Research Article

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# Synthesis, Characterization, Electrochemical and Antibacterial Studies of Synthesized PVC Supported CP Composite

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## Abstract

*The copper phosphate {$Co_3(PO_4)_2$} inorganic material has been synthesized by the sol gel method. The PVC supported CP membrane was designed by the mixing of inorganic CP and organic polyvinyl chloride (PVC) materials in 1:3 ratios of percentage. This membrane is used as a barrier for transportation of electrolyte and heavy metal ions due the charged particles on it. Due to this nature of membrane, it governs to adsorb as well as absorb characteristics of cations and anions. The structural, thermal and electrochemical characterizations were done by using different sophisticated techniques like FTIR, XRD, TGA/DTA as well as SEM-EDX, LCR and potentiometer analysis. The characterizations of material and membrane indicated the information of functional groups, material nature, thermal stability, surface structure, porosity, elemental percentages, dielectric nature, ionic transportation etc. Teorell-Meyer-Sievers (TMS) theoretical method is used to determine the charge density of membrane which is an important theory is used to analyze the performance of membrane. The other important parameters of membrane have also been determined easily by the help of obtained values of charge densities.*

**Keywords:** PVC based CP composite material, XRD analysis, TMS theoretical approach, Charge density, Antibacterial study

## Introduction

Polymeric–inorganic fused materials have been broadly investigated since the last two to three decades in order to achieve new type of composite membranes with unique filtration and purification properties. Such composite materials are prepared by a homogenous mixing of organic and inorganic compounds in a definite ratio of percentages. Nowadays the organic–inorganic composite or fused materials are mainly focusing the novel or innovative research due to the combining characteristics of materials into a single solid with attractive properties [1]. The improvements as well as modifications in the properties of materials are due to the characteristics of thermally stable inorganic backbone and mechanically stable elastic polymers. Therefore such types of composite materials are being explored in the industrial perspective due to wide potential applications in the field of chemistry, biology and material sciences. Membranes which are prepared by fusing the organic and inorganic materials are broadly show lot of applications in different fields like foods, drugs, dairy and beverages as well as power generation, fuel cells, energy savings, pollution control, waste water treatment etc. Simultaneously, they are also have been used in many other important processes like electro-dialysis, membrane electrolysis and electro-deionization processes. Polymers like polyvinyl pyrrolidone, polyvinyl chloride, polystyrene, polythiophene, polypyrrole, polycarbazole and polyaniline have been renowned to show the most important and great significance to make the membrane for commercialization purposes. The valuable characteristics of polymers are due to their exclusive electrical, optical, mechanical and photoelectrical properties. Beside this PVC is one of the most applicable polymer that has been used in the field of material, biological, environmental and medical sciences [2-4].

The primary significance of membrane processes mainly highlighted on the advantages as compared to the conventional processes, through which the distillation, precipitation and stabilization have been easily studied and industrially modified. However these processes remains sometime more costly than the other conventional processes in terms of investment and maintenance point of views, while it should be more efficient, more economical, less destructive, low electrical power consuming and eco friendly [5,6]. The charged membrane can easily transfer the charged particles according to their charges, while neutral membrane can separate transferable solutes according to the sizes or their interaction with membrane surface. The charged membrane separate the ionic solutions due to the presence of fixed-charged groups, through which it can easily separate at least one dissolved ionic components from the aqueous, and electrolyte solutions. So these types of membranes are indicated to show an important application in the preparation of ion-selective electrodes, which are used as a chemical sensor, fuel cell, electro dialysis for brackish and seawater desalination etc [7-9].

The electrochemical characterization of composite membranes is depended on some of the physical parameters like ion

exchange capacity, water content nature, membrane thickness, ionic transportation, thermal plus chemical stabilities etc [10,11]. So the plan of above experimental work is to develop a novel organic–inorganic composite material with a novel and superior characteristics. The potential observation through composite membrane is a powerful and straightforward method which is used to investigate the ionic transportation of some electrolyte salts and heavy metal ions [12,13]. The measurement of charge density which is an important phenomenon of membrane process determined by theoretical approaches is elaborated the membrane model to focus on the application point of views. It has been calculated by obtaining the coinciding position of both the observed and theoretical potential values of used uni univalent electrolyte solutions. Related to charge density of membrane the other important parameters which included the transport number, mobility ratio and charge effectiveness have also been calculated by applying these theoretical equations [14-16].

## Experimental

### Chemicals and Instruments

Electrolyte solutions like KCl, NaCl and LiCl of various concentrations were required, 200 mesh size of PVC powder, 0.2 M $Na_3PO_4$ and $CoCl_2$ solutions of 99.90% purity were required to make the cobalt phosphate (CP) material. All these reagents and powder should be of analytical grade and pure double distilled water was used for the preparation of aqueous electrolyte solutions. Instruments like Scanning electron microscopy (SEM) is used to determine the surface structure of membrane, X-ray diffraction (XRD) stated about the chemical composition and crystallographic structure, Fourier transform infrared spectroscopy (FTIR) is used for determining the functional groups, Thermo gravimetric and Differential thermal analysis (TG-DTA) are used to indicate the mass change or weight loss taken by materials and the digital potentiometer is used to determining the ionic potential of used solutions [17,18].

### Synthesis of CP materials by sol-gel process

CP was synthesized by sol-gel method of material synthesis through which the mixing of 0.2 M aqueous solution of $Na_3$ (PO4) with $CoCl_2$ solution took place. Then the constant stirring of the solution till 2-3 h has been done, while the pH of solution must be neutral after stirring process. Then filter the solution and coagulated precipitate has been well washed nearly 4-5 times by deionized water to remove the free electrolytes and ions and then it was dried till 3-5 h at 100 °C temperature. Lastly the material has been crushed into fine powder by pestle and mortar until the size of it must be less than 200 meshes [19].

### Preparation of PVC based CP composite membrane

The synthesized CP material was mixed with PVC powder in 1:3 ratios of percentages by pestle and mortar, and mixing of both the materials should be very cautiously and homogenously until it gets totally mixed with each other. Then mixture was kept into a cast die of diameter 2.45 cm, which then has been transferred to place in a digital furnace for 1-2 h by maintaining 50 °C temperature to equilibrate the reaction mixture. Then the die was transferred into a pressure device of SL-89, UK to apply 100 MPa pressure which results to form good membrane fabrication. By putting 1:3 ratios of polymer and CP material respectively, shows an appropriate mechanically and morphologically stable membrane. If it exceeded or decreases the above mentioned ratio that is 25-75%, it does not show the desired stability and function. Lastly the prepared membrane was subjected to microscopic and electrochemical examination, which results to show the cracks and homogeneity of surface. After gaining the appropriate stability membrane is ready to observe the potential readings of different used electrolytic solutions [20,21].

### Potential observation

The ionic potential of uni univalent strong electrolytes was observed by a self designed model of two chambered glass cell and a digital potentiometer. In this observation the synthesized charged membrane has been placed at the centre of glass cell which has the cavity of 35 ml each, is used to introduce the electrolyte solutions of unequal concentration and saturated calomel electrodes of potentiometer. By potential reading it indicated that only cations of the electrolytes like $K^+$, $Na^+$, and $Li^+$ are affected the potentiometric response, which is due to the characteristic of incubated charged membrane [22,23]. The rough pictorial representation of used electrochemical setup is represented by the following Figure1.

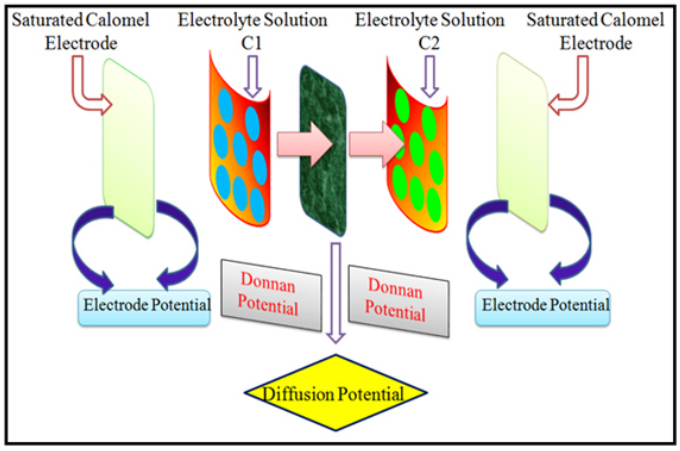


**Figure1**: Electrochemical setup used electrolyte potential measurement

### Chemical stability

The chemical study of examined membrane has been checked by using *"ASTM D543-95"* method, which analyzes the morphological changes and durability of membrane. It gives the information of change in color, membrane surface deviation, their brightness, decomposition, splits, holes, deviation etc [24].

### Ionic exchange capacity

By titration procedure we have obtained the ion exchange capacity of CP ion exchange material. In this titration firstly the $HNO_3$ treatment of CP for 24 h took place and then it was washed more than two times by DMW. Then it has been titrated with 0.01 M NaOH solution which results to get the $H^+$ ions releases by $Na^+$ ions through an ion-exchange reaction. To complete this titration phenolphthalein is used as an indicator. The equation which is used to determine the ion exchange capacity of CP material is as follows [25].

IEC = *volume of consumed NaOH* × *molarity of NaOH / weight of dried material*

### Dielectric properties of composite membrane

For measuring the dielectric and impedance property of PVC based composite material, firstly it has been modified into a circular pallets which was coated with silver paste on adjacent faces, through which it is formed a parallel plate capacitor geometry, then the values of $Z$, $\theta$ and $C_p$ have been recorded. By these data many dielectric

parameters were calculated easily. The dielectric loss was calculated by the formula: $tan\delta = 1/tan\theta$ (a)

Where tanδ is dielectric loss tangent which is proportional to the loss of energy from applied field to the sample and this energy is dissipated as heat, so denoted as dielectric loss [26]. The real and imaginary part of impedance was also been calculated by using the following formula:

$Z' = Zcos\theta$ *and* $Z'' = Zsin\theta$ (b)

### Antibacterial activity of composite material

The Antibacterial activity of PVC based CP composite material has been done in vitro condition, in which disc diffusion method is used against the two gram-positive and two gram-negative bacteria Staphylococcus aureus (*MSSA 22*), Bacillus subtilis (*ATCC 6051*) and Escherichia coli (*K12*), Streptococcus pneumonia (*ATCC,BAA-1705*) respectively. The antifungal activity was also done by Candida albicans (diploid fungus). The discs of 5 mm diameter were prepared by using whatmann filter paper and sterilized by dry heat at 140 °C for at least 1–2 h, and these discs should be placed in a nutrient agar medium. The plates then have supplied in an incubator for 24 h at 37 °C, and then after it have been observed. The screening was performed for 114.4 mg/mL concentration of tested composite material and antibiotic disc, whereas the tetracycline (30 mg/disc, Hi-Media) was used to control it. The nutrient broth of logarithmiely serial took place by two fold diluted amount of tested composite material. It controls by inoculated within the range of 107–108 cfu/ml, however the highest dilution are required to capture the growth of bacteria. To spread on the agar plates each one has 0.1 ml volume diameter zone and the number of colony forming units (cfu) has been counted after passing the 24 h of time [27].

### Percentage of water absorption

Water content or percentages of water absorption by membrane has been calculated by using following equation.

$$\text{Water absorption (\%)} = \left[\frac{Wwet - Wdry}{Wdry}\right] \times 100$$

Where $W_{wet}$ is the weight of swollen membrane which was incubated in water that is obtained by soaking it into water for 5-8 hrs, and $W_{dry}$ is the weight of dry membrane.

The porosity of membrane can also be measured easily by the following equation.

$$\text{Porosity (\%)} = \left[\frac{Wwet - Wdry}{AL\rho w}\right] \times 100$$

$A$ = area of membrane, $L$ = thickness of membrane, $\rho w$ = density of water.

### Membrane diameter, thickness and swelling

By screw gauze apparatus the diameter, thickness and swelling of PVC based composite membrane are calculated by measuring the average thickness of 4-5$^{th}$ replicates. The swelling was measured by taking the difference between average thickness of membrane which was equilibrated in 1 M NaCl or KCl solution and the dry membrane [28].

## Result and discussion

In Figure2, there is SEM supported EDX images are presented which indicated the surface structure and elemental percentages of synthesized porous membranes. Surface structure indicated that that the mixing of PVC and CP materials has been done very uniformly and cautiously. The PVC and inorganic CP materials are homogenously distributed throughout the membrane body according to their percentages. There is no any visible breakage or cracks are found on the surface of porous membrane, which confirmed that the ion exchange membrane can easily transport the respective ions as well as molecules according to their nature, whereas the EDX graph shows all the percentage of present elements in this organic inorganic composite membrane. So it is indicating that PVC has very excellent binding characteristic with CP inorganic materials [29].

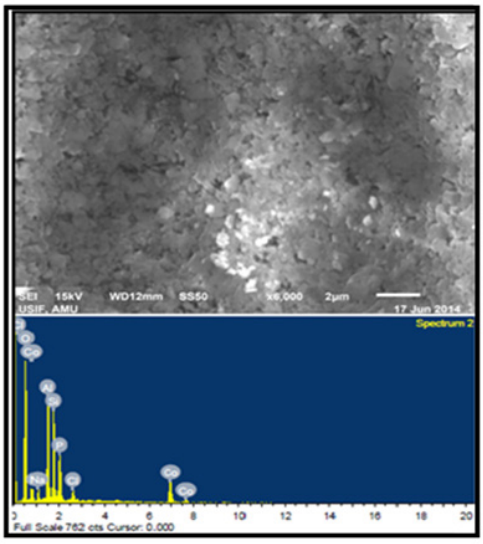


**Figure 2**: SEM supported EDX images of PVC based CP composite membrane

Figure3 indicated the FTIR spectrum of only CP and PVC based CP composite materials through which the graph shows the presence of phosphate ($PO_4^{3-}$) and hydroxyl ($OH^-$) ions in composite material of membrane. The spectra between 1000–1500 $cm^{-1}$ arises due to the P-O stretching vibrations, the band at about 700-800 $cm^{-1}$ is assigned the characteristic vibrational mode of polymeric $Mx(PO_4)y$, confirming their integrity in the material. The band around 500 $cm^{-1}$ shows the presence of different groups at different ranges in PVC based CP composite material. The broad peaks at about the range from 1500-1600 $cm^{-1}$ and at about 3400 $cm^{-1}$ are assigned to -OH- bending and stretching vibrations respectively [30]. The XRD graphical representation of PVC based CP composite material is indicated by Figure4 which confirmed that there is very sharp and intense peak found in the composite material of membrane and this peak is found at the range from 20-30° 2θ values. Many others small and less intense peaks are also found at the range from 20-70° values respectively. So it is indicated that the PVC based CP composite material shows high as well as less intense peaks at different 2θ ranges which confirmed to explain that used material of membrane show crystalline nature [31].

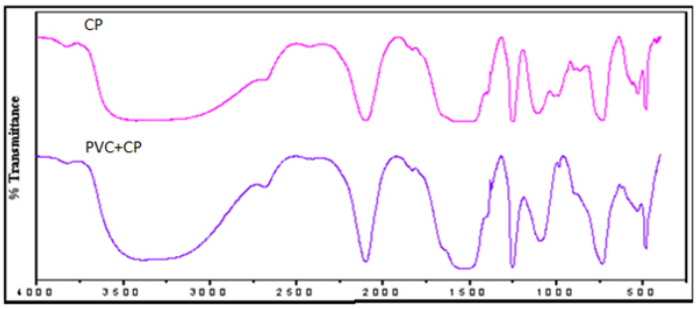


**Figure 3**: FTIR Spectra of only CP and PVC based CP composite material

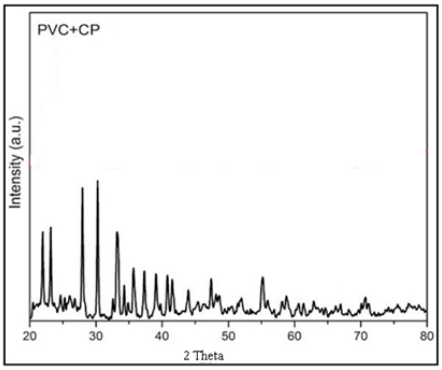


**Figure 4**: XRD spectra of PVC based CP composite material

Figure5 shows the TGA characterization, which stated the weight loss of PVC based CP composite material at different temperature ranges. The graph indicated the weight loss of only CP and PVC based CP composite material. The graph of only CP material shows two times weight loss of 26.14% and 12.69% consecutively at different temperature ranges whereas the PVC based CP composite material is indicated only one time weight loss of about 19.92% at the 50 °C temperature. So it indicated that the used sample of membrane has hydrophilic nature that can easily absorbs moisture from the surrounding atmosphere, and it shows endothermic property also, means that the increasing of temperature leads to weight loss taken by material [32].

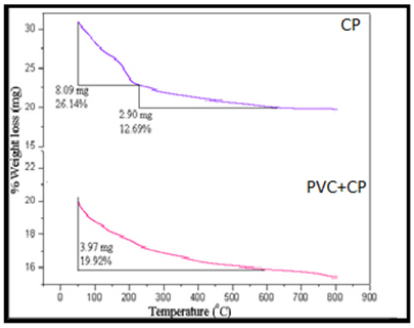


**Figure 5**: TGA spectral analysis of only CP and PVC based CP composite material

Figure6 shows the dielectric constant of PVC based CP composite material which indicated variations according to frequency. It means that the composite material shows frequency dependent behavior. By increasing frequency the dielectric constant is decreases regularly, firstly it was randomly decreases and then move constant for a short period. By graphical representation the dielectric loss also shows alike behavior with respect to dielectric constant, which means that the dielectric loss is directly proportional to dielectric constant. It also indicated that real part of impedance also shows frequency dependent behavior at very low frequency and the value of $Z' = Z\cos\theta$ have increases quickly but at high frequency it shows frequency independent characteristics, means that it shows constant nature which has calculated by the given formula. The graph of imaginary part of impedance that is $Z'' = Z\sin\theta$ also shows the frequency dependent behavior, but it increases quickly at zero frequency or slightly more than but again at high frequency it behaves as constant property [33].

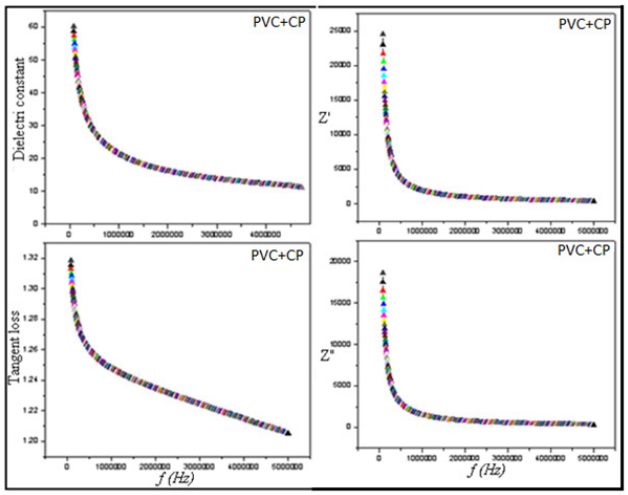


**Figure 6**: Dielectric (constant and loss) and dielectric nature (real and imaginary part) of PVC based CP composite membrane

The antibacterial observation which was carried out to investigate the bacterial action of membrane material shows in Table1. Two gram-positive, two gram-negative bacteria and a diploid fungus were used to analyze the activity with the concentration range of 200-800 mg/mL, and tetracycline was used as a standard drug for comparing the bacterial action and the examined data represent in above given table. So it is clear that the newly synthesized PVC based CP has extraordinary inhibitory effects against the growth of bacterial strains. This given data illustrated the evidences of activity against different types of bacteria and fungus which means that the PVC based CP composite material can be used as a potent antibacterial and antifungal agent [34].

**Table1: Zone of inhibition by gram-positive and gram-negative bacteria of PVC based CP composite sample**

| Antimicrobial activity of test sample | | | | | | |
|---|---|---|---|---|---|---|
| Sample | Conc. ( µ g / disc) | B. subtilis | S . aureus | E.coli | K . pneumoniae | C . albicans |
| PVC+CP | 200 | - | - | - | - | - |
| | 400 | 11 | 13 | 11 | 14 | 13 |
| | 800 | 15 | 15 | 17 | 19 | 15 |
| Tetracycline | 30 (µg/ disc) | 19 | 21 | 24 | 20 | - |
| - Indicates no activity | Value indicate the diameter of the zone of inhibition | | | | | |

The membrane which was incubated in acidic, basic and alkaline medium shows very well chemical stability and durability. But after passing more and more time into the harsh pH i.e. high acidic or basic solutions membrane loses their shape and structure, and these morphological changes were seen after passing 12, 24, 36, 48 and lastly 60 h. It is indicated that membrane has exhaustive in these intense solutions after passing more time, or by increasing the concentration of solutions. So the chemical stability is an exclusive feature of membrane which decided the durability and performances of it. The diameter, porosity, water content percentage and swelling of membrane are clearly designated by Table2 [35].

**Table 2 : Thickness, porocity, swelling and diameter of PVC based CP composite membrane**

| Applied Pressure | Diameter (cm) | Thick ness (cm) | Water content | Porosity | Swelling |
|---|---|---|---|---|---|
| 100 (Mpa) | 2.45 | 0.072 | 0.03 | 0.014 | No swelling |

## Theories

The theoretical approaches which are normally used to calculate the fixed charge density of composite membrane are TMS, Altug and Hair, Kobatake, et. al. and the most new one are Nagasawa and coworkers [36-43]. In this paper TMS theory are used to calculate the fixed charge density of composite membranes that has several important points and postulates which are illustrated as follows:

In TMS approach there be must found an equilibrium development at all the interfaces of solution and membrane which has proper connection with the Donnan equilibrium. The other important postulations are described as follows:

(i) The transference of water from either side of membrane may be ignored.
(ii) The ionic movement and concentration of fixed charges are constant throughout the membrane matrix.
(iii) It is also independent on the salt concentration of solutions.

Additional assumptions are that the activity coefficient of salt is similar in both the solution and membrane phases. The introduction of activities for salt concentration can only be approved through Donnan potential either by using the Planck's or Henderson equation. The TMS graphical approach determines the fixed charge density and cation-to-anion mobility ratio.

In this experimental analysis the PVC based CP composite membrane has created ionic potentials due to the interphase present between two unequal concentrations of electrolyte solutions. The data of observed potential shows the selectivity of some ions due to charged particles on membrane surface. The activity of ions is more flourished in high concentration, through which the membranes behave as a cations or anions selective property. In this observation anions did not influence the potentiometer respond. Figure7 shows the positive potential order which means that the potential has increases by decreasing the concentration of solutions and this process follows Nernst equation. By affecting through cations it is clear that the membrane has negatively charged i.e. perfectly cations selective nature [44].

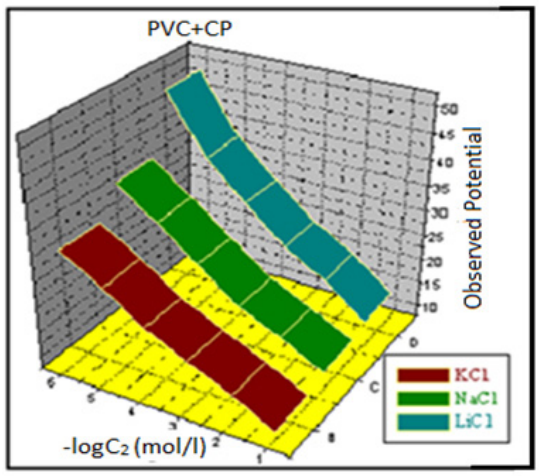


**Figure 7**: Plots of observed membrane potentials against logarithm of concentration for PVC based CP composite membrane

In common membranes there is important electrochemical property of differences in permeability of co-ions, counter ions as well as neutral molecules, whereas charged membranes produces adsorption or absorption property which depends on their nature and also it indicated less activity in dilute region over the more concentrated region. Charges are generating potential which depends on the porous characteristic of membrane, means if pores of membranes are broad much charges are required to generate appropriate potential, while narrow porous membrane require little quantity to generate admirable potential of ions. The transference of cations as well as anions cannot be completed by evaluating the thermodynamically effective fixed charge density of membrane. In this experimental observation, Figure8 shows the graph of theoretical and observed potential values which has designated by dark and broken line respectively and it is plotted by taken as a function of –logC2. The coinciding position on the graph gives the value of charge density of membrane which always shows $\bar{D} \leq 1$ and in this study it follows KCl>NaCl>LiCl order. Charge density depends on the early stage of material synthesis and their characteristic, and it may also indicate the above relation due to the size factor of used electrolyte solutions [45,46].

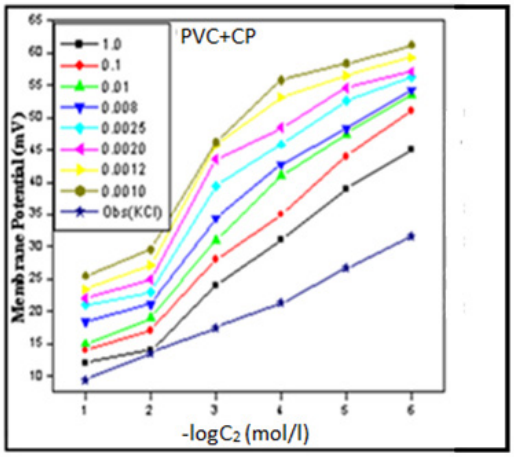


**Figure 8**: Plots of membrane potential (theoretical and observed) against logarithm of concentration of KCl electrolyte solution for PVC based CP composite membrane

The electrochemical setup which was used to determine the ionic potential is indicated that there are two donnan potential arises at two solution and membrane interfaces, while the incubated membrane arise diffusion potential due to unequal concentration of electrolyte solutions. So it indicated that there must have an equilibrium development at both the solution and membrane interfaces which has proper similarity with donnan equilibrium. There should be an internal salt diffusion potential which has represented by Henderson equation and leads to Planck expression. TMS theoretical approach is more applicable in high concentrated solutions because in low concentration it shows high deviation between observed and calculated potential values. TMS equation for membrane potential is described as follows [47].

$$\Delta\bar{\psi}_m = 59.2\left(\log\frac{C_2}{C_1}\frac{\sqrt{4C_1^2+\bar{D}^2}+\bar{D}}{\sqrt{4C_2^2+\bar{D}^2}+\bar{D}}+\bar{U}\log\frac{\sqrt{4C_2^2+\bar{D}^2}+\overline{DU}}{\sqrt{4C_1^2+\bar{D}^2}+\overline{DU}}\right) \quad (1)$$

$$\bar{U}=\left(\bar{u}-\bar{v}\right)/\left(\bar{u}+\bar{v}\right)$$

Where $u^-$ and $v^-$ are the mobility of cations and anions respectively, and $C_1$ and $C_2$ are the concentration of solutions of chamber 1 and 2, and $D^-$ is the charge density of membrane. Eq.1 can also expressed by the sum of Donnan potential ($\Delta\Psi_{Don}$) and diffusion potential ($\Delta\Psi_{Diff}$).

$$\Delta\bar{\psi}_{m,e}=\Delta\psi_{Don}+\Delta\bar{\psi}_{diff} \quad (2)$$

$$\Delta\psi_{Don}=-\frac{RT}{V_kF}\ln\left(\frac{\gamma_{2\pm}C_2\bar{C}_{1+}}{\gamma_{1\pm}C_1\bar{C}_{2+}}\right) \quad (3)$$

*F*, *R* and *T* have their standard values, $\gamma_1\pm$ and $\gamma_2\pm$ are mean ionic activity coefficients and $C_1+$, $C_2+$ are the cation concentration on both the chamber of membrane.

$$\bar{C}_+=\sqrt{\left(\frac{V_x\bar{D}}{2V_k}\right)^2\left(\frac{\gamma_\pm C}{q}\right)^2}-\frac{V_x\bar{D}}{2V_k} \quad (4)$$

Here $V_k$ and $V_x$ is valancy of cations and fixed-charge groups on membrane respectively and q is the charge effectiveness of membrane.

$$q=\sqrt{\frac{\gamma_\pm}{K_\pm}} \quad (5)$$

Here K± is the distribution coefficient expressed as:

$$K_\pm=\frac{\bar{C}_i}{C_i},\bar{C}_i=C_i-\bar{D} \quad (6)$$

$C_i^-$ and $C_i$ is the $i^{th}$ ion concentration in membrane and external solutions. The diffusion

potential is as follows

$$\Delta\bar{\psi}_{diff}=-\frac{RT\bar{\omega}-1}{V_kF\bar{\omega}+1}\times\ln\left(\frac{\left(\bar{\omega}+1\right)\bar{C}_2+\left(V_X/V_k\right)}{\left(\bar{\omega}+1\right)\bar{C}_1+\left(V_X/V_k\right)D}\right. \quad (7)$$

Here $\omega^-= u/v$ is the mobility ratio of cation to anion through membrane phase. So the total membrane potential can easily obtain by the addition of $\Delta\Psi_{Don}$ and $\Delta\Psi_{diff}$

$$\Delta\bar{\psi}_{m,e}=-\frac{RT}{V_kF}\ln\left(\frac{\gamma_{2\pm}C_2\bar{C}_{1+}}{\gamma_{1\pm}C_1\bar{C}_{2+}}\right)-\frac{RT\bar{\omega}-1}{V_kF\bar{\omega}+1}\times\ln\left(\frac{\left(\bar{\omega}+1\right)\bar{C}_2+\left(V_X/V_k\right)\bar{D}}{\left(\bar{\omega}+1\right)\bar{C}_1+\left(V_X/V_k\right)\bar{D}}\right) \quad (8)$$

$$\Delta\bar{\psi}_m=-\frac{RT}{F}\left(t_+-t_-\right)\ln\frac{C_2}{C_1} \quad (9)$$

Where $\frac{t_+}{t_-}=\frac{\bar{u}}{\bar{v}}$ (10)

The values of transport number ($t_+$) and mobility ratio ($\omega^-$) can easily be obtained by above given equations. To show the applicability of TMS equation the donnan and diffusion potential can clearly calculated through the observed potential values. The symbols of all the equations like , $\gamma_{1\pm}$, $\gamma_{2\pm}$, $\bar{C}_{1+}$, $\bar{C}_{2+}$, $\bar{\omega}$, $V_x$, $V_k$ and $\gamma_\pm$ have the usual charted values. By the analysis it is clear that the higher transport number always follows high mobility ratio of ions, which increases by decreasing the concentration of solutions. The ionic mobility and transport number of composite membrane follows the LiCl>NaCl>KCl order which is graphically represented by Figure9 and 10 respectively [48,49]. An important property that is distribution coefficient of solutions is decreases by increasing the concentration of solutions and the values of $U^-$ is also represented by the Figure11. The very important observed potential and charge density were easily calculated by equations (3) and (7) and the obtained data is represented by Table3 [50].

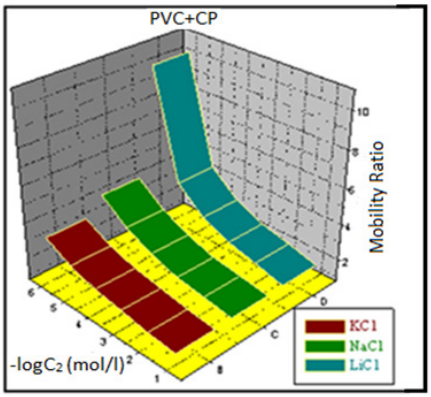


**Figure 9**: Plots of mobility ratio against logarithm of concentration of PVC based CP composite membrane

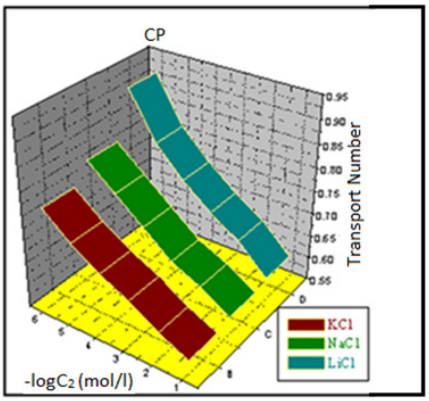


**Figure 10**: Plots of transport number against logarithm of concentration of PVC based CP composite membrane

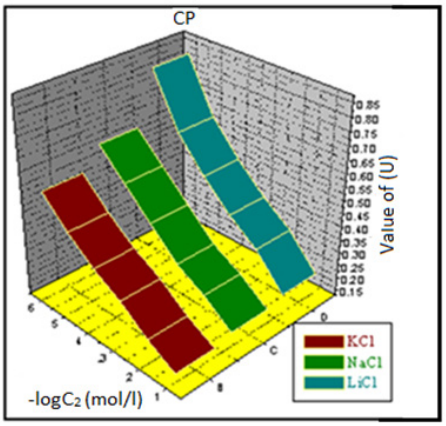


**Figure 11**: The plot of (U) value against logarithm of concentration of PVC based CP composite membrane

**Table 3: Observed membrane potential and charge densities across the PVC based CP composite membrane**

| Membrane Potential (Conc) | KCl | NaCl | LiCl |
|---|---|---|---|
| 1.0 | 9.4 | 11.4 | 12.5 |
| 0.1 | 13.6 | 15.6 | 18.8 |
| 0.01 | 17.5 | 19.4 | 23.4 |
| 0.001 | 21.3 | 25.4 | 30.2 |
| 0.0001 | 26.7 | 31.5 | 37.2 |
| 0.00001 | 31.6 | 37.0 | 48.5 |
| **Charge densities ($Dx10^{-3}$Eq/l)** | **1.99** | **1.74** | **1.58** |

## Conclusion

The novel PVC based CP composite membrane was synthesized by sol gel method of material synthesis and it shows appropriate mechanical stability due to the good PVC interaction with CP material. All the characterizations of membrane show good results that make it industrially applicable accordingly their functions. The IEC of composite materials which is used to make the membrane is indicated to show cation selective characteristic of material. The morphology of membrane like thickness, diameter, porosity and water incorporation are clearly calculated and indicated in manuscript. Observed potential and charge density are the important parameters that govern the transport property of membrane which depends on the characteristics and applied pressure of membrane. The TMS theoretical approach and experimental results are satisfying with each other by getting the appropriate values of charge density. The electrolyte potential of membrane shows KCl<NaCl<LiCl order while the charge density indicated the reverse order. So it is concluding that this membrane model can be acceptable and withstand for upcoming industrial purposes.

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