Chapter

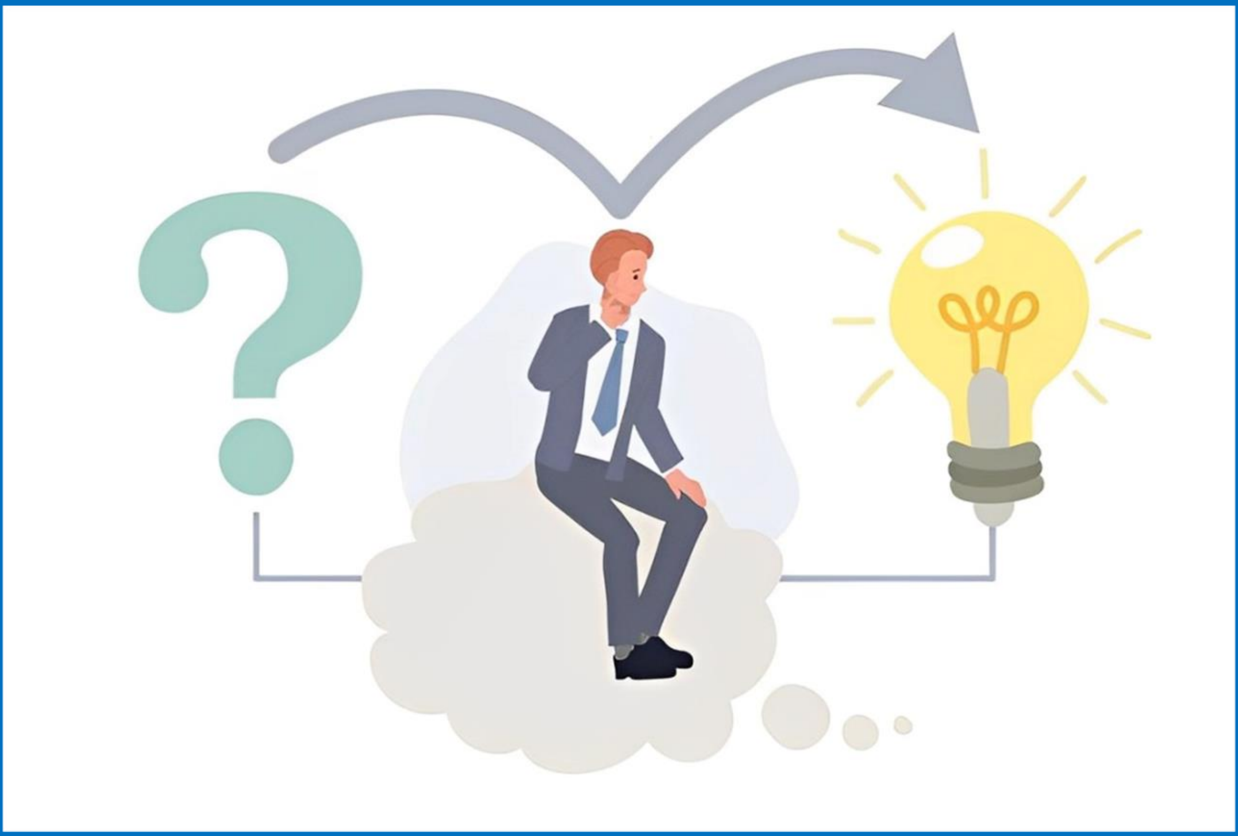
6

Conclusion and Future Scope

Contents

Chapter – 6

Conclusion and Future Scope



6.1 Conclusion

The basic objective of the research was to fabricate the series of membranes that modify the permeability of gases to maintain the selectivities and also fabricate the membranes for carbon capturing application. The improvement of gas transport properties, mainly the permeability which causes the reverse effect on the separation factor. It was aimed to improve selectivity of desired gas pairs with gain in the permeability. Although the novel composite membranes recline within MMM region of Robeson's plots of 1991 and 2008. Researchers are work to develop new composite membranes, however, their working vicinity needs to tend towards the attractive region of the Robeson's plot. For the vast industrial applications, the trade-off parameters must be linearly lifted up towards the commercial interesting region. For this purpose, a unique structural design micro-voids need to be generated within such membranes by variety of ways including thermal rearrangement or polymer intrinsic microscopy. Thus, the integration of various modification techniques may lead the membrane technology for a long-term pilot scale industrial application.

Chapter 1 describes the fundamentals of membrane technology and the literature review. **Chapter 2** provides a detailed description of the various experimental methods use to synthesize and characterize the variety of membranes. Details of the techniques are provided for different characterization methods and their features in **Chapter 2**. A number of changes made during membrane synthesis influences the transport behavior concept that is developing in membrane technology. In **Chapter 3**, it was observed that the permeability of glassy polymers decreases with increasing kinetic diameter of gases. The permeability of the polyimide changes by incorporation of silica nanoparticles, and this was more substantial for all gases. The composition of the silica nanofillers and heat change of the HAB-6FDA coating resulted in remarkable performance. Compared to N_2 and CH_4, the TR nanocomposite has a more significant influence on permeability for softer gases such as CO_2 and O_2. It lies directly across the upper-bound boundary line for the H_2/CH_4 gas pair, which makes the structure a novel type for gas separation polymer material. Silica nanoparticles play a critical role in improving H_2 molecule transport modes in these nanocomposite polyimides. Furthermore, as silica content increases, so does the amount of free space, which improves permeability. The TR process provides a better pathway for penetrants to become soluble in the membrane material, increasing permeability. This novel membrane material removes H_2 from a gas combination and maintains the H_2/CO_2 selectivity. Some of the materials that cross Robeson's 1991 or 2008 upper-bound limit were being developed.

Modified membranes performance in terms of permeability and selectivity for alteration in the transport of hydrogen molecules, in **Chapter 4.1**. Graphene provides greater access to the penetrant to make them soluble in the membrane material, resulting in a higher permeability. The result were plotted for Robeson's 2008 upper bound for nanocomposite membrane separation tends for all of the gas pairs for H_2/O_2 and it is an excellent example of a gas pair whose composition fits perfectly inside the upper bounds for gas separation membrane compositions. The hydrogen bonding between the hydroxyl and carboxyl groups of GO nanofillers and hydroxyl groups of PMMA and PS polymeric matrices has been confirmed by FT-IR measurements of PS/GO and PMMA/GO nanocomposites. For nanocomposite polymer membranes, hydrogen permeability increases dramatically while its selectivity for H_2/CO_2 gas is remains unchanged. The hydrogen molecules have been formed soluble within the membrane matrix for the GO nanocomposite, which creates a new pathway. The modification maintains the selectivity while allowing for the separation of hydrogen from carbon dioxide. The materials used in this **Chapter 4.2** may useful in for food packaging industry. Since, food packaging material must survive transportation, manipulation at supermarkets, and need to arrive in excellent shape to consumers, while retaining the products freshness and shelf life, tensile and impact qualities were tested. According to studies on the permeability of O_2, etherified samples are less permeable in case of PET/PEG-DES/TiO_2 material compared to Amul Milk and Amul Butter Milk bags. The permeability of all membranes for O_2 decreases as the weight percentage of DES/TiO_2 polymer increases in PET/PEG- DES/TiO_2 blend composites. Materials with a PET_{50}/PEG_{50}-DES/TiO_2 blend show the strongest compression force results, which are better than those of PET/PEG blends. Additionally, all blended samples are stiffer than those of pure PEG, with those that include all blends of PET/PEG being the stiffest. Moreover, other characteristics like bending strength and modulus increases, large specific areas and surface-active centers enhance physical or chemical interactions between DES/TiO_2 nanofillers and the polymer matrix of PET/PEG, which improves the more mechanical characteristics as compared to Amul Milk and Amul Butter Milk bags. It has been observed that nanocomposites have synthesized, and nanoparticles dispersed equally throughout the polymer structure. There is harmony between the organic and inorganic phases, compared to PET, the PET/PEG blend samples exhibit much larger phase separation, less phase interference, a higher glass transition temperature and a higher degree of amorphousness. To maintain the quality of chilled packaged food items, this study provides information on the development of heat management polymeric materials that are relevant for food packaging applications. Moreover, the blend composite of PET/PEG-DES/TiO_2 material is more effective for packing material than current packing material that Amul uses.

In **Chapter 5.1**, it is reported that an immense change has been observed in gas permeation and selectivity by membrane modification. The mechanical capacity of PS/PDMS blend ratios are better than those of pure PS polymer. The observation of membrane performances at raised solution temperature in this research advised that decreased macro voids at the bottom section of the membrane should be encouraged since industrial membrane operations needed high operating pressure and temperature. It can be inferred from the results that a blend of rubbery and glassy polymers can combine high permeability among with high selectivity, which may not be adopted by the pure polymer membrane. The permeability steadily increases as the PDMS amount is increases. Moreover, enhanced permeability is due to the improved selectivity of the gas species with the blend membranes. By increasing the PDMS, the final composition tends towards Robeson's upper bound limits of 1991 and 2008 which settles them into a novel category of modified materials. Such combination of materials improved and modified provide the cost-effective performance. In this study, the blending of PDMS and PS possesses various separation and physiochemical properties to obtain excellent outcomes, which may not be achieved by an individual pure polymer. It has been reported to obtain better CO_2 permeability characteristics in a PS/PDMS blend composites with DES/CNT and CNT nanofillers. The permeability of CO_2 increases with percentage of DES/CNT fillers increases, and the composite with CNT nanoparticles provides good nanocomposite processability and high thermal capacity. Concisely, the study regarding blend-composites embedded with DES/CNT improves overall gas transport behaviour compared to that of the virgin blend and composites with CNT nanofillers as were used in previous study of PS/PDMS blends. These voids promote diffusion of gas molecules and finally overall enhances the penetrant transport within the hybrid membrane. Therefore, the improved permeability results due to gain in the diffusion coefficient. On the other hand, solubility faces a small reduction as the filler amount is increases. However, the deterioration of the sorption coefficient does not affect to a large extent on the permeability outcome. By increasing DES/CNT and CNT loading into blend composition separation performance of various gas pairs has inclined to a large extent with increasing the DES/CNT, the optimised composition tends towards Robeson's upper bound limits of 1991 and 2008 which keeps them into the novel category of composite materials.

In **Chapter 5.2**, the implementation of GO and DES into the polymer phase has tuned the transport parameters compared to conventional membranes. Although, in previous study PS/PDMS blend has improved the transport parameters but the additional filler composition has significantly improves physio-chemical factors responsible for gas permeability and selectivity. GO nanofillers stuffing has dramatically improved diffusion of gas species by increasing its weight fraction as it contains active functional groups and tailors nano-channels within the interlayer polymer phase. However, DES has given an outstanding performance as only DES modified fillers composite with the membrane gains the transport parameters than PS-PDMS/GO membrane. The final output can be observed by the Robeson's plots where the blend composite crosses the 2008 boundary. The performance of the membranes for H_2 separation gains attention towards energy as well as industrial applications. Moreover, the highest selectivity has been obtained for CO_2/CH_4 which is applicable for carbon capturing application.

6.2 Future Scopes

Transport routes to the penetrant can be facilitated by using metal oxide nanoparticles, such as MgO and TiO_2, as fillers because of their strong attraction for certain gas molecules and how they interact with them. Therefore, in future contexts, the element of separation may be altered. Moreover, transport routes are enhanced by chemically altered nanofillers. Although the fabricated membranes recline within MMM region of Robeson's plots, they are still applicable in research experiments. However, their working vicinity needs to tend towards the attractive region of the Robeson's plot. For the vast industrial applications, the trade-off parameters must be linearly lifted up towards the commercial interesting region. For this purpose, a unique structural design micro-voids need to be generated within such membranes by thermal rearrangement or polymer intrinsic microscopy. Thus, the integration of various modification techniques may lead the membrane technology for a long-term pilot scale industrial application.

The field of membrane separation for hydrogen permeability has been an area of active research with promising applications in various industries, particularly in hydrogen production, purification, and storage. Membrane separation technologies for carbon capture applications play a crucial role in mitigating greenhouse gas emissions. Looking into the future, several potential directions and advancements can be anticipated in this field.

Enhanced selectivity and permeability, focus on developing membranes with higher selectivity for CO_2 over other gases and improved permeability to enhance the efficiency of carbon capture processes. Material innovation, nanomaterials and nanocomposites explore the use of advanced nanomaterials and nanocomposites to enhance the selectivity and permeability of membranes. This includes materials such as graphene, carbon nanotubes, metal-organic frameworks (MOFs), and novel polymers. Mixed Matrix Membranes (MMMs), investigate the development of mixed matrix membranes, combining traditional polymer matrices with nanoparticles or other materials to create composite structures. This approach can enhance the mechanical and separation properties of membranes. The use of membrane separation techniques to selectively separate hydrogen isotopes (e.g., deuterium and tritium) for applications in nuclear fusion and isotopic studies. Explore integration with complementary technologies, such as adsorption and catalysis, to create hybrid systems that offer improved efficiency and selectivity in hydrogen separation. Selective gas separation, develop membranes with higher selectivity for hydrogen over other gases. This is especially important for applications like hydrogen purification from mixed gas streams. Focus on developing scalable and cost-effective manufacturing processes for high-performance membranes to facilitate large-scale industrial adoption. Investigate smart or responsive membranes that can adapt to changing conditions, providing dynamic control over hydrogen permeability. This could involve stimuli-responsive materials or self-healing membranes. Address environmental concerns related to membrane production and disposal. Develop eco-friendly and sustainable membrane materials and manufacturing processes. Explore new application areas for hydrogen separation membranes, such as decentralized hydrogen production, fuel cells, and emerging technologies like hydrogen-powered vehicles.

Utilize advanced computational modeling and simulation techniques to predict and optimize membrane performance. This can guide experimental efforts and accelerate the development of new membrane materials. Contribute to the establishment of industry standards and regulations for membrane materials and systems, facilitating their integration into existing industrial processes.

As researchers continue to push the boundaries of membrane technology, advancements in these areas could significantly contribute to the broader adoption of membrane separation for hydrogen permeability in various industrial applications and have the potential to significantly contribute to more efficient and sustainable carbon capture solutions for a wide range of industries.