of stainless steel) and anode (made of Ti coated with Ti-Ru-Pd oxides). In order to minimize the cell voltage generated during the initial stages of the performance, dilute HCl (0.01 N) and dilute NaOH (0.01 N) solutions were used in AC and BC respectively. And 0.05 mol/L of NaCl solution was used in each electrolyte compartment (EC). During the performance, at every 15 min time interval, various process parameters were evaluated. After 8h treatment the final solutions of various synthetic feed concentrations and reproducibility test sample were analyzed for their sodium-chloride ion concentration, salinity and electrical conductivity measurements.

3. Results and Discussion

3.1. pH change in various compartments with time

Figures 1 and 2 represent the variation of solution pH in FC, EC, AC and BC with time for both laboratory synthesized RPSEBS-PVP based IEM and commercially procured PSDVB based IEM systems. It was clear from these figures that with increase in salt or feed concentration, the initial pH value of the corresponding solution was also found to be increasing in FC for both IEM systems. In case of RPSEBS-PVP based system (Figure 1), pH in FC showed acidic nature at their final stages except that instead of increasing towards basic pH at their initial stages, it started decreasing steadily towards acidic pH with time. This is because with increasing time higher quantities of acid were produced due to water dissociated products thereby resulting in

proton leakage through IEMs depending on the capacity of protons to undergo back diffusion. Due to its intrinsic mobility in the presence of water, FC remained slightly acidic in nature9. On the other hand, as per Figure 2 in case of PSDVB based IEM system, the feed solution finally became basic in nature for all ranges of feed concentration. PSDVB based cell experienced greater leakage of ions from BC to FC and thus it remained basic in nature. Moreover, proton leakage through IEM was low due to low concentration of acid that was produced during BPMED process using PSDVB based IEM systems [10].
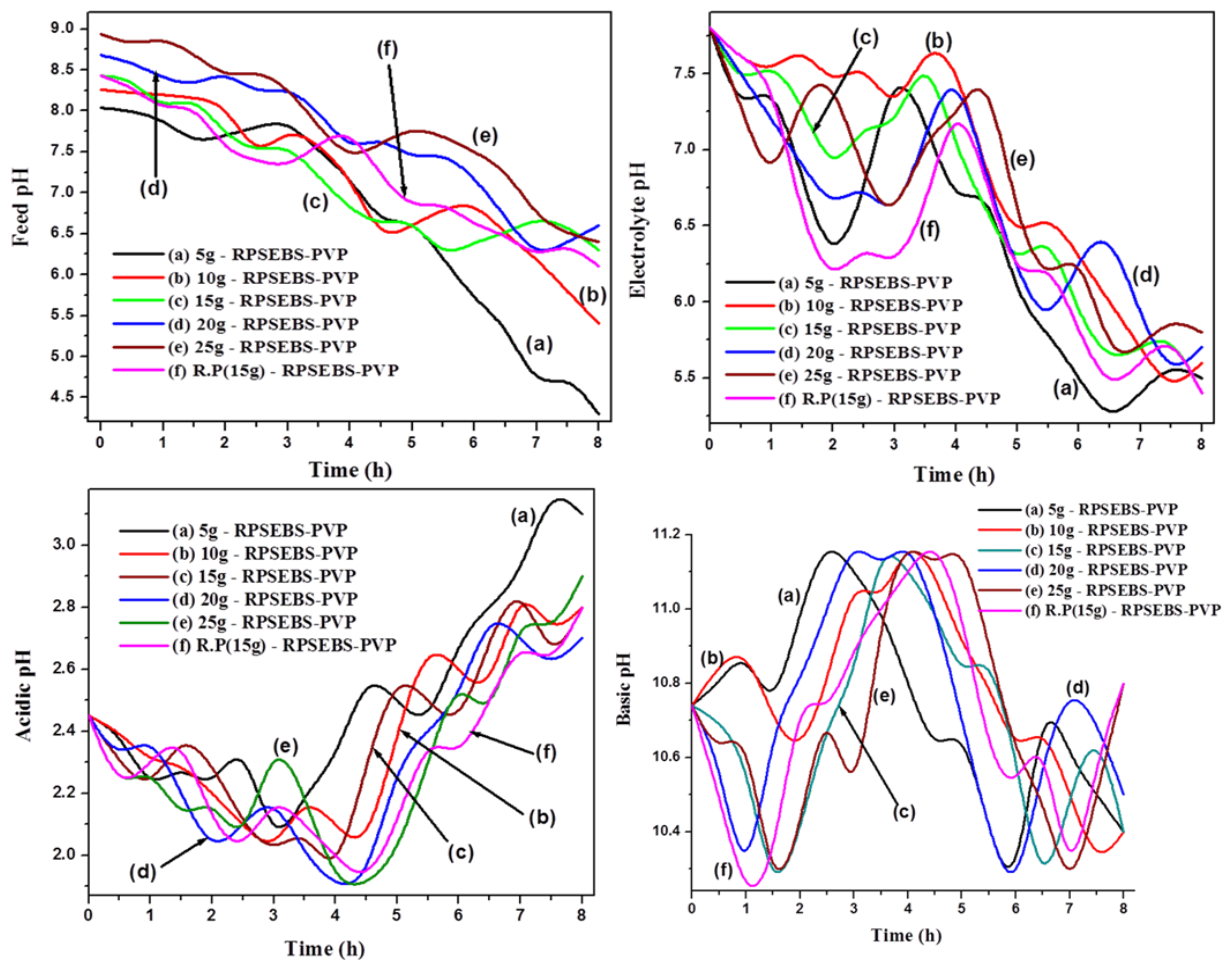

Figure 1. pH changes in FC, EC, AC and BC with time for various feed concentrations of RPSEBS-PVP based IEM system

Whereas in the case of EC, since 0.05M NaCl was taken as electrolyte solution each time, the initial pH remained constant for all performances. Though both type of IEM systems showed the final solution to be acidic, the acidity was greater in the case of PSDVB based IEM system than compared with RPSEBS-PVP based IEM system. The difference in pH observed between two types of IEM systems in FC and EC was mainly attributed to the leakage of ions occurring through the membranes between the compartments in a stack. Similarly, in case of AC and BC the solution pH remained to be in the range of ~ 2.45 and ~ 10.74 respectively for all performances because of initially taken dilute acid and base solutions. From Figure 1 and 2, it was clear that the acid pH for both types of IEM system was found to get increased during the

first half stage of performance and the increase was not uniform because of the leakage of some ions into the neighboring compartments. In the case of basic pH instead of rising in pH initially RPSEBS-PVP based system resulted in a decreasing trend while PSDVB based IEM system showed a similar increasing trend similar to acid pH. The nature of pH change reflects their acid and base production for both PSDVB and RPSEBS-PVP based IEM systems. Also it should be observed that for reproducibility test more or less same results as that of its original feed concentration was noticed.
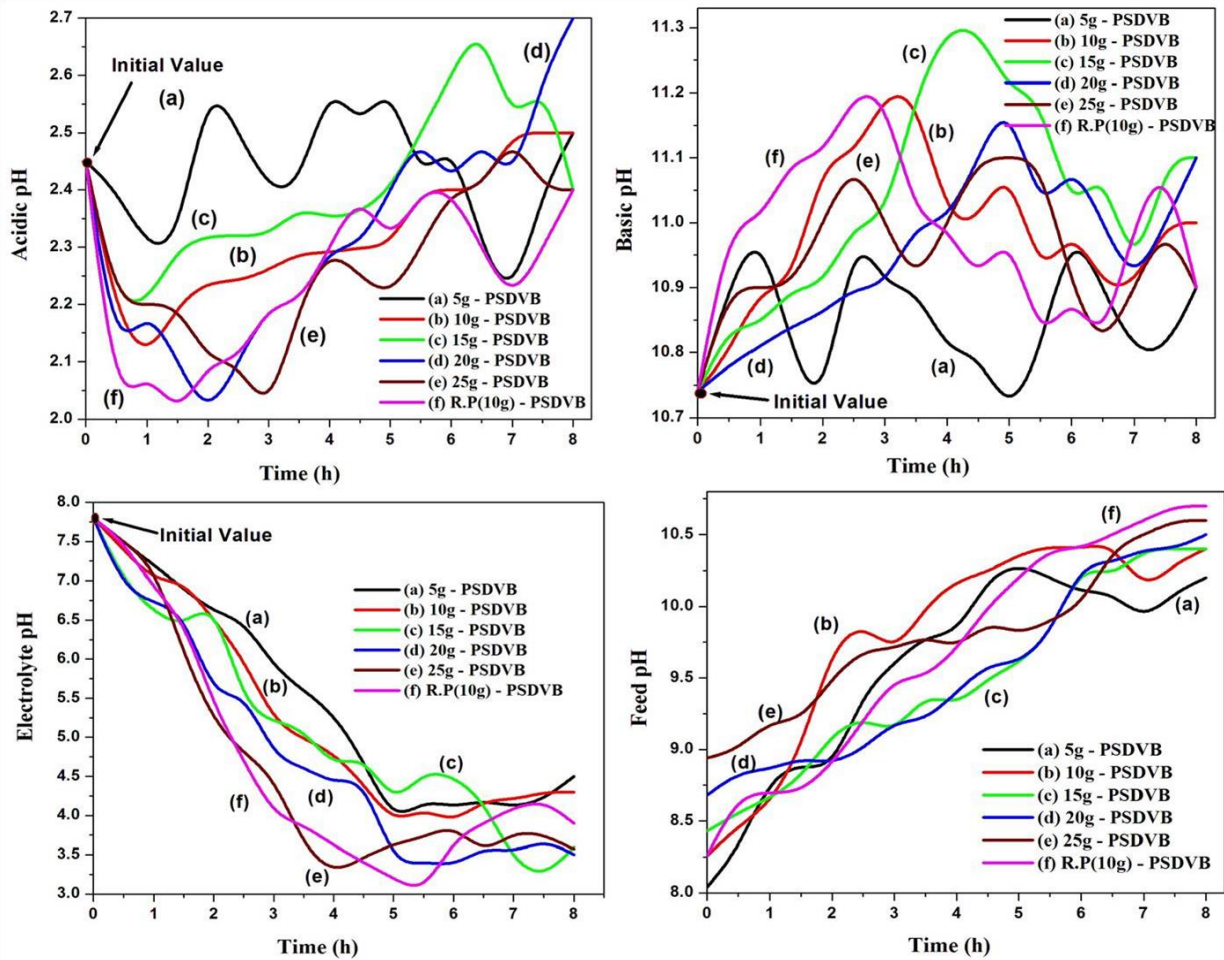

Figure 2. pH changes in FC, EC, AC and BC with time for various feed concentrations of PSDVB based IEM system

3.2. Variation of Acid, Base and Feed Conductivities with Time

The changes in pH values are justified using its respective conductivity values. In this case also the initial conductivity remained same for all feed concentration ranges in AC and BC and it showed some value other than the conductivity values of the distilled water. Since the ionic mobility of protons was higher than that of the hydroxyl ions, correspondingly, the conductivity value was found to be higher in the case of AC when compared with BC. From Figure 3 for RPSEBS-PVP based IEM system the higher acid conductivity observed was about 1.7 mS/cm than base conductivity (of about 0.89 mS/cm) values among all feed concentration ranges. In case of both acid and base conductivity after that highest value was reached, either decrease or increase was expected mainly due to the loss of ions from this compartment or introduction of

other ions from the neighboring compartment to AC and BC which was assured by its acid and base concentration. In case of FC, it showed a wide range in decrease of conductivity values for a longer time before its rise and the observed increase in conductivity value does not exceed its initial conductivity value of that particular feed concentration.
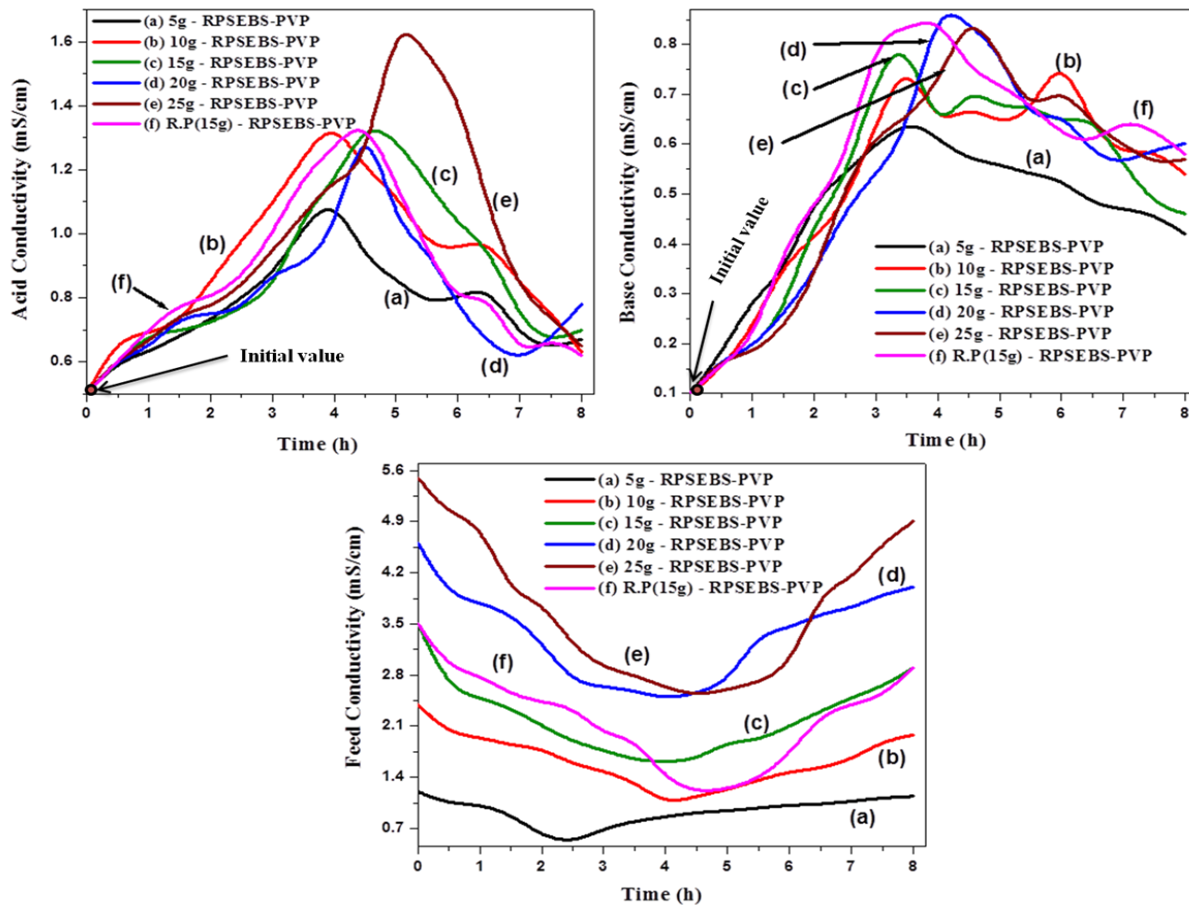

Figure 3. Conductivity changes in AC, BC and FC for different feed concentrations with time for RPSEBS-PVP based IEM system

For PSDVB based IEM system from Figure 4, the conductivity value was found to be higher in the case of AC of about 1.29 mS/cm when compared with 0.7 mS/cm in BC. In addition, the lower acid and base conductivity value for 5 g/L among other feed concentration ranges indirectly proves its lower acid and base pH change. In case of FC the conductivity initially decreased depending upon the feed concentration then increased slightly and finally remained constant with time. This increased conductivity value was observed to be little higher than its initial value of that particular feed concentration mainly because of leakage of ions occurred from the neighboring compartment through the IEM into FC. It should also be noticed that the reproducibility test in both these cases showed more or less the same results as that of its original feed concentration.
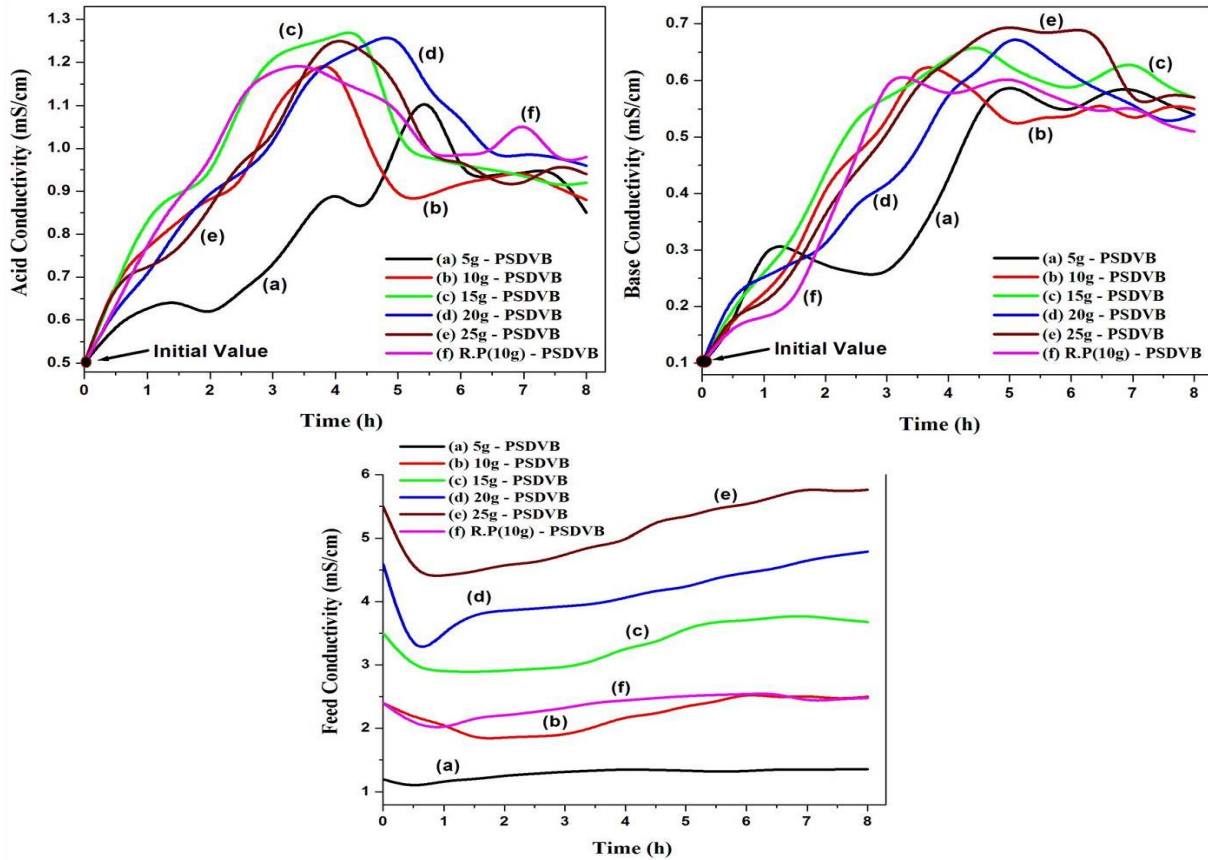
Figure 4. Conductivity changes in AC, BC and FC for different feed concentrations with time for PSDVB based IEM system

3.3. Effect of BPMED Process on Acid-Base Production

When the entire BPMED cell was kept under an electric field using electrodes, due to the large electric field appearing at the membrane interface, an excess of OH^- and H^+ ions was produced due to the field enhanced chemical reaction. Along with this, Na^+ and Cl^- ions were also continuously transported through IEMs from FC into BC and AC respectively resulting in the formation of acid and base of certain normality concentrations which was evidently proved by pH and conductivity studies. The maximum concentration of both NaOH and HCl depends on feed concentration, time, IEC and functional group nature of that membrane.

Figure 5 (a) clearly shows that for RPSEBS-PVP based IEM system higher acid production of about 0.014 N was observed compared to 0.006 N of base production for the same feed concentration. It has to be noted that once the higher concentration of acid/base was reached in a particular feed concentration it remained constant until certain duration of time after which it decreased with increase in process time due to decrease of NaCl concentration or diminished mass transfer of Na^+ and Cl^- ions in the feed solution. It was observed that PSDVB based IEM system showed higher acid and base concentration of about 0.009 N and 0.006 N respectively for various feed concentration from Figure 5 (b). Though PSDVB based IEM cell is meant for base production rather acid production because of higher specific perm selectivity of CEM for H^+ ions as per reported in the literature [11], from Figure 6 (b) the alkalinity concentration was observed to be lower in the case of the PSDVB based IEM system. Furthermore, H^+ ions in the presence of water have a higher intrinsic mobility than OH^- ions thereby resulting in more

leakage of H^+ ions through AEM which leads to decrease of concentration in AC [12]. Similar decreasing trend was also observed in case of BC for various feed concentration ranges. It should also be noticed that the reproducibility test in both type of IEM system showed more or less the same results as that of its original feed concentration.
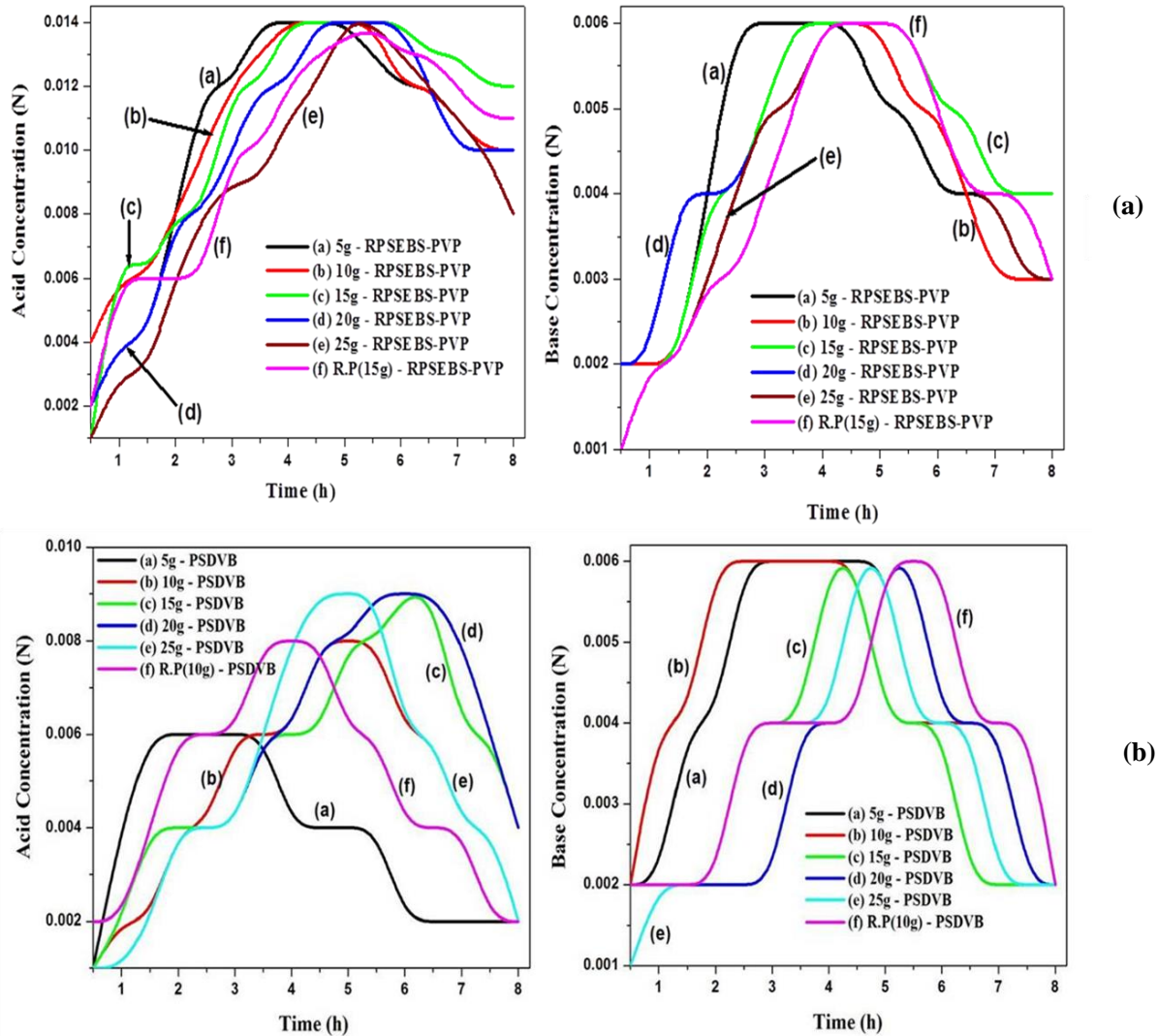

Figure 5. Change in acid-base yield with time for various feed concentrations for (a) RPSEBS-PVP based IEM system and (b) PSDVB based IEM system

3.4. Ion Transport Number and WDE Changes with Time

Since CE depends upon the ion transport and ionic mobility, for a better process efficiency it was expected that system should have both higher T. No. of ion and better WDE. Figures 6 and 7 represent T. No. properties of both sodium and chloride ions and WDE for RPSEBS-PVP based and PSDVB based IEM systems respectively. From these figures it was clear that depending upon the membrane capacity, time and feed concentration range, T. No. of both Na^+ ion and Cl^- ions was observed to have higher value at its initial stage and then starts decreasing with increase in time for both types of IEM systems. In case of WDE, both types of IEM system showed the lowest value initially and with increase in time the same was observed to increase

and then finally remained constant. This is because at the beginning of the BPMED process, since NaCl concentration was higher in FC transfer of a large amount of Na^+ and Cl^- ions through IEM was observed. But with increasing time due to decrease of NaCl concentration the current was now carried by water dissociated products such as H^+ and OH^- ions.
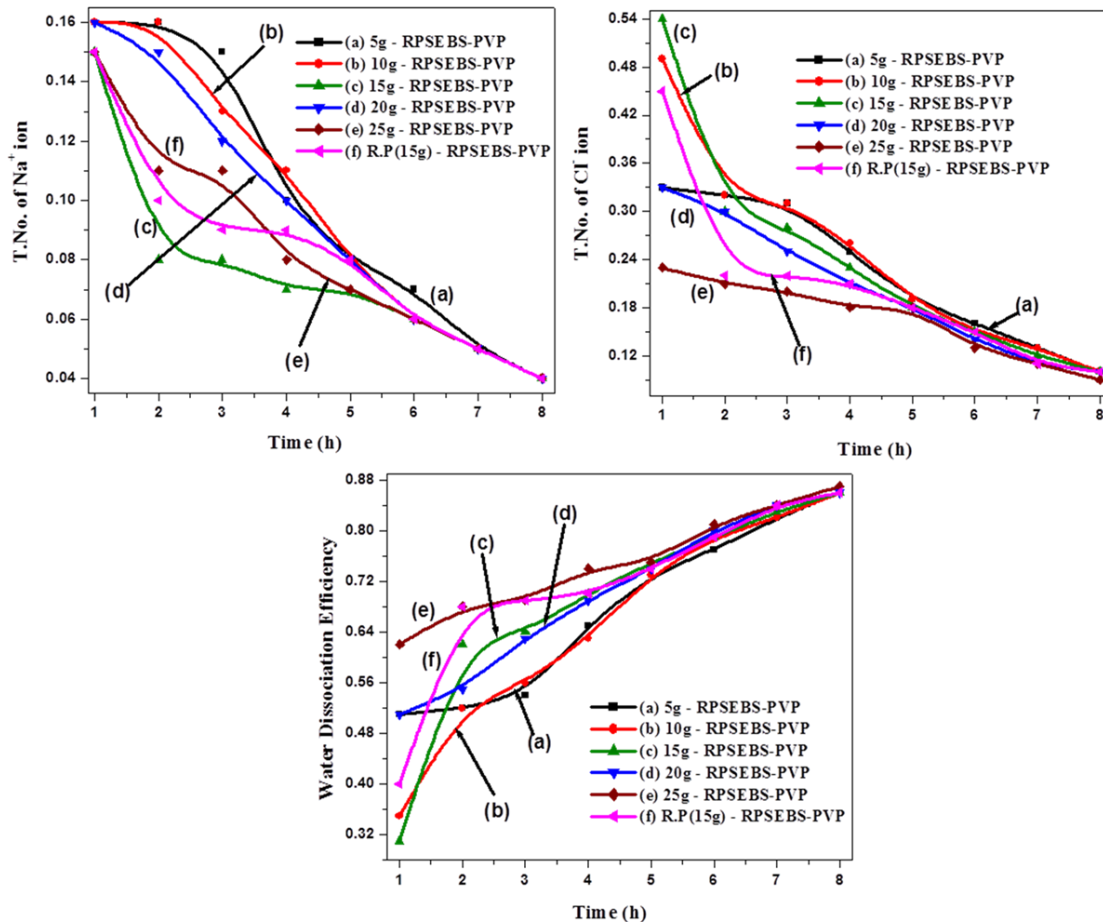

Figure 6. Changes in T. No. of ions and WDE for various feed concentrations with time for RPSEBS-PVP based IEM system

From Figure 6, RPSEBS-PVP based IEM system showed highest T. No. for both chloride and sodium ions to be of about 0.54 and 0.16 respectively. Similarly, from Figure 7, PSDVB based IEM system showed greater value of about 0.16 as T. No. for chloride ion than compared with 0.08 of sodium ion for the same higher feed concentration. While in the case of WDE, as per Figure 6 RPSEBS-PVP based system showed results of about 0.86 finally for both highest and lowest feed concentrations respectively. Whereas as per Figure 7 the highest WDE value observed for PSDVB based IEM system was about 0.07 for both 10 g/L and 25 g/L of feed concentrations. The highest T. No. and steady increase in WDE with time observed for RPSEBS-PVP based IEM system was mainly due to the increase in electric field, pre-polarization of water molecules at the membrane-solution interface and presence of a hydrophilic catalytic PVP intermediate in between the two monopolar layers of BPM [13].

In terms of reproducibility test for RPSEBS-PVP based IEM systems, T. No. of chloride ions was observed to have little lesser value whereas regarding T. No. of sodium ions and WDE they

showed a little higher performance value when compared with that of its original feed concentration performance. And for PSDVB based IEM system T. No. of ions was observed to be little lesser whereas WDE showed a more or less same performance as that of its original feed concentration performance.
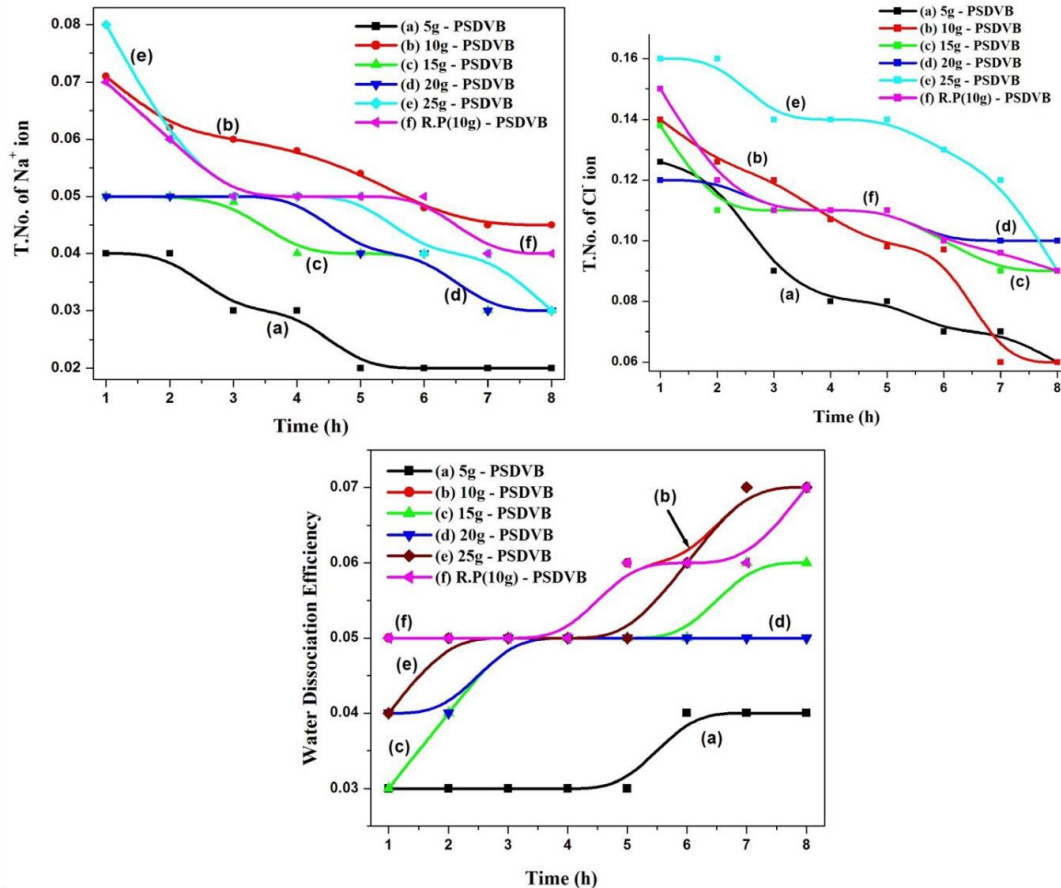

Figure 7. Changes in T. No. of ions and WDE for various feed concentrations with time for PSDVB based IEM system

3.5. Determination of Process Efficiency Parameters with Time

For any system, higher CE with lower energy consumption was one of the factors which determine the feasibility of any electrochemical process towards higher process efficiency. Figure 8 represents the variation of CE and energy consumption of both RPSEBS-PVP based and PSDVB based IEM system with time for various feed concentrations. It was observed that both CE and energy consumption increases with increase in feed concentration range due to the same reason as discussed for T. No. of ions and WDE. With respect to increase in time CE was observed to decrease for each feed concentration range mainly due to leaching out of resin particles from the functionalized polymer because of ballooning, flexible and higher elongation nature of the polymer when placed in water for a longer duration of time. The reason for the increase of energy consumption with time was mainly to overcome the electrical resistance in various compartments. The increase of resistance in FC resulted from the exhaustion of NaCl in the solution can be offset by the decrease of electrical resistance in AC and BC caused by the increase of acid-base concentrations as a consequence of transfer of Cl^- and Na^+ ions from the feed solution.

In the case of RPSEBS-PVP based IEM system as per Figure 8 (a), the highest CE and energy consumption values observed was about 53.6 % and 0.56 Wh respectively for 15 g/L feed concentration. In case of PSDVB based IEM system the same was observed to be 53 % and 1.39 Wh respectively for 10 g/L feed concentration from Figure 8 (b). From Figure 8 (a) RPSEBS-PVP based IEM system showed a uniform increase in energy consumption with time until final stages of experiment without any observation of oscillations with respect to various feed concentrations. This is mainly because of the presence of IER in addition to the fiber reinforcements during the membrane preparation which created an increased electrical resistance. So to overcome this additional resistance, this system consumes a little additional energy till the final stage of a performance resulting in the steady increase in value. Whereas from Figure 8 (b) PSDVB based IEM system though displayed oscillations at initial stages its increase in energy consumption with later time finally depends upon its feed concentration. In terms of reproducibility test, CE was observed to be lower and energy consumption was observed to be higher than its original feed concentration for both types of IEM system because the membrane loses some of its IEC and functional groups depending on its usage time.
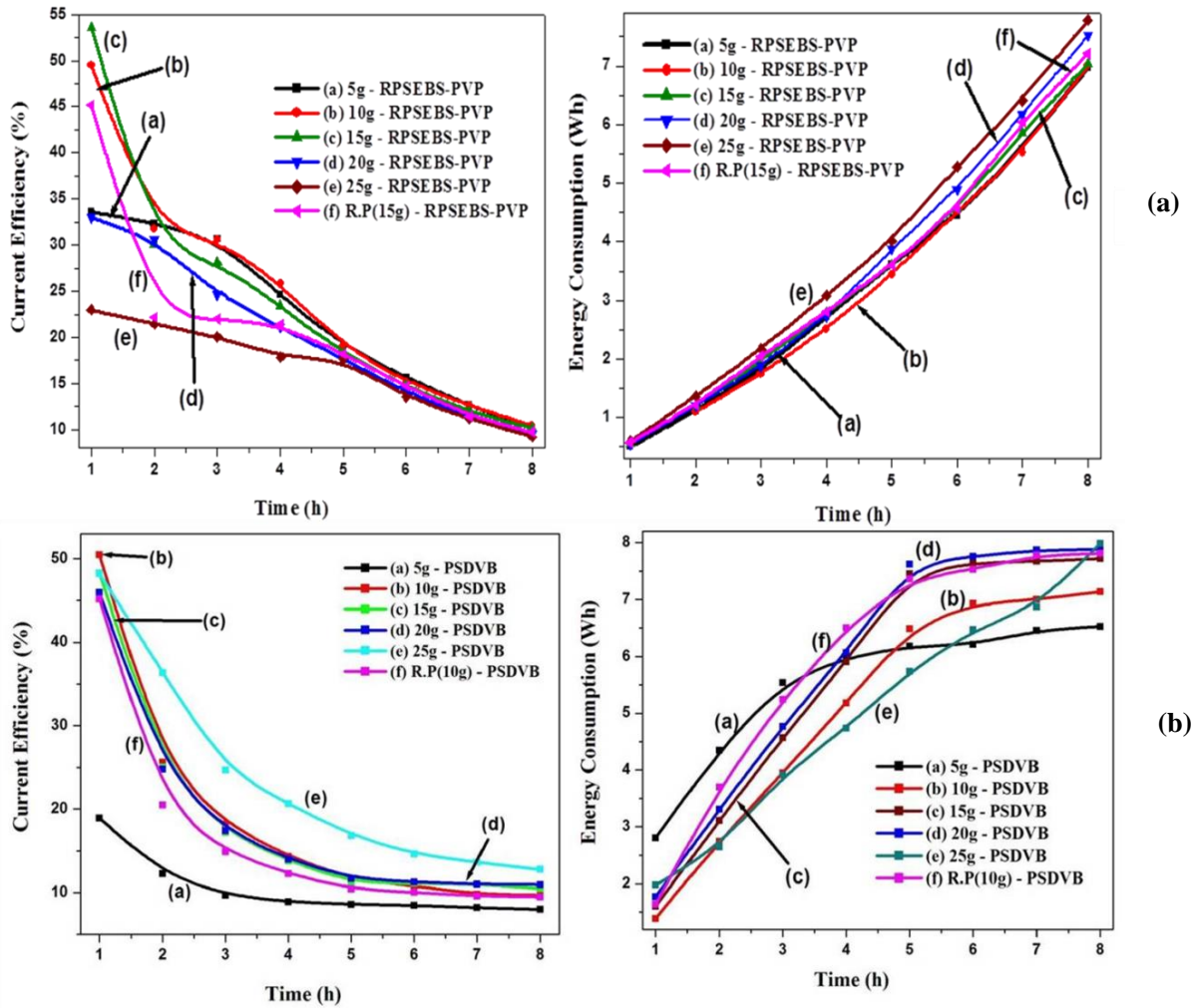

Figure 8. Variation of CE and energy consumption for various feed concentrations with time for (a) RPSEBS-PVP based IEM system and (b) PSDVB based IEM system

3.6. Variation of Current, Potential and Water Dissociation Fluxes with Time

Figure 9 and 10 reveals the relationship between current, potential and water dissociation flux of protons and hydroxyl ions with time for various feed concentration ranges for both RPSEBS-PVP and PSDVB based IEM systems. Similar to the results of Michael Rajesh et al [13] from Figure 9 and 10, it was clear that the current increases with time for both types of IEM system depending upon the type of feed concentration range. The reason was mainly because of the production of OH^-/H^+ during water dissociation and overall decrease of stack resistance due to resistance difference in various compartments caused by IEM. The maximum current observed finally for lowest and a highest feed concentration was about 74 mA and 81 mA respectively and it was about 105 mA and 89 mA respectively for PSDVB based IEM system.
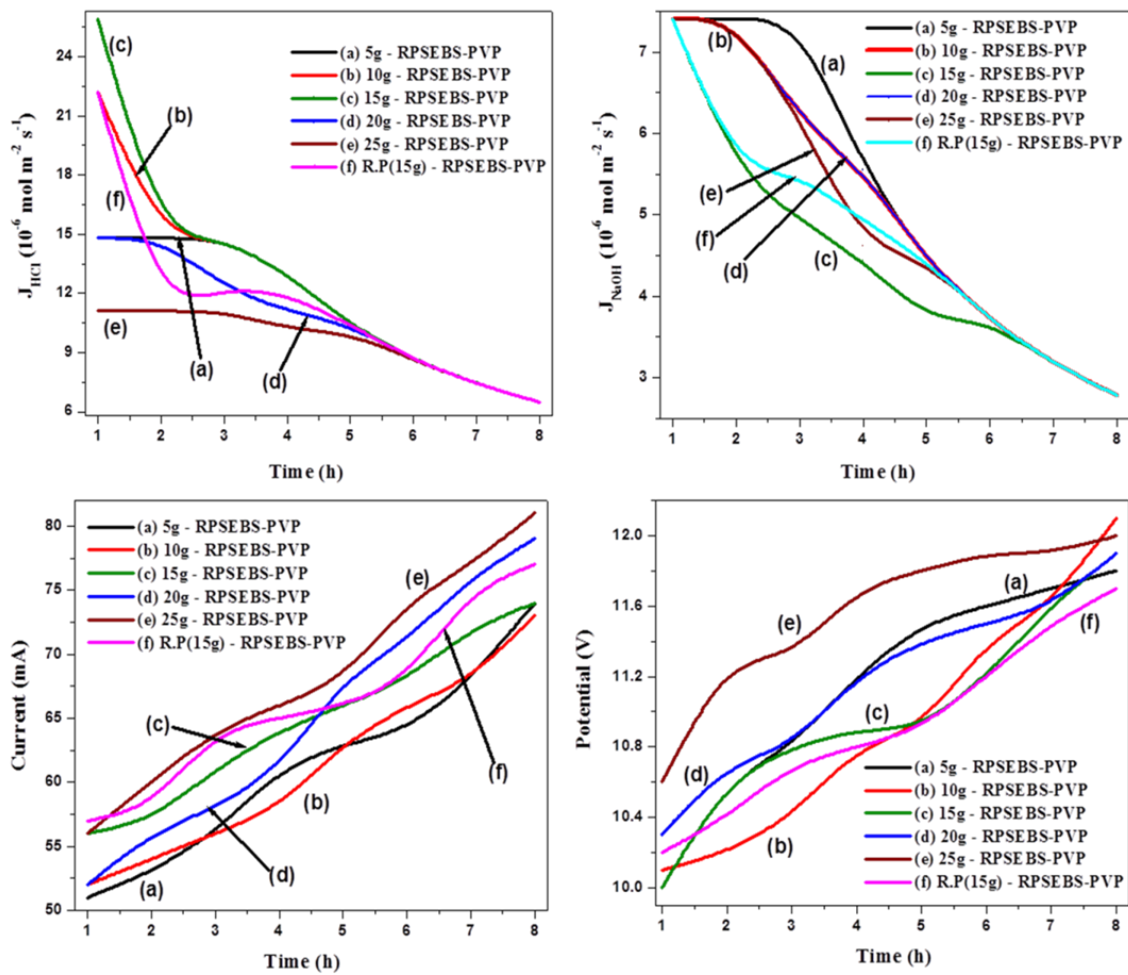

Figure 9. Variation of current, potential, protons and hydroxyl ions water dissociation fluxes with time for RPSEBS-PVP based IEM system

In the case of voltage variation, it slightly increased with increasing time, attained a maximum depending upon type of feed concentration range and then decreased. This is because the purity of acid and alkali were increased with increase in voltage to some extent, after which further increase in voltage had adverse effect on membranes, concentration and purity of acids and bases due to heating of stack and deterioration of membrane properties as discussed by Trivedi et al [14]. The highest volt reached by RPSEBS-PVP based system among various feed

concentration ranges was about 12 V as per Figure 9 and it was about 23.1 V for PSDVB based IEM system from Figure 10. The reason for the observed low voltage in case of RPSEBS-PVP based IEM system can be explained theoretically using protonation and de-protonation reactions model and the hydrophilicity change in the interface [15].
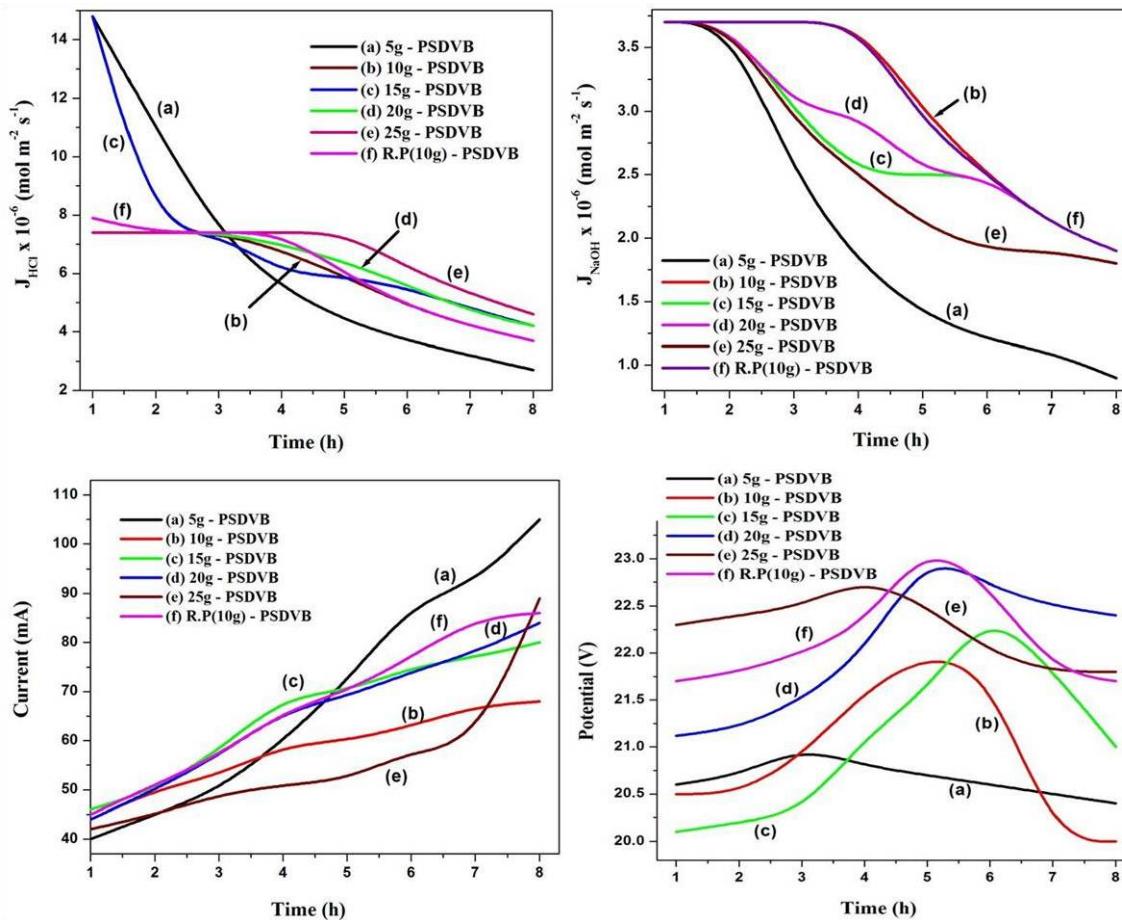

Figure 10. Variation of current, potential, protons and hydroxyl ions water dissociation fluxes with time for PSDVB based IEM system

From Figure 9 and 10 it was clear that for both types of IEM system whether acidic or basic the water dissociation fluxes were observed to decrease with time for the various feed concentration ranges mainly due to depletion of Na^+ in anode compartment and Cl^- ion in cathode compartment. The higher acid and basic flux observed as per Figure 9 was about 25.9 mol $m^{-2}s^{-1}$ and 7. 41 mol $m^{-2} s^{-1}$ in AC and BC respectively for RPSEBS-PVP based IEM system. And for PSDVB based IEM system the same was about 14.8 mol $m^{-2} s^{-1}$ and 3.7 mol $m^{-2} s^{-1}$ respectively. The greater flux value for RPSEBS-PVP based IEM system in turn confirmed the catalytic activity of intermediate PVP layer at BPM interface by means of hydrogen bonding and polar interactions between the intermediate PVP and water molecules. On the other hand, PVP is a kind of strong hydrophilic substance and when used as an intermediate the number of hydrophilic sites in the interfacial region increased due to the higher absorption of PVP which correspondingly increased the efficiency of water splitting.

In terms of reproducibility test in case of RPSEBS-PVP based IEM system, acidic fluxes were

observed to be lower and basic fluxes were slightly higher than its original feed concentration range. Whereas in the case of current change with time it was observed to have higher value and in the case of potential change with time it fluctuates around its original feed concentration and showed a slightly lower than its original performance value. In case of PSDVB based IEM system for reproducibility test, both water dissociation fluxes were observed to be lower than its original feed concentration and in case of current and potential the reverse condition was observed.

3.7. Determination of Electrical Conductivity, Salinity and Sodium-Chloride Ion Concentration

Table 2 and Table 3 represent the electrical conductivity, salinity and sodium-chloride ion concentration values in 100 mL of various feed sample solutions for both RPSEBS-PVP and PSDVB based IEM systems respectively. It should be noted that all these parameters increase with increase in feed concentration range mainly because of two reasons. First was due to the increased NaCl concentrations in the feed solutions. The second reason was due to restriction in the transport of sodium ion and chloride ion through IEMs because of decreased membrane capacity especially during high feed concentration performance at longer duration of time due to the adhesion of the salt ion over the surface of the membrane. Though the removal of NaCl ions from FC to neighboring compartment under the electric field was confirmed by lower electrical conductivity, sodium and chloride ion concentration value of final feed solutions than compared with their initial value for various feed solutions; the effectiveness of this process for both types of IEM systems was confirmed through its salinity measurements as from Tables 2 and 3. The higher difference between the initial and final value for all these parameters represents the process effectiveness in removal of NaCl and higher acid-base production with higher purity. The results of reproducible test can be discussed in the similar way.

Table 2. Electrical conductivity, salinity and sodium-chloride ion concentration values for various final feed solutions using RPSEBS-PVP based IEM systems

Final feed sample solution	Electrical conductivity (mS/cm)		Salinity (%)		Chloride ion concentration (mg/100 mL)		Sodium ion concentration (ppm)	
	Initial	Final	Initial	Final	Initial	Final	Initial	Final
5 g/L	12.53	6.65	8.2	4.1	35.96	15.3	42.9	10.2
10 g/L	20.90	8.10	14.3	5.1	39.12	16.35	44.4	10.9
15 g/L	30.40	10.92	21.3	7.2	46.69	24.45	46.2	16.3
20 g/L	37.7	18.26	26.9	12.3	54.26	25.95	48.0	17.3
25 g/L	44.9	19.51	33.1	13.2	58.68	26.10	49.1	17.4
Reproducibility test (15 g/L)	30.40	10.88	21.3	7.0	46.69	23.15	46.2	14.9

Table 3. Electrical conductivity, salinity and sodium-chloride ion concentration values for various final feed solutions using PSDVB based IEM systems

Final feed sample solution	Electrical conductivity (mS/cm)		Salinity (%)		Chloride ion concentration (mg/100 mL)		Sodium ion concentration (ppm)	
	Initial	Final	Initial	Final	Initial	Final	Initial	Final
5 g/L	12.53	11.30	35.96	20.8	35.96	20.8	42.9	24.5
10 g/L	20.90	19.4	39.12	27.3	39.12	27.3	44.4	38.9
15 g/L	30.40	27.5	46.69	30.4	46.69	30.4	46.2	44.3
20 g/L	37.7	31.3	54.26	37.6	54.26	37.6	48.0	45.3
25 g/L	44.9	36.9	58.68	43.4	58.68	43.4	49.1	46.5
Reproducibility test (10 g/L)	20.90	20.4	39.12	28.7	39.12	28.7	44.4	40.0

4. Conclusion

A functionalized PSEBS based resin-glass fiber reinforced monopolar and bipolar ion exchange membranes with PVP as intermediate were prepared in order to evaluate its desalination efficiency towards various feed concentration ranges using BPMED technology. Also the results obtained for various parameters using this IEM system was compared with commercial PSDVB based IEM system. Based on the results obtained for various process parameters such as current efficiency (maximum of about 53.6 % for RPSEBS-PVP and 53.61 % for PSDVB), energy consumption (of about 0.56 Wh for RPSEBS-PVP and 1.39 Wh for PSDVB), acid-base production (maximum of about 0.014 N acid: 0.006 N base for RPSEBS-PVP and 0.009 N acid: 0.006 N base for PSDVB) and WDE (maximum as 0.87 for RPSEBS-PVP and 0.07 for PSDVB), it can be concluded that RPSEBS-PVP based IEM system showed a better performance than that of the commercial PSDVB based IEM system. Also electrical conductivity, salinity and sodium-chloride ion concentration results were observed to be better for RPSEBS-PVP based IEM system than with PSDVB based IEM system due to the presence of a catalytic and hydrophilic intermediate PVP region in RPSEBS-PVP based IEM system by means of hydrogen bonding and polar interactions between the intermediate PVP and water molecules.

Acknowledgement

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