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Research Article

H-ZSM-5 ZEOLITE LOADED SODIUM ALGINATE MIXED MATRIX MEMBRANE FOR PERVAPORATION SEPARATION OF WATER – ISOPROPANOL MIXTURE

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ABSTRACT

Mixed Matrix Membranes of H-ZSM-5 Zeolite incorporated sodium alginate was prepared by solution casting method and crosslinked with glutaraldehyde. The prepared membranes were characterized by Fourier transform infrared spectroscopy, Scanning electron microscopy and Differential scanning calorimetry. Resulting membranes were tested for Pervaporation (PV) separation of water- isopropanol mixtures at 30^0 C. The H-ZSM-5 Zeolite, with its hydrophilic nature as well as molecular sieving effect and its favourable interaction with hydrophilic NaAlg was responsible to enhance the PV dehydration of isopropanol interms of selectivity, flux and pervaporation separation index (PSI). The experimental studies explain that there is an increase in membrane performance such as swelling, permeation flux and water selectivity with H-ZSM-5 content in the membrane. In addition membrane swelling experiments with feed water-composition were performed to understand the PV results.

INTRODUCTION

Pervaporation is a membrane – based process for the separation of liquids by partial vaporization through non-porous membranes. Unlike the conventional distillation where the separation depends on the vapor-liquid equilibrium, the pervaporation separates the liquid mixtures by the difference in the affinity (or solubility) and diffusivity of each liquid component with the membrane. This makes the pervaporation appropriate for breaking up of the azeotropes. In order to achieve a good separation, the membrane must contain the active sites that interact strongly with the separated – species. Taking the dehydration process for example, the membranes usually compose of hydrophilic polymers such as Sodium alginate [1-3] which posses, respectively, the hydroxyl and carboxylic water – attractive pendant groups.

Sodium alginate (NaAlg) is a linear chain structure consisting of (1,4)-linked β-D-mannuronic acid(M) and α-L-guluronic acid (G) residues arranged in block-wise fashion in three different ways: homopolymeric MM blocks, homopolymeric GG blocks and heteropolymeric sequentially alternating MG blocks [4,5]. Alginate is a sodium salt of alginic acid, a naturally occurring non-toxic polysaccharide, which belongs to carbohydrate group of polymers, found in brown algae. The presence of α-L-guluronic acid in various ratios alters the physico-chemical properties of the polymer [6]. In the earlier literature, NaAlg and its modified membranes have been successfully used to separate aqueous – organic mixtures [7-11]. Zeolites are the versatile materials used in a variety of applications including catalytic reactions and adsorbents in hydrocarbon processing. However, in recent years, zeolites have been used as filler particles to form dense mixed matrix membranes that can be conveniently used in pervaporation (PV) dehydration of organic [12, 13]. The hydrophilicity of plain NaAlg membrane is not only the essential factor in dehydration of organics, but also it needs high mechanical strength properties in the presence of water or aqueous-organic media. A good water solubility and poor mechanical strength property of NaAlg membrane has been a major drawback in its usage as a PV membrane. Despite these disadvantages, many studies have been devoted to utilize the modified NaAlg membranes to improve its flux and selectivity to water. Generally, NaAlg has been crosslinked with glutaraldehyde using HCl as a catalyst in acetone solution to develop PV membranes [14].Over the years, the importance of potential use of NaAlg based membranes is greatly increased. Literature findings suggest that the modified NaAlg membranes can extract almost pure water from water + isopropanol mixture [12].

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Now a days there is much attention on preparation of membranes using zeolite as filled mixed matrix or composite membranes for pervaporation application [15]. Ideally, a zeolite particle increases the mobility of component that is more permeable in polymer while decreasing the mobility of component that is less permeable. Zeolite incorporated membranes often increase flux with little decrease in selectivity [16-18]. The mixed matrix membranes offer improved mechanical strength, thermal stabilities and increase separation performance [19, 20] and have been successfully used for separation of aqueous-organic [21,22], organic-organic separations [23,24], gas separation [25,26] and fuel cell applications[27,28].

Isopropanol is chosen in the present study, since it is a very important and commonly used solvent in biopharmaceutical and chemical industries. It is miscible with water in all proportions and forms an azeotrope at 12.5wt % of water. This mixture is hard to be separated by the normal distillation process, but can only be done through azeotropic distillation. However, azeotropic distillation is more energy consuming than conventional distillation. For azeotropic distillation, benzene, a highly carcinogenic and toxic substance is used as an azeotropic dehydrating agent in many plants, making the process health hazardous. In this regard, PV eliminates the use of benzene and the process is more economic than distillation. Table 1 shows energy consumptions required by different separation methods in isopropanol dehydration [29]. In terms of energy requirement, PV is therefore, an alternative choice for water – isopropanol separation.

Table 1 Energy requirements by different separation Processes for isopropanol dehydration

Purification (wt. %)	Energy required (Kj/kg) isopropanol	Process
8-99.5	10,376	Distillation
95-99.5	3,305	Azeotropic distillation
95-99.5	423	Pervaporation

In continuation of our research on pervaporation studies [30-32] our present study is aimed to study by incorporation of H-ZSM-5 zeolite in NaAlg, stable MMMs have been prepared by covalently crosslinking with glutaraldehyde, which would help to reduce the swelling characteristics and induce better mechanical strengths along with thermal stability. Physico-chemical interactions and equilibrium swelling studies of the membranes have been performed to support PV performance of the mixed matrix membranes as compared to plain unfill NaAlg membrane. The results are presented here and discussed in terms of the polymer – particle and polymer- interactions.

MATERIALS AND METHODS

H-ZSM-5 zeolite a gift sample received from Poorna pragna Institute of Research, Bangalore, Sodium alginate (NaAlg) having a viscosity of average molecular weight of 50,000, Acetone and Hydrochloric acid were purchased from S.D fine chemicals, Mumbai. India. Isopropanol was purchased from qualigens fine chemicals, Mumbai, India and glutaraldehyde was purchased from Merck chemicals, Mumbai. Deionised water having a conductivity of 20 µS/cm was used for the preparation of feed solution, which was generated in the laboratory itself.

Preparation of membranes

Membranes were prepared by dissolving 4gm of NaAlg in 100ml of distilled water at room temperature by constant stirring on a magnetic stirrer (Remi Equipment Model 2MLH, Mumbai, India) for 24 hr. To this 4% of NaAlg solution different amounts of 5 & 10 wt % H-ZSM-5 zeolite with respect to weight of polymer were prepared separately and added. Above mixture was stirred for 24 hr in order to get homogenous solution. The resulting solution was mixed thoroughly and then filtered to remove any suspended particles. It was then poured on a clean glass plate leveled perfectly on a table top kept in a dust free atmosphere and dried at the ambient temperature (30°C) to obtain dense non-porous membrane. Dried membranes were peeled off carefully from the glass plate and immersed in cross linking bath containing water: Acetone mixture (30:70) along with 2.5 ml of HCl, 2.5 ml of Glutaraldehyde (GA). After allowing for 12 hrs, the membrane is taken out from the cross linking bath and washed with deionized water repeatedly, then dried in an oven at 60° C to eliminate the residual acid, if any. Membrane thickness was measured by a micrometer screw gauge at different positions on the flat surface of the membrane and the thickness of the membranes were around 35-40 µm. The pristine NaAlg membrane was also prepared in the same manner in the absence of H-ZSM-5 zeolite.

Pervaporation experiments

Pervaporation (PV) apparatus consists of stirred stainless steel cell through which retentate is circulated to the feed tank. Effective surface area of the membrane in the cell is 28.27 cm^2 with a radius of 3.0 cm and volume capacity of the cell is about 250 cm^3. Temperature of the feed mixture is maintained constant using a thermostatic water jacket. The Pervaporation (PV) cell is provided with an efficient three- blade stirrer powered by a DC current motor in the feed compartment. Turbulent flows were obtained even at low rotation of the stirrer, i.e., < 200 rpm speed. Mass transfer limitations due to concentration polarization are negligible. The permeate is collected in a glass container, cooled in a Dewar flask with liquid nitrogen. The vacuum is maintained by a two-stage vacuum pump. The experimental procedure remained the same as reported elsewhere (Misono, 1987). Weight of the permeate vapours collected in a Dewar flask with liquid nitrogen trap was measured and its composition was determined by measuring its refractive index by comparing it with the standard graph of refractive index Vs. mixture composition of the feed system. The selectivity (α), of a given membrane can be estimated by using the following equation (Hung, 1999).

$$\alpha = \left(\frac{Y_A}{1-Y_A}\right)\left(\frac{1-X_A}{X_A}\right) \qquad (1)$$

Where X_A is mole fraction of water in feed and Y_A is the mole fraction of water in permeate. Flux, J (Kg/m^2 h), was calculated from the weight of liquid permeated, W (Kg), effective membrane area, A (m^2) and actual measurement time, t (h)

$$J = \frac{W}{At} \tag{2}$$

Membrane Swelling

The swelling experiments on the circularly cut membranes were performed at 30°C gravimetrically[30] in 5-30wt% water-containing feed mixtures. Membrane samples with compositions ranging from 5 to 30 wt % water at 30°C ± 0.5°C in an electronically controlled incubator (WTB Binder, model BD-53, Tuttilgen, Germany) as per procedures reported previously (Aminabhavi, 1996). Initial weights of the circularly cut (dia=2.5 cm) disc shaped membranes were stored in a desiccators over anhydrous calcium chloride maintained at 30°C for about 24 h before performing the swelling experiments. Mass of the soaked samples were measured using a single-pan Adam digital microbalance (model AFP 210L) having a sensitivity of ±0.01mg. The swollen membranes were weighed immediately after careful blotting to remove surface adhered water. The percent degree of swelling (DS) was calculated as

$$\text{Degree of Swelling (\%)} = \left(\frac{W_s - W_d}{W_d} \right) X\,100 \tag{3}$$

Where W_S and W_d are the mass of the swollen and dry membranes, respectively.

Fourier Transform Infrared Spectroscopy (FTIR) analysis

FTIR Spectra measurements were recorded in the wavelength region of 4000-400 cm^{-1} under a N_2 atmosphere at a scan rate of 21cm^{-1} using Bomem MB-3000 (Make: Canada) FTIR spectrometer, equipped with attenuated total reflectance a (ATR). About 2mg of the sample was ground thoroughly with KBr, and pellets were made under a hydraulic pressure of 600 kg/cm^2.

X-ray diffraction (XRD)

A Siemens D 5000 (Germany) powder X-ray diffractometer was used to study the solid-state morphology of the pristine NaAlg and NaAlg-H-ZSM-5 loaded membranes. The X-rays of 1.5406 A° wavelengths were generated by a Cu Kα radiation source. The angle of diffraction (2θ) was varied from 0° to 65° to identify any changes in crystal morphology and intermolecular distances between inter-segmental chains of the polymer.

Measurement of refractive index

Refractive index, nD for sodium–D line was measured using the thermostatically controlled Abbe Refractometer (Atago 3T, Japan) with an accuracy of ± 0.001. Refractometer was fitted with hollow prism casings through which water was circulated. The experimental Temperature of the prism casing was observed with a digital display (±0.01ºC). The instrument directly gives the values of nD. Permeate composition was determined by measuring refractive index and comparing it with the established graph of refractive index versus mixture composition.

Scanning electron microscopy (SEM)

SEM micrographs of the beads were obtained under high resolution (Mag: 300X, 5kv) Using JOEL MODEL JSM 840A, Scanning electron microscope (SEM), equipped with phoenix energy dispersive. SEM micrographs were taken at Anna University, Chennai.

Thermo gravimetric analysis (TGA)

TGA curves of blend membranes of different compositions were recorded using TA instruments differential scanning calorimeter (Model – SDT Q600, USA).The analysis of the samples was performed at heating rate of 10°C/min under N_2 atmosphere at a purge speed of 100 mL/min.

RESULTS AND DISCUSSION

SEM studies

The homogeneous distribution of H-ZSM-5 particles in NaAlg matrix was further explored by performing surface SEM experiments. The typical surface SEM images of pristine NaAlg membrane and 10 wt. % H-ZSM-5zeolite filled NaAlg-mixed matrix membrane are shown in fig.1. Comparing these two SEMs it is noticed that that H-ZSM-5 zeolite particles are uniformly distributed in the NaAlg matrix. Such a homogeneous mixing of H-ZSM-5 is attributed to hydrophilic nature of zeolite with a lower silica alumina ratio value and this presence is responsible to create channels between interface of polymer and zeolite particle surfaces that are more selective to water than IPA. It is important to have uniform dispersion of particles in the NaAlg matrix to exhibit enhanced effects of flux and selectivity during PV dehydration experiments.

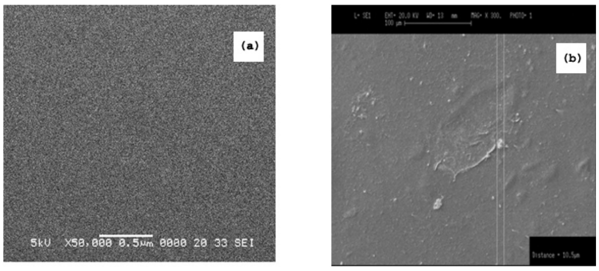


Fig.1 SEM photo graphs of (a) virgin NaAlg and (b) 10 wt% H-ZSM-5zeolite filled NaAlg Mixed Matrix Membrane

FTIR studies

The IR measurements were performed in attenuated total reflectance (ATR) model as the polymeric complex membranes were in film form. All the samples were analyzed before and after heat treatment. Fig.2 shows FTIR Spectra of uncross linked NaAlg membrane (a), cross linked NaAlg membrane (b) and those of different amounts: 5 wt % (c) & 10 wt % (c) of H-ZSM-5 zeolite loaded membranes respectively. From curve 2 (a) the peak observed at 3420 cm^{-1} corresponding to O–H stretching vibrations of the hydroxyl group of NaAlg. The strong bands appeared at around 1620 and 1416 cm^{-1} are assigned, respectively, to anti symmetric and symmetric COO stretching vibrations of the carboxyl group of sodium alginate [30]. In the curve 2 (b) a peak at 3390cm^{-1} conforming the utilization of O-H groups during cross linking. The sharp peak appeared at 1250 cm^{-1} assigned to the formation of an acetal ring and ether linkage as a result of the reaction between the hydroxy group of alginate and the aldehyde groups of Glutaraldehyde (as per the scheme shown in scheme 1).

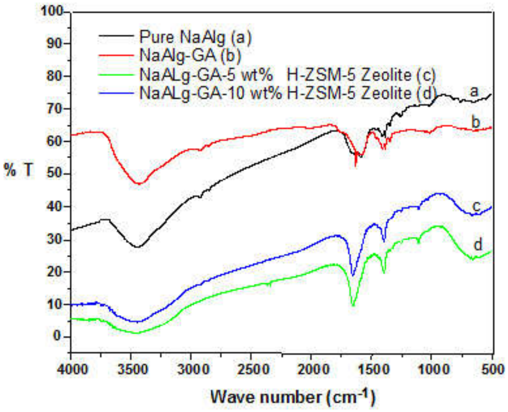
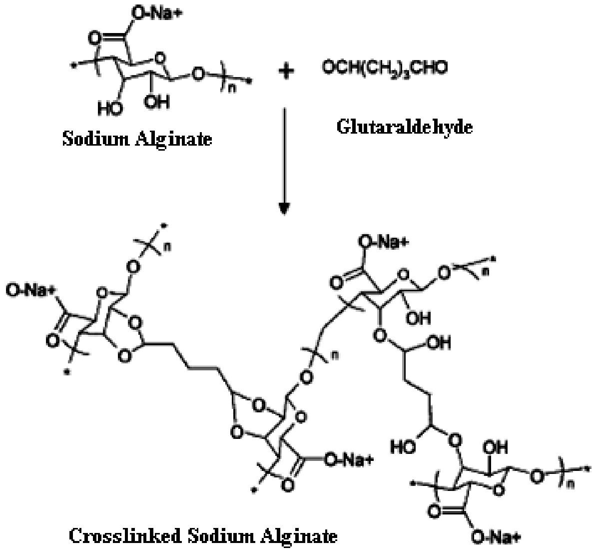


Fig.2 FTIR spectra of pristine NaAlg membrane (a), crossed NaAlg membrane(b), 5 wt % H-ZSM-5zeolite filled NaAlg (c) and 10 wt % H-ZSM-5zeolite filled NaAlg membrane (d)



Scheme 1 Schematic chemical structure of crosslinked SA.

The intensity of these bands did not change upon loading different amounts of zeolite in polymer matrix, indicating that OH and COO groups of SA are not involved in bond formation with the zeolite. In addition, a strong peak appeared at around 1100 cm^{-1} is assigned to C–O stretching of SA. The Si–O band [31] also appeared at the same wavelength upon loading zeolite in the polymer matrix and hence, C–O and Si–O bands are almost overlapping in the spectra. Upon increasing the zeolite loading, the intensity of Si–O band was increased in the spectra from 5 wt % to 10 wt % zeolites. This ascertains the complete dispersion of zeolite in the sodium alginate membrane.

Mechanical properties

The tensile strength and elongation break of a membrane often determines its suitability for Pervaporation applications. Therefore to demonstrate the effect of H-ZSM-5 content on the mechanical properties of pure NaAlg and zeolite filled membranes are measured.

The values of Tensile strength and elongation break of 5 wt % and 10 wt.% ZSM-5zeolite-loaded NaAlg membranes as well as pristine NaAlg membrane in dry state given in Table 2 from the data, it is observed that mixed matrix membranes exhibit higher tensile strengths than the pristine NaAlg. Hence, the present membranes are stable and so far to use in Pervaporation runs. These values varied, depending upon the filler loadings. The enhancement is attributed to the interaction of filler particles with NaAlg matrix. NaAlg chains in the presence of zeolite filler particles will experience a restriction in chain segmental mobility, resulting in an increase of rigidity or tensile strength, thereby reducing elongation at break. Such enhancement will be more pronounced for 5 wt % and 10 wt % H-ZSM-5 zeolite loaded mixed matrix membranes than the pristine NaAlg membrane. However, the H-ZSM-5zeolite loaded mixed matrix membranes exhibited high-mechanical strength due to higher interaction/ compatibility with NaAlg matrix. It is evident that with increase of zeolite concentration the tensile strength also increases and is clear from the results given in table 2.

Table 2 Tensile strength and % elongation at break of pristine NaAlg- and H-ZSM-5 zeolite-filled NaAlg mixed matrix membranes

Membrane type	Tensile strength (N/mm2)	Elongation at break (%)
NaAlg	21.01	8.1
5 wt.% of H-ZSM-5zeolite + NaAlg	63. 37	5.9
10 wt.% of H-ZSM-5zeolite + NaAlg	90.13	3.6

TGA studies

The thermo gravimetric analysis of crosslinked SA and ZSM-5 zeolite filled SA membranes are determined and discussed here. Fig.3 shows the TGA thermograms of crosslinked NaAlg (3.a) and 5 wt % and 10 wt % H-ZSM-5 zeolite filled NaAlg (3.b and 3.c) respectively. These curves showed the thermal stability of the system under study. Thermal stability refers to the weight of zeolite in the mixed matrix membrane and the temperature at which 50% weight loss (i.e., 5 wt % H-ZSM-5 shows at 260 ^{0}C whereas i.e., 10 wt.% H-ZSM – 10 at 290 ^{0}C.). Figure.3 illustrates the weight loss of sodium alginate zeolite composite membranes as a function of temperature. From the Fig.3 it is also noticed that the stability of MMMs in the present study is in the following order NaAlg –GA -10 wt % H-ZSM-5 > NaAlg –GA -5 wt % H-ZSM -5 > NaAlg –GA-0 wt % H-ZSM -5.

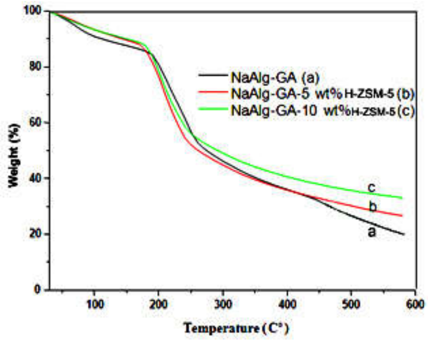


Fig. 3 Thermograms of crosslinked NaAlg (a), 5 wt % H-ZSM-5 zeolite filled NaAlg (b) and 10 wt % H-ZSM-5 zeolite filled NaAlg (c) membranes.

The weight losses of these membranes indifferent temperature regions are associated with the splitting of the main chain and the final decomposition of the polymer. The above trend is attributed to increasing order of thermal stability from NaAlg-0 to NaAlg-GA-10wt % membrane due to zeolite loaded.

This is clearly evident that the increase in the thermal stability of pristine NaAlg with an increase in zeolite loading is due to the adsorption of polymer chains on the zeolite surface. These adsorbed polymer chains on a zeolite surface form a complex and the polymer chains which are away from the activated surfaces degrade faster. The adsorbed polymer chains hinder the diffusion of volatiles from the polymer resulting in the enhancement of thermal stability of NaAlg membrane. It is also observed that wt% residue after thermal decomposition of the matrix at 500 ^{0}C is high and it is in the order NaAlg-GA-10 wt%. H-ZSM-5 membrane >NaAlg-GA-5wt % H-ZSM-5 membrane >NaAlg-GA-0 wt%. H-ZSM-5 indicating the presence of H-ZSM-5 filler in the NaAlg matrix, same filler remains intact even at this temperature.

Pervaporation studies on water-Isopropanol separation

Membrane swelling studies

The swelling parameters can be controlled by modifying the pristine NaAlg membrane with the addition of hydrophilic H-ZSM-5zeolite filler. In the presence of zeolite the hydrophilic nature of NaAlg will be enhanced due to the more adsorption molecules of zeolite membrane. This situation is more favourable for higher selectivity of water compared to organic mixtures. In general the dielectric constant of the solvent plays an important role in interacting with the membrane. In addition, the nature of filler particles, polymer and mixed matrix membranes are equally important to induce improved performance of the membrane. Degree of swelling with pristine NaAlg and mixed matrix membrane are shown in Fig.4 in case of water-Isopropanol mixture.

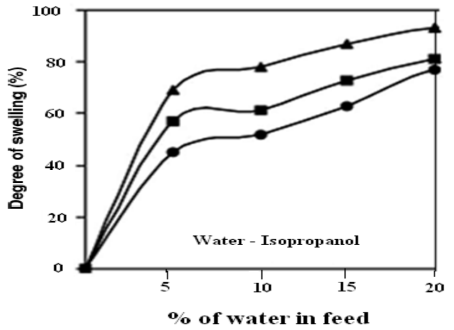


Fig.4 Degree of swelling of membrane vs. wt % of water in the feed. Symbols: (●) Prisitne NaAlg; (■) 5 wt % H-ZSM-5zeolite filled NaAlg-mixed matrix membranes; (▲) 10 wt % H-ZSM-5zeolite filled NaAlg-mixed matrix membranes.

When 5 wt % of ZSM-5 zeolite is loaded and it leads to the uniform spreading of zeolite in the mixed matrix membrane. Such a matrix is likely to absorb more of water molecules as compared to unfilled NaAlg matrix. However, at higher filling of zeolite, if feed i.e., (20 mass %), the degree of swelling would be higher because of the filler particles will help the hybrid matrix to absorb more of water molecules. The higher swelling in zeolite filled membranes compared to pristine membrane is due to the result of performance interaction of water molecules which would accommodate higher amount of water than Isopropanol. This could be possibly due to: (i) Vaporization on the permeate side, (ii) Strong adsorptive hydrophilic interaction of water molecules onto H-ZSM-5zeolite particles and (iii) Surface diffusion from cage to cage. Physical adsorption involves both vanderwaals type dispersion-repulsive and electrostatic interactions due to polarization, as well as dipole and quadrupole type interactions. The complimentary effects of molecular sieve on water transport would thus improve the membrane performance.

Membrane performance on Flux and Selectivity

PV performances of pristine NaAlg, 5 wt % and 10 wt % H-ZSM-5 zeolite mixed matrix membranes have been studied by calculating flux, selectivity, pervaporation separation index and enrichment factor and mass % of water in the permeate for water + isopropanol mixture at 30^{o}C and the values are presented in Table 3.Figures 5,6 and 7 shows the variation of flux, selectivity and mass % water in permeate with mass % of water in the feed for different wt % of zeolite particles into NaAlg matrix respectively. The addition of H-ZSM-5 zeolite particles in to NaAlg membrane led to the better improvement of membrane performence over that of pristine NaAlg membrane. H-ZSM-5 zeolite being hydrophilic would adsorb large quantity of water in the pores by restricting the transport of organic components. This effect was more pronounced due to the adsorptive nature of the filler zeolite particles. Flux results show that the values are higher for zeolite filled membranes compared to pristine NaAlg. This may be due to increased hydrophilicity of H-ZSM-5zeolite. A somewhat stronger interaction between hydrophilic H-ZSM-5 zeolite particles and water seem to render more of water molecules to readily transport across the membrane compared to organic component. With high concentration of H-ZSM-5 zeolite, flux increased and selectivity decreased due to increased hydrophilicity of zeolite in the NaAlg matrix. However, compared to pristine NaAlg membrane, H-ZSM-5mixed matrix membranes have shown unique permeation trends due to (i) adsorption and diffusion of liquid molecules through the molecular sieve pores and (ii) transport along the boundaries between molecular sieve crystals and of the NaAlg segments. The former process would play a dominant role, since H-ZSM-5 loaded NaAlg membrane would form a good adhesion, whereas the latter will become dominant when H-ZSM-5–polymer interface is poor [32].

Effect of feed water composition

The feed concentration is one of the most important operating factors of a membrane separation process as show in Fig 7. The Table 3 gives the Pervaporation results of H-ZSM-5 zeolite filled NaAlg membrane for water isopropanol mixtures at 30^{o}C. Permeation flux increases with increasing water content of the feed, which is caused due to higher concentration of water molecules within the membrane. At the same time, wt % of water in permeate line and selectivity values decreased for all the water - isopropanol mixtures of this study. There is a two-fold increase in the permeation flux for water- isopropanol mixtures because of the hydrophilic nature of the zeolite used and its interaction with NaAlg matrix. For all the feed mixtures, flux values of H-ZSM-5 zeolite-loaded NaAlg membranes are higher than that of the pristine NaAlg membrane the increase in permeation flux for water–isopropanol mixture is purely due to

Table 3 Pervaporation results of H-ZSM-5-zeolite filled NaAlg membrane for water-Isopropanol mixtures at 30^{o}c.

Sl. No.	Mass% of water in the feed	Water flux Kg/m2h	Selectivity (α)	Mass% of water in the permeate	PSI	Enrichment factor (β)
0% H-ZSM-5-zeolite filled NaAlg Membrane:						
1	10	0.047	678.00	98.69	31.90	14.09
2	15	0.061	342.00	98.37	20.88	9.37
3	20	0.077	222.00	98.23	16.97	7.02
4	25	0.094	145.00	97.97	13.45	5.59
5	30	0.104	96.00	97.63	9.92	4.65
5% H-ZSM-5-zeolite filled NaAlg Membrane:						
1	5	0.208	6766.71	99.72	1410.89	19.94
2	10	0.287	1627.36	99.45	466.08	12.43
3	15	0.300	760.09	99.26	227.49	6.71
4	20	0.315	356.36	98.89	111.14	4.77
10% H-ZSM-5-zeolite filled NaAlg Membrane:						
1	5	0.222	14596.38	99.87	3252.28	19.97
2	10	0.246	1905.89	99.53	469.30	12.44
3	15	0.259	711.63	99.21	183.28	6.70
4	20	0.278	334.98	98.82	92.43	4.77

an increase in thermodynamic interactions between water and isopropanol.

Membrane performances were also studied by Pervaporation Separation Index (PSI) and Enrichment factor (β) data. These results displayed in Table 3. From these results it is noticed that PSI and β values follow a decreasing trend with increasing amount of water in the feed. The β values of all the membranes decreasing systematically with an increasing composition of water in the feed. The value of PSI also follows as same trends as those of β. The % of water in permeate decreases with increase of mass % of water in feed. It is also observed that the % of water in permeate also increase with increase in zeolite concentration in the membrane. The pristine membrane % of water in the permeate is less than the zeolite filled membranes.

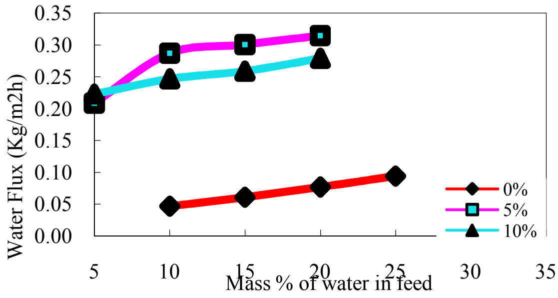


Fig.5 Water Flux Vs Mass % of water in feed for various percentages of H-ZSM-5 zeolite filled NaAlg membrane for water Isopropanol mixtures at 30^{o}C

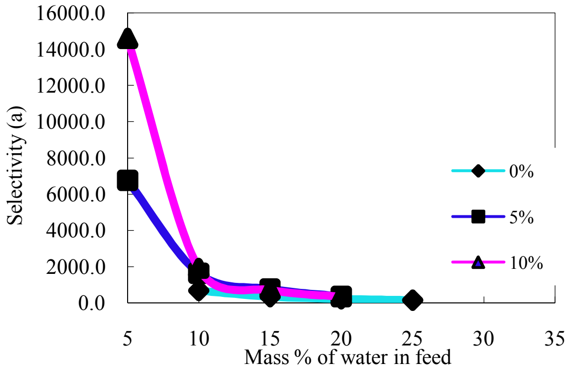


Fig.6 Water Selectivity Vs Mass % of water in feed for various percentages of H-ZSM-5 zeolite Filled NaAlg membrane for water Isopropanol mixtures at 30 ^{0}C

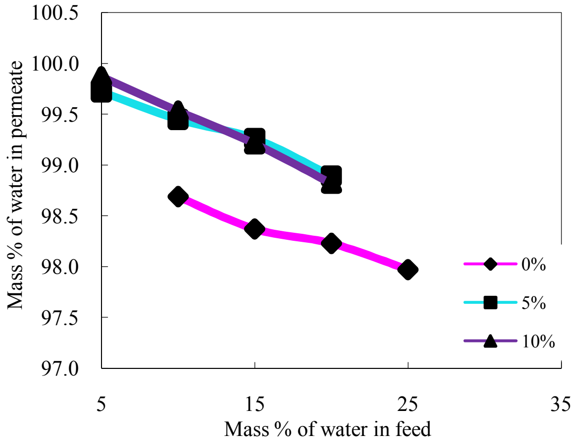


Fig.7 Mass % of Water in permeate Vs Mass % of water in feed for various percentages of H-ZSM-5 zeolite filled NaAlg membrane for water Isopropanol mixtures at 30^{o}C

CONCLUSIONS

Mixed matrix membranes exhibited higher or improved performances than the pristine NaAlg membrane in the PV dehydration of ethanol and isopropanol. Zeolite forms the hybrid mixed matrix with NaAlg, which exhibited an improved PV performance. Selectivity and flux values of 10 wt % H-ZSM-5 zeolite incorporated NaAlg mixed matrix membrane were superior as compared to lower amount of zeolite incorporated NaAlg membranes. This could be due to increased hydrophilicity as a result of more number of zeolite particles in 10 wt% H-ZSM-5 zeolite filled NaAlg. However, molecular sieving effect, selective sorption/adsorption by the filler particles as well as the selective diffusion increased the mobility of the preferentially permeating water molecules in the mixed matrix membranes. The present experimental data suggest that zeolite filled NaAlg mixed matrix membranes can be employed successfully in PV-aided method.

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