The findings of this study are described in this chapter.

Chapter 1 offers information on the membranes, its classification and brief history for the evaluation of the membranes. It includes the details of polymers used to prepare the synthetic membranes and described the properties of polyethersulfone. This chapter also deals with the various methods of modifications which will help to attain the polymer hydrophilic properties. Different methods for the fabrication of membranes are described in details. Synthesis, sorts and applications of carbon nanotubes are also described in brief. Particularly literature survey of applications of nanotubes in membrane technology is discussed here in detail. Importance and scarcity of water was pointed out worldwide. Due to increasing population and industrialization various toxic ions which are major source of water pollution and their adverse effects on health are described in this chapter. Different techniques which can be used for the water purification and the advantage of membrane based separation technology over other methods have also been incorporated.

In Chapter 2 problems that has caused the present study to be done is described. It gives the scope of the work carried out. The objective of the study is also given in this chapter.

Chapter 3 deals with the experimental procedure used to functionalize multiwalled carbon nanotubes. It gives the experimental route for the preparation of pristine PES as well as f-MWCNT incorporated polyethersulfone mixed matrix membranes. It illustrates the procedure for the sulfonation of PES followed by the production of pristine sulfonated polyethersulfone as well as f-MWCNT incorporated SPES mixed matrix membranes. It also provides the synthetic route for the click reaction between the azide group present on the surface of 1w% Az-MWCNT/PES membrane and terminal alkyne (1-pentyne) for the formation of triazole group on the surface of the membrane. The characterization to ensure the functionalization of nanotubes and sulfonated polyethersulfone were given in this chapter. The evidence against the successful click reaction of the membrane surface is given by X-ray photoelectron spectroscopy (XPS). The chemical, thermal and electrical characterization of all the prepared membranes is discussed in this chapter.

Chapter 4 comprise of the filtration studies of all the prepared membranes. The pure water flux was measured in order to study the permeation behaviour of pure water through the membranes. Heavy metals are the foremost constituent of waste water expelled from industries thus amputation of heavy metals from the contaminated water is an essential field of research in the separation and purification technology. As a matter of our study we have selected Cr(VI), Pb(II), Cd(II), Cu(II) and As(III) heavy metals which are having deleterious effects on human and other creature of the earth. The removal of heavy metal at acidic and neutral pH was studied. The effect of pressure for the removal of heavy metals is also monitored in this chapter. The wastewater collected from Municipal wastewater treatment plant, Vadodara, Gujarat is first analyzed in terms of COD, UV_{254}, TOC, Turbidity, pH, total nitrogen and total phosphorous. Further the wastewater was treated with our membranes and analysis of permeate samples were carried out to find the ability of the membranes to reject contaminants presents in the wastewater. The major inadequacy of membranes is due to the fouling of membranes. Generally protein molecules present in the contaminated water are main cause of membrane fouling. We have selected bovine serum albumin as model protein to study the antifouling behaviour of our membranes.

In Chapter 5 the synthesized membranes are analyzed in terms of their morphology. The morphology of the membranes play crucial role in the permeation of pure water as well as solute permeation. The rejection performance of the membranes are also depends on the morphology of membranes. In this chapter FESEM analysis of surface and cross-section of the membranes is carried out. Atomic force microscopy has been used to observe the roughness parameters of the membranes. The hydrophilicity of the membranes is measured in terms of contact angle. The charge generated on the membranes is quantified using zeta potential analysis. Capillary flow porometry analyzed the pore size of the membranes. Further small angle neutron scattering is used to overcome the limitation of capillary flow porometry (not analyzing the pore size below 100 nm). SANS study has first time been used in our study to explore the morphology of the membranes.

Chapter 6 includes the summary of the work carried out and conclusions which can be drawn from the various studies done throughout the course of this work.

In conclusion, our studies show that the incorporation of nanotubes has resulted in enhancement of all relevant factors like porosity, flux and thermal stability. These studies also highlight that the nanotubes form linked channels which explains the higher flux for those reported in our previous studies as well as in other investigations. The SANS study reported here indicates that there could be alignment of the nanotubes parallel to the membrane surface resulting from the phase inversion process. This observation is also supported by the impedance studies that show enhanced conductivity.

Further this study reports the mixed matrix membranes with higher flux which is due to the better interaction of the functionalized nanotubes and polymer matrix as well as frictionless transport of water through nanotube channels. The nanotubes facilitate the ease of flowing water through the linked channels results in higher rejection as well as enhanced pure water flux. The Azide functionalized nanotubes as fillers serves best results for the removal of toxic metals Cu (II), As (III), Cd (II), Cr (VI) and Pb (II). We are getting highest rejection of Cu (II) i.e.

92.1% from 1 weight % concentration of azide functionalized MWCNT/PES mixed matrix membranes, among all the above mentioned heavy metals.

The use of SPES as membrane matrix has not affected the rejection efficiency of the membranes however hydrophilicity of the membranes is enhanced to a great extent. SANS study revealed that the f-MWCNT/SPES membranes are having bigger pore size than when PES was used as polymeric membrane matrix. However the morphology of membranes cross-section and surface was remained unaltered as examined by the FESEM images. The sulfonate moiety has increased the surface charge of the pristine SPES as well as SPES mixed matrix membranes which supports the increase in hydrophilicity of the membranes. Thus antifouling properties have been improved.

This study also conclude that the surface modification using novel chemistry is possible by introducing suitably functionalized nanotubes into a membrane matrix and also opens up other avenues of using chemical reactions to modify the membrane surface. In this work the well-known click reaction was used to introduce the triazole group to the membrane surface which interestingly enhanced the hydrophilicity of the membrane surface. The triazole group is also a good ligand to complex metals that can influence the rejection of metal ions and at the same time improve the flux recovery ratio.

Future scope

Further conclusive establishment of the alignment of nanotubes needs investigations which should be done. The work regarding the mechanism of membrane filtration performance should be carried out. The membranes selectivity towards the binary heavy metal solution should be examined to study the selectivity of the membranes. Other inorganic fillers such as graphene oxide, modified graphene oxide etc. should be used to examine and compare the efficiency of membranes with membranes having f-MWCNT as filler.