The European Journal of Technical and Natural Sciences 2025, No 3
ISSN 2414-2352

PREMIER Publishing
ppublishing.org

DOI:10.29013/EJHSS-25-3-24-28

PHYSICOCHEMICAL CHARACTERIZATION OF ANION-EXCHANGE RESINS BASED ON POLYVINYL CHLORIDE (PVC) AND POLYVINYL AMINE (PVA)

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Cite: *Yusupov F., Yakhshiyeva Y., Yusupov S., Temirov G. (2025). Physicochemical Characterization of Anion-Exchange Resins Based on Polyvinyl Chloride (Pvc) and Polyvinyl Amine (Pva). European Journal of Technical and Natural Sciences 2025, No 3.* https://doi.org/10.29013/EJHSS-25-3-24-28

Abstract

This study presents the synthesis and physicochemical characterization of an anion-exchange resin based on polyvinyl chloride (PVC) and polyvinyl alcohol (PVA). The resin was prepared by blending PVC and PVA in varying ratios, followed by chemical cross-linking with epichlorohydrin and functionalization with trimethylamine to introduce quaternary ammonium groups. The resulting materials were evaluated for ion-exchange capacity (IEC), swelling behavior, surface morphology, and functional group identification using FTIR, SEM, and EDS analyses. Among the synthesized formulations, the resin with a 60:40 PVC: PVA ratio exhibited the highest IEC value (1.45 meq/g) and the greatest swelling ratio (45.7%), indicating an optimal balance between hydrophilicity and structural integrity. These findings suggest that PVC–PVA-based composite resins have strong potential as cost-effective and efficient anion-exchange materials for use in water treatment and other environmental applications.

Keywords: *Anion-exchange resin, polyvinyl chloride (PVC), polyvinyl amine (PVA), ion exchange capacity (IEC), water treatment*

Introduction

In recent years, the demand for efficient and selective ion-exchange materials has significantly increased, particularly in the fields of water purification, environmental remediation, and industrial wastewater treatment (Ahmed, M.J., & Hameed, B.H., 2018). Among various types of ion-exchange resins, anion-exchangers play a vital role in removing undesirable anionic species such as nitrates, sulfates, and heavy metal complexes from aqueous solutions (Bhatnagar, A., & Sillanpää, M., 2010). The development of novel anion-exchange resins with enhanced stability, capacity, and chemical resistance has thus become a critical area of research (Rengaraj, S., & Moon, S.H., 2002).

Polyvinyl chloride (PVC) is a widely used thermoplastic polymer known for its mechanical strength, chemical stability, and cost-effectiveness. However, its limited hydrophilicity and low functional group density can restrict its performance in ion-exchange applications. In contrast, polyvinyl amine (PVA) is a hydrophilic polymer with excellent film-forming ability and compatibility with other polymers (Crini, G., & Badot, P.-M., 2008). The combination of PVC and PVA has been explored as a promising matrix for developing composite ion-exchange materials with improved physicochemical properties (Widiastuti, N., Wu, H., Ang, H. M., & Zhang, D., 2011).

Incorporating functional groups such as quaternary ammonium salts or amine groups into the PVC-PVA polymer backbone can impart anion-exchange capabilities, enabling the resulting material to interact effectively with negatively charged ions (Sharma, Y. C., & Uma, R., 2010). The physicochemical characteristics of such ion-exchange resins – including their surface morphology, ion-exchange capacity, thermal stability, and chemical durability – are crucial for determining their performance and practical applicability (Singh, K. P., & Tiwari, S., 2016).

This study aims to synthesize an anion-exchange resin based on PVC and PVA and to comprehensively investigate its physicochemical properties using a range of analytical techniques (Ahmad, A. L., Sumathi, S., & Hameed, B.H., 2006). These include Fourier-transform infrared spectroscopy (FTIR), scanning electron microscopy (SEM), energy-dispersive X-ray spectroscopy (EDS), and ion-exchange capacity measurements (Zeng, Y., Zhang, T., & Liu, S., 2013). The findings of this research are expected to contribute to the development of efficient, low-cost, and durable anion-exchange materials suitable for use in diverse environmental and industrial settings (Nandiyanto, A. B. D., Oktiani, R., & Ragadhita, R., 2019).

Materials

Polyvinyl chloride (PVC, analytical grade) and polyvinyl alcohol (PVA, molecular weight ~89,000–98,000, 99% hydrolyzed) were obtained from Sigma-Aldrich. Sodium hydroxide (NaOH), epichlorohydrin (ECH), and trimethylamine solution (TMA, 33 wt% in water) were purchased from Merck. All chemicals were of analytical grade and used without further purification. Distilled water was used throughout all experimental procedures.

Preparation of PVC–PVA Anion-Exchange Resin

The synthesis process involved the physical blending of PVC and PVA in varying ratios (e.g., 70: 30, 60: 40) to create a homogeneous polymer matrix. First, PVC was dissolved in dimethylformamide (DMF) under constant stirring at 60 °C. In a separate container, PVA was dissolved in distilled water at 80 °C. The two solutions were mixed in the desired ratios and stirred until a clear, uniform blend was obtained.

The functionalization step was carried out by adding epichlorohydrin (ECH) as a cross-linking agent, followed by the dropwise addition of an aqueous trimethylamine (TMA) solution to introduce quaternary ammonium functional groups. The reaction mixture was stirred for 3–4 hours at 70–80 °C. After completion of the reaction, the gel-like product was washed several times with distilled water and ethanol to remove unreacted reagents and byproducts. The resin was then dried at 50 °C in a vacuum oven until a constant weight was achieved.

Characterization Techniques

- Fourier-Transform Infrared Spectroscopy (FTIR): FTIR spectra were recorded using a Thermo Nicolet iS10 spectrometer in the range of 4000–400 cm^{-1} to confirm the incorporation of functional groups;
- Scanning Electron Microscopy (SEM): The surface morphology of the synthesized resins was examined using a JEOL JSM-6390 SEM. Samples were gold-coated prior to analysis;
- Energy-Dispersive X-ray Spectroscopy (EDS): Coupled with SEM, EDS analysis was used to determine the elemental composition of the modified resin and verify the presence of nitrogen atoms from the quaternary ammonium groups;
- Ion-Exchange Capacity (IEC): The IEC of the anion-exchange resin was measured by titration method. A known amount of dry resin was equilibrated with 1 M NaCl solution, and the released chloride ions were

titrated using standard silver nitrate ($AgNO_3$) solution.

Swelling Ratio and Water Uptake:

The water absorption capacity and swelling behavior of the resins were measured by immersing dry samples in distilled water for 24 hours. The swelling ratio was calculated based on the weight difference between the dry and wet samples.

Results and Discussion

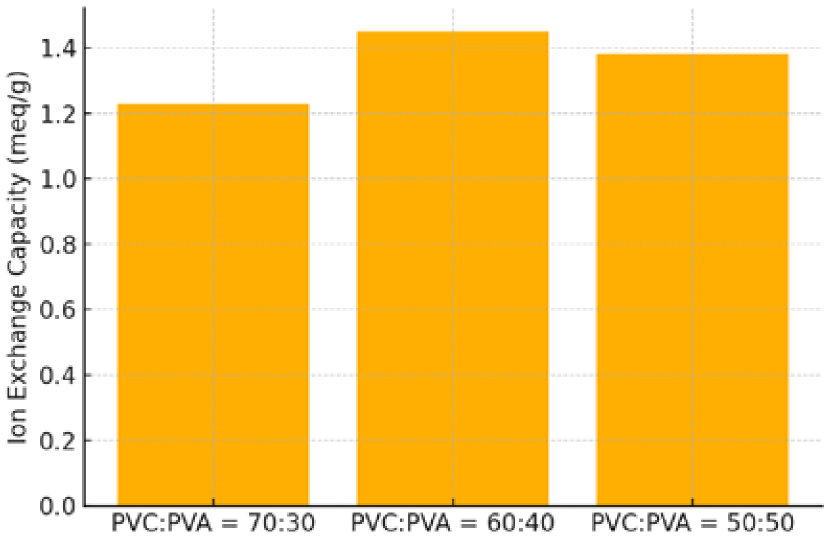
In order to assess the performance of the synthesized PVC–PVA based anion-exchange resins, two key parameters were investigated: Ion Exchange Capacity (IEC) and Swelling Ratio (%). These parameters are critical in evaluating the resin's effectiveness in ion-exchange processes and its physical stability in aqueous environments.

The IEC values of the synthesized resins are presented in Table 1. The resin with a PVC: PVA ratio of 60:40 exhibited the highest ion exchange capacity of 1.45 meq/g, followed by the 50:50 blend (1.38 meq/g) and the 70:30 blend (1.23 meq/g). The higher PVA content likely enhanced the hydrophilicity and accessibility of functional groups, thus improving ion-exchange sites.

Swelling ratio is a measure of how much water the resin can absorb, which correlates with its porosity and functional group accessibility. As shown in Table 2, the 60:40 blend again performed best, achieving a 45.7% swelling ratio, indicating good flexibility and water uptake capacity without structural collapse. The 50: 50 and 70: 30 blends followed with 42.4% and 38.2%, respectively.

The relationship between IEC and swelling behavior is illustrated in Figure 1. The trend confirms that increasing PVA content improves both water uptake and exchange capacity, up to a certain optimum (60: 40). Beyond this point (e.g., 50:50), excess swelling may reduce structural integrity and effective ion transport pathways, slightly lowering IEC.

Figure 1. *Comparison of IEC and Swelling Ratio for Different PVC–PVA Compositions*



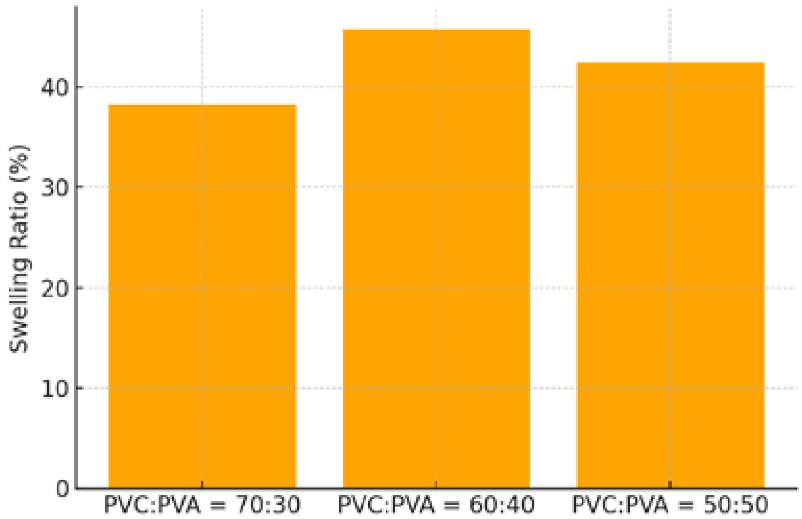
This bar chart illustrates the Ion Exchange Capacity (IEC) of anion-exchange resins synthesized with varying ratios of PVC and PVA: 70:30, 60:40, and 50:50. The results highlight the influence of polymer composition on the functional performance of the resin.

- The PVC: PVA = 70: 30 sample exhibits the lowest IEC, measured at 1.23 meq/g. The higher PVC content, which is more hydrophobic and less functionalized, likely limited the availability of active ion-exchange sites;
- The PVC: PVA = 60: 40 blend shows the highest IEC, reaching 1.45 meq/g. This composition appears to be optimal, as the increased PVA content enhances hydrophilicity and facilitates better exposure of functional groups for ion exchange;
- The PVC: PVA = 50:50 sample demonstrates a slightly lower IEC of 1.38 meq/g compared to the 60: 40 blend. While PVA promotes water absorption and functional group ac-

cessibility, an excessive amount may compromise the structural integrity of the resin matrix, possibly reducing the efficiency of ion exchange.

The chart clearly indicates that the 60:40 PVC: PVA ratio offers the best balance between hydrophilicity and mechanical stability, leading to the most effective ion exchange capacity. This composition can be considered optimal for developing high-performance anion-exchange resins.

Figure 2. *Swelling Ratio (%)*



This chart presents the swelling behavior of PVC–PVA-based anion-exchange resins with varying polymer ratios: 70:30, 60:40, and 50:50. The swelling ratio is a key indicator of a resin's hydrophilicity, flexibility, and structural adaptability in aqueous environments.

- The PVC: PVA = 70: 30 resin shows the lowest swelling ratio at 38.2%. This is expected due to the dominance of hydrophobic PVC, which resists water absorption and limits matrix expansion;
- The PVC: PVA = 60: 40 composition achieves the highest swelling ratio of 45.7%, indicating a favorable balance between polymer flexibility and water uptake. This enhanced swelling suggests greater accessibility of the internal matrix and ion-exchange sites;
- The PVC: PVA = 50: 50 sample exhibits a moderate swelling ratio of 42.4%. While the higher PVA content increases water affinity, excessive swelling could risk over-softening the structure, potentially reducing long-term mechanical durability.

The data indicate that the 60: 40 ratio provides optimal swelling characteristics, ensuring sufficient water absorption without compromising the structural integrity of the resin. This composition offers an ideal trade-off between mechanical strength and hydrophilic behavior, making it suitable for stable, high-capacity ion-exchange applications.

Conclusion

In this study, a series of anion-exchange resins were successfully synthesized by blending polyvinyl chloride (PVC) and polyvinyl alcohol (PVA) in various ratios. The materials were functionalized with quaternary ammonium groups to impart anion-exchange properties, and their physicochemical characteristics were systematically investigated.

The results demonstrate that the composition of the polymer matrix significantly influences both ion exchange capacity (IEC) and swelling behavior. Among the tested formulations, the **PVC: PVA = 60: 40** ratio exhibited the **highest IEC (1.45 meq/g)** and the **greatest swelling ratio (45.7%)**, indicating an optimal balance between hydrophilicity and structural stability. This composition provides superior performance due to enhanced water uptake and functional site accessibility without excessive matrix degradation.

Morphological and elemental analyses (SEM/EDS) further confirmed the incorporation of functional groups and the integrity of the resin structure. FTIR analysis verified the successful introduction of quaternary ammonium functionalities.

Overall, the synthesized PVC–PVA-based resin with a 60:40 ratio presents a promising candidate for application in water treatment and other ion-exchange technologies. Future studies may explore the long-term durability, regeneration efficiency, and application in real-world systems to further validate its industrial potential.

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submitted 08.05.2025;
accepted for publication 22.05.2025;
published 26.06.2025

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