

# Removal of Pyridine from Water by Pervaporation Using Crosslinked and Filled Natural Rubber Membranes

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**ABSTRACT:** Natural rubber (NR) of grade RSS4 was efficiently cured (crosslinked) by using sulfur: accelerator weight ratio of 1 : 4. This was further compounded with high abrasion grade carbon black filler (grade N330) with three different doses, that is, 5, 10, and 20 wt % of rubber to form three different filled and crosslinked membranes designated as NR5, NR10, and NR20, respectively. These filled rubber membranes and one unfilled but efficiently cured membrane, that is, NR0, were used for pervaporative removal of low concentration of pyridine from water. The filled membranes were found to show higher pyridine

selectivity but lower flux than the unfilled membrane. All of these membranes showed reasonably good range of flux and pyridine selectivity. Among all of the used membranes, NR5-filled membrane yielded high pyridine selectivity (122) with reasonable thickness normalized flux ( $2.2 \text{ kg m}^{-2} \text{ h}^{-1} \text{ m}\mu$ ) at  $40^\circ\text{C}$  for 0.5 wt % of pyridine in water. © 2011 Wiley Periodicals, Inc. *J Appl Polym Sci* 124: E99–E107, 2012

**Key words:** filled rubber membranes; crosslinking; efficient vulcanization system; pervaporation; selectivity

## INTRODUCTION

Pyridine is an important solvent and catalyst. It is frequently found in effluents from rubber and plastics, petrochemicals, and some other organochemical industries such as pharmaceuticals and agrochemicals. The recovery of pyridine from outflow is an important problem because it is often necessary to reuse relatively expensive chemicals. Pyridine also forms azeotropic point with water at 58.7 wt % at  $93.6^\circ\text{C}$ .<sup>1</sup> In recent times, many researchers are working on the separation of pyridine–water mixtures by an energy-intensive and environment-friendly separation process like pervaporation (PV).

PV is a membrane-based separation process used for dehydration of organics, organic–organic separation, and removal of traces of organics from water. The removal of low concentration of organics like pyridine from water demands a highly selective organophilic membrane because separation becomes more difficult as the concentration of organics decreases in water.<sup>2</sup> Thus, most of the works on pervaporative separation of pyridine–water mixtures report removal of water from pyridine by using

hydrophilic membranes made from glassy polymers such as polyvinyl alcohol,<sup>2</sup> chitosan,<sup>3</sup> sulfonated<sup>4</sup> or carboxylic ion exchange polymers,<sup>1</sup> or copolymer of acrylonitrile.<sup>5</sup> However, the removal of low concentration of pyridine from water using a pyridine-selective membrane is very significant considering hazardous nature of this organic chemical. Various organophilic membranes made from elastomers such as styrene–butadiene rubber (SBR),<sup>6</sup> polydimethyl siloxane (PDMS) rubber,<sup>2</sup> silicalite-filled silicone composite membrane<sup>7</sup> and thermoplastic elastomers such as poly(ether-*block*-amide)<sup>8</sup> were reported on the removal of pyridine from water using PV technique. Elastomeric membranes used for pyridine removal shows poor selectivity because of high water permeation. In most of the cases, the poor selectivity of elastomeric membranes in comparison with other nonrubber polymers is associated with its poor crosslinking. The selectivity of these rubber membranes can be improved by “efficient vulcanization” using more accelerator than sulfur (accelerator: sulfur > 1)<sup>9</sup> and also by filling with suitable filler such as organophilic N330 grade carbon black filler.<sup>10</sup> Earlier, these efficiently vulcanized and filled natural rubber (NR) membranes were used for pervaporative separation of organic–organic mixtures, that is, mixture of toluene and methanol with encouraging results.<sup>9,10</sup> However, most of the organophilic rubber membranes cannot be used for this kind of organic removal from water because of much higher diffusion rate of water molecule through rubber membranes. Crosslinked PDMS membranes when tried

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for removal of piperzine from its aqueous solution<sup>11</sup> resulted in water permeation although the membrane showed preferential piperzine sorption. Among the various elastomeric membranes efficiently cured, unfilled and filled SBR membranes were reported to yield high pyridine selectivity with a reasonable flux.<sup>6</sup> In the current work, unfilled and filled NR membranes with similar state of curing and filler loading (unfilled NR0 and filled NR5, NR10, and NR20 containing 5, 10, and 20 wt % of N330 carbon black filler, respectively) were used for the removal of low concentration of pyridine (0.48–9.79 wt % of pyridine in water) from water.

## EXPERIMENTAL

### Materials

NR of grade RSS4 was obtained from M/S Tyre Corporation (West Bengal, India). Carbon black filler of N330 grade and zinc diethyldithiocarbamate (ZDC), an ultrafast room temperature curing accelerator, were also supplied by the same company.

### Preparation of PV membranes

The rubber (NR) was masticated and swelled in toluene for 24 h followed by addition of required amount (5, 10, and 20 wt % of NR) of carbon black in portions with mechanical stirring of the dispersion for 24 h. Sulfur (crosslinker, 1.5 wt % of NR) and accelerator (6 wt % of NR) were then added, and the dispersion was stirred for another 8 h. From this, rubber dispersion membrane was cast on a smooth and clean glass plate and it was air dried overnight at ambient condition. This air-dried rubber membrane was then cured (cross-linked) in a hot air oven at 110°C for 40 mins. The cured membrane on glass plate was then cooled by immersing the glass plate in cold water. The cured membrane was then peeled out from water. The thickness of the membrane was then measured at its different regions with a thickness gauge. The average thickness of the membranes used for PV study was ~ 50  $\mu$ m.

### Permeation studies

The preparation and characterization of these filled membranes have been reported elsewhere.<sup>9,10</sup> PV experiments of pyridine–water mixtures with these filled rubber membranes were carried out in a batch-stirred cell<sup>9</sup> with adjustable downstream pressure that was maintained at 1 mmHg by liquid (mercury) column method using a manometer. The feed compartment of the PV cell was equipped with a stirrer to ensure adequate mixing of the liquid

feed so as to eliminate any concentration or temperature gradient. Effective membrane area ( $A$ ) in contact with the feed mixture was 19.6 cm<sup>2</sup>, and the feed compartment volume was 150 cm<sup>3</sup>. The pyridine–water mixtures in contact with the membrane were allowed to equilibrate for around 3 h for the first experiment and for 1 h for the subsequent experiments with different feed concentrations. When the steady state was reached, the permeate was collected in traps immersed in liquid nitrogen. Permeation flux ( $J$ ) was calculated by dividing the amount of total permeate ( $W$ ) by the time ( $t$ ) of experiment and area of the membrane ( $A$ ) according to the following equation:

$$J = \frac{W}{At} \quad (1)$$

The PV experiment was performed at a constant temperature by circulating constant temperature water around the jacket of the PV cell. The water content of the permeate was determined by an Abbe-type digital refractometer (model. Abbemat-HP, Anton Paar, Austria) at 25°C for all the samples. The pyridine selectivity of the membranes was evaluated in terms of separation factor ( $\alpha_{PV}$ ) according to the following equation:

$$\alpha_{PV} = \frac{\frac{y_{\text{Pyridine}}}{x_{\text{Pyridine}}}}{\frac{y_{\text{Water}}}{x_{\text{Water}}}} \quad (2)$$

Here,  $y_i$  and  $x_i$  are weight fraction of component  $i$  (pyridine or water) in permeate and feed, respectively.

The performance of the membrane was also evaluated in terms of another two important parameters, that is, permeation separation index (PSI) and enrichment factor ( $\beta$ ) as obtained from the following equations:

$$\text{PSI} = J_P(\alpha_{PV} - 1), \quad (3)$$

$$\beta = \frac{y_{Py}}{x_{Py}} \quad (4)$$

Here,  $J_P$  is partial flux of pyridine from the membrane and  $y_{Py}$  and  $x_{Py}$  are permeate and feed concentration of pyridine, respectively.

The effect of one component on permeation of the other component at different feed pyridine concentrations was quantitatively expressed in terms of permeation factor<sup>6</sup> ( $\theta$ ) as a measure of the deviation of the actual permeation rate,  $J_{\text{expt}}$ , from the ideal rate,  $J^0$ , to explain interactions between membrane polymer and permeants as described in the

following equations:

$$\theta_i = \frac{J_{i \text{ expt at } x_i}}{J_{i \text{ expt at } x_i}^0} \quad (5)$$

$$J_i^0(\text{at } x_i) = J_{(\text{pure } i)}^0 \times x_i. \quad (6)$$

## RESULTS AND DISCUSSION

### Choice of rubber, accelerator, filler, and vulcanization

#### Rubber

NR is an easily available elastomer that is extensively used in rubber industries for making various products such as tyre, tubes, cable, and different molded products. The objective of this study was to synthesize an organophilic membrane from an easily available low-cost polymer. Thus, for this study, unfilled and filled membranes were prepared from NR. Among the various grades of NR, RSS4 was chosen because it contains the lowest percentage of nonrubber impurities.<sup>12</sup>

#### Accelerator

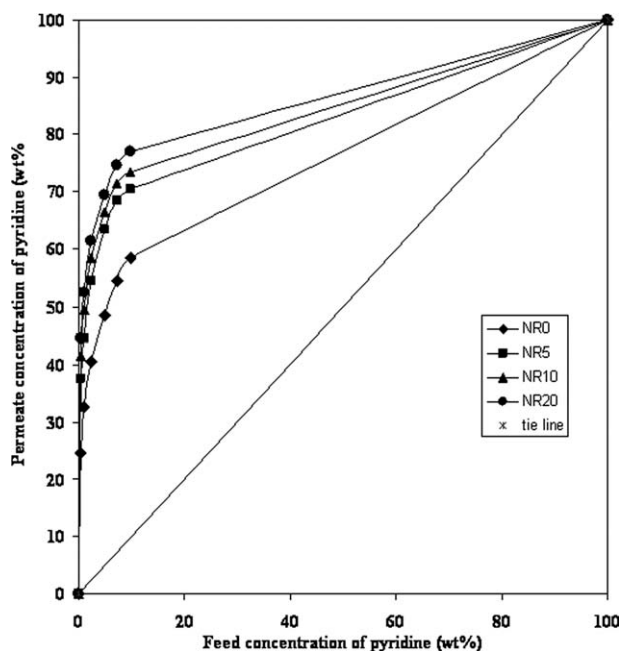
ZDC was chosen as an accelerator because it is an ultrafast curing accelerator effective even at ambient condition.<sup>12,13</sup> It also yields monosulfide linkage between rubber chain molecules during curing, which is required for getting increased selectivity of the resulting membrane.

#### Filler

Carbon black filler was chosen because it is known to provide better reinforcement and physical crosslinking than any other nonblack filler. Among the various grades of carbon black fillers, furnace grade N330 was chosen for this study because of its very small particle size (30–45 nm) and high structure.<sup>12</sup>

#### Vulcanization

The curing or crosslinking of rubber with sulfur and accelerator is called vulcanization. The state of curing significantly influences permeation mechanism through a rubber membrane. The state of curing of a membrane depends on the type of vulcanization (curing) reactions. Efficient vulcanization with accelerator (sulfur ratio > 1) was used for this study because it gives more monosulfide linkages between rubber chains than polysulfide or cyclic sulfur linkages.<sup>13</sup> Monosulfide linkages offer more resistance to chain mobility of rubber molecules than polysulfide linkages. Hence, selectivity of the membrane crosslinked with efficient vulcanization increases because of restricted flow. Thus, efficient vulcanization sys-



**Figure 1** Variation of permeate concentration of pyridine with its feed concentration at 40°C for NR membranes.

tem was chosen for the current study to obtain rubber membranes with increased selectivity.

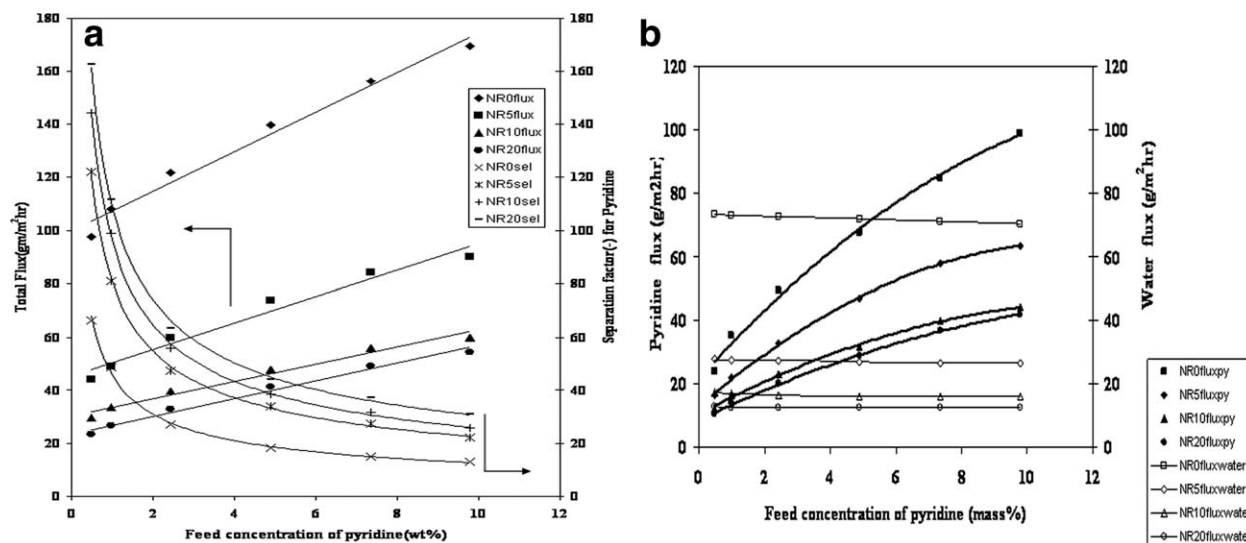
### Permeation studies

#### Effect of feed concentration on pyridine separation

Figure 1 shows the variation of weight percent of pyridine in permeate against weight percent of pyridine in feed for separation of pyridine from water with NR0, NR5, NR10, and NR20 membranes at 40°C. It appears from these McCabe-Thiele-type  $xy$  diagrams that the filled NR membranes show high pyridine separation over the used concentration separation range (0.48–9.79 wt % of pyridine in feed) without any pervaporative azeotrope. It is also seen that for the same feed concentration, the separation characteristic of the membranes increases from NR0 to NR20 with increasing filler loading. All of the above membranes have similar state of chemical crosslinking because of similar accelerator: sulfur ratio used for curing all of these membranes. However, with increasing filler, loading extent of physical crosslinking increases from NR0 to NR20 resulting in the above order of separation characteristic.

#### Effect of feed concentration on flux, selectivity, PSI, and enrichment factor

**Flux and pyridine selectivity.** Figure 2(a) shows the effect of feed concentration of pyridine on total flux and pyridine selectivity for NR membranes at 40°C. From this figure, it is seen that with the increase in pyridine concentration in feed, total flux increases

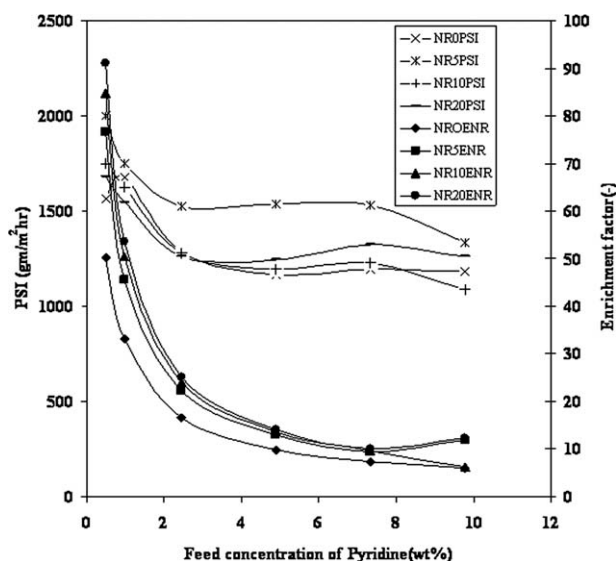


**Figure 2** Variation of (a) total flux and selectivity and (b) partial flux with feed concentration at 40°C for NR membranes.

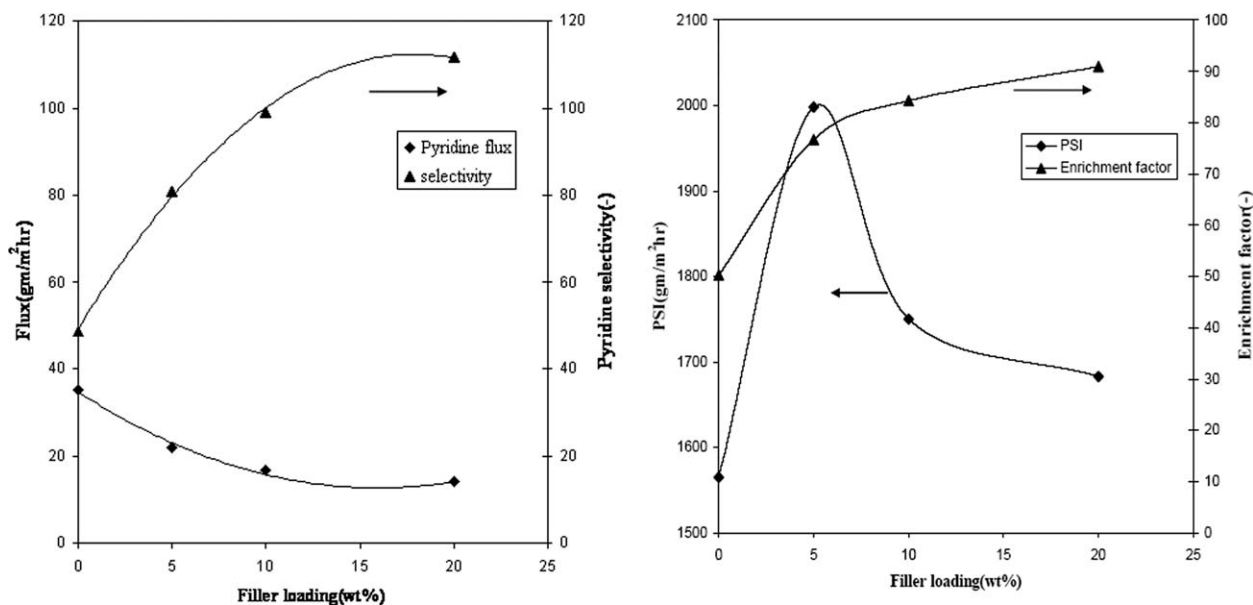
linearly (regression coefficient  $> 0.95$ ), whereas selectivity for pyridine decreases drastically with a power regression (regression coefficient  $> 0.95$ ). Variation of partial water and pyridine flux with feed concentration of pyridine is shown in Figure 2(b). From this figure, it is observed that partial pyridine flux increases linearly at lower feed concentration for all the membranes. At higher feed concentration, the feed versus partial flux plot for pyridine is no longer linear (the slopes are not constant, and overall, the plots show a polynomial trend with degree of freedom 2) signifying plasticization of the membranes. It is interesting to note that partial water flux remains marginally constant over the used concentration range. It is also observed that at the lowest feed concentration, partial water flux of all the membranes are higher than its partial pyridine flux. However, all of the membranes still maintain a measurable pyridine selectivity [Fig. 2(a)] because of very low concentration of pyridine in feed ( $\sim 0.5$  wt %) that increases manifold in the permeate ( $\sim 25$ – $45$  wt % of pyridine). As the feed pyridine concentration increases further, the organophilic membranes yield higher pyridine flux than its water flux signifying organic selectivity of the membranes.

**PSI and enrichment factor.** In Figure 3, PSI and enrichment factor for pyridine is plotted against its feed concentration at the same temperature. The separation potential of a membrane is expressed in terms of flux and selectivity that bears a “trade off” relationship, that is, when one factor increases, the other decreases. PSI combines both flux and selectivity in one equation [eq. (3)]. It is observed from Figure 3 that the membranes show very high PSI (much above 1000) over the entire range of feed concentration. It is also observed that the filled mem-

branes show much higher PSI than the unfilled NR0 membrane, that is, decrease in flux by filler incorporation is more compensated than by increase of selectivity in these filled membranes. Among all the membranes, NR5 shows the highest PSI and hence may be considered as the best membrane showing optimum performance in terms of flux and selectivity over the entire feed concentration range. Preferential permeation of pyridine through the organophilic membranes is also evident from the values of enrichment factor, that is, ratio of permeate concentration of pyridine to its feed concentration as shown in Figure 3. Enrichment factor of the membranes is also observed to increase from NR0 to NR20, signifying increased pyridine–filler interaction in the filled



**Figure 3** Variation of PSI and enrichment factor of NR membranes with feed concentration at 40°C.



**Figure 4** Effect of filler loading on (a) flux and selectivity and (b) PSI and enrichment factor for 0.97 wt % of pyridine in water.

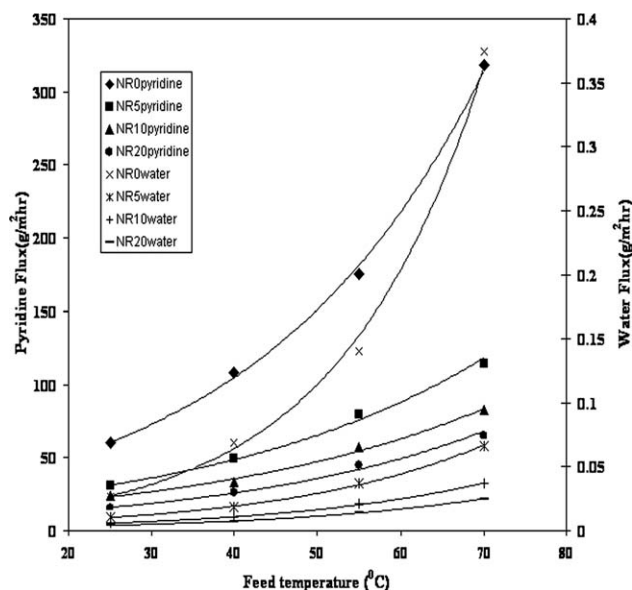
membranes. Similar kind of trend lines were also obtained for flux, selectivity, PSI, and enrichment factor at the two other PV temperatures, that is, at 55 and 70°C.

#### Effect of filler loading on flux, selectivity, PSI, and enrichment factor

**Flux and selectivity.** From Figure 4(a), it is observed that for the same feed concentration (0.97 wt % of pyridine in water), pyridine selectivity of NR membranes increases linearly with a very steep slope up to 10 wt % of filler (i.e., NR10) in membrane and above it the increase in pyridine selectivity is marginal. Altogether, selectivity shows a polynomial trend. Similar kind of trend line is observed for pyridine flux except it decreases with filler loading. These kinds of trend lines of flux and selectivity were also observed at other feed concentrations. At any feed concentration, unfilled NR0 membrane shows maximum flux; however, minimum pyridine selectivity is observed for this unfilled membrane. The intersection of trend line of flux and selectivity meets at around 5 wt % of filler loading, that is, NR5 membrane shows optimum performance in terms of flux and selectivity, which is also supported by PSI data given in Figure 3. From Figure 4(a), it is observed that NR0 membrane yielded a thickness normalized flux of  $5.4 \text{ kg m}^{-2} \text{ h}^{-1} \mu\text{m}^{-1}$  (obtained by multiplying flux data with membrane thickness, i.e., 50  $\mu\text{m}$ ); however, this flux is reduced by around 50% in filled NR5 membrane ( $2.5 \text{ kg m}^{-2} \text{ h}^{-1} \mu\text{m}^{-1}$ ). As the filler loading is further increased, flux is also drastically reduced in NR10

membrane ( $1.7 \text{ kg m}^{-2} \text{ h}^{-1} \mu\text{m}^{-1}$ ). However, the decrease in flux from NR10 to NR20 ( $1.3 \text{ kg m}^{-2} \text{ h}^{-1} \mu\text{m}^{-1}$ ) is not so high. From the figure, it is also observed that selectivity showed an opposite trend, that is, selectivity increases from a low value of 49 (NR0 membrane) to a much higher selectivity of 112 for NR20 membrane. Unfilled NR0 membrane contains a large amount of free volumes in its structure and thus it shows high flux and comparatively lower selectivity. With incorporation of organophilic N330 filler in its matrix, flux decreases because of decrease in free volume and increase in physical crosslinking. Furthermore, the organophilic filler repels water but shows increased interaction with pyridine resulting in higher pyridine selectivity in filled membranes.

**PSI and enrichment factor.** From Figure 4(b), it is observed that PSI of the NR membranes increases sharply with increase in filler loading and it becomes maximum at 5 wt % of filler loading (i.e., for NR5 membrane). The PSI is also found to decrease almost exponentially above 5 wt % of filler loading, signifying NR5 as the membrane showing optimum performance of pyridine flux and selectivity at low level of pyridine concentration (< 1 wt %) in water, which is usually practiced for pervaporative removal of organics from water. The increase in selectivity above 5 wt % of filler loading is not very high, but flux decreases by around 50% above 5 wt % of filler loading. Hence, PSI which is a product of flux and selectivity decreases drastically above this filler loading. Enrichment of pyridine in permeate is also observed to increase sharply up to around 5 wt % of carbon black filler in membrane. As seen in



**Figure 5** Variation of pyridine and water flux with feed temperature for 0.97 wt % of pyridine in water.

Figure 4(b), the increase in enrichment factor above 5 wt % of filler loading in feed is marginal.

#### Effect of feed temperature on flux and separation factor

It is evident from Figure 5 that both pyridine and water partial flux increase exponentially with temperature. However, the rate of increment of water flux is much higher than that of pyridine. In fact, the kinetic diameter of water molecule is shorter (0.265 nm)<sup>14</sup> than that of pyridine molecules (0.585 nm).<sup>15</sup> Hence, at higher temperature, the movement of rubber chains allows permeation of more water molecules through the membranes. The decrease in pyridine selectivity at higher temperature, as observed in Figure 6, may be ascribed to the increased flux of water at higher temperature. It is interesting to note that with increasing filler loading movement of the rubber molecules become restricted, and hence, the rate of increment of flux with temperature decreases for the filled rubber membranes.

#### Effect of feed concentration on apparent activation energy

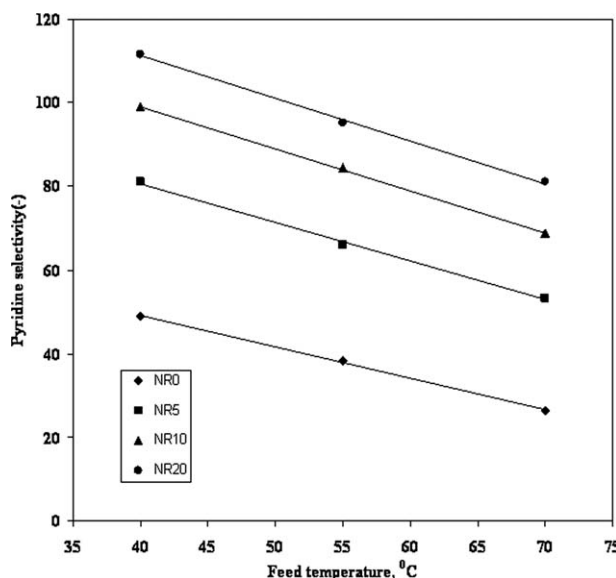
Apparent activation energy for permeation is calculated from the slope of the Arrhenius-type linear plot of logarithmic of permeation flux ( $J_p$ ) against inverse of absolute temperature ( $1/T$ ) from the following equation:

$$\ln(J_p) = \ln B - \left( \frac{E_p}{RT} \right). \quad (7)$$

Here, “ $B$ ” is a pre-exponential factor and “ $R$ ” is the universal gas constant. Thus, apparent activation energy for permeation of pyridine and water could be calculated at several feed concentrations from similar plots. For each of these linear plots by best-fit method, the values of regression coefficient were also found to be close to unity. Apparent activation energy for permeation of both pyridine and water through filled NR membranes at different feed concentrations of pyridine are shown in Figure 7. From this figure, it is observed that activation energies of water remain marginally constant over the used feed concentration range of pyridine (0.48–9.79 wt %), whereas activation energy for pyridine permeation increases linearly up to around 6 wt % of pyridine in feed and thereafter the change is very small signifying plasticization of the organic selective membranes by pyridine. The membranes also show lower activation energy of pyridine than water as shown in the figure.

#### Effect of filler loading on activation energy

From Figure 7, it is also observed that for the same feed concentration, activation energy of both pyridine and water decreases with increasing filler loading. Activation energy is calculated from the slope, that is, the rate of change of flux with temperature. The change of flux with temperature is less for a membrane loaded with filler due to restriction of movement of the otherwise mobile rubber chain with increasing temperature. This may be the reason for the highest activation energy of the unfilled NR0 rubber membrane, and in absence of any filler, the



**Figure 6** Variation of pyridine selectivity with feed temperature for NR membranes. Feed concentration = 0.97 wt % of pyridine.

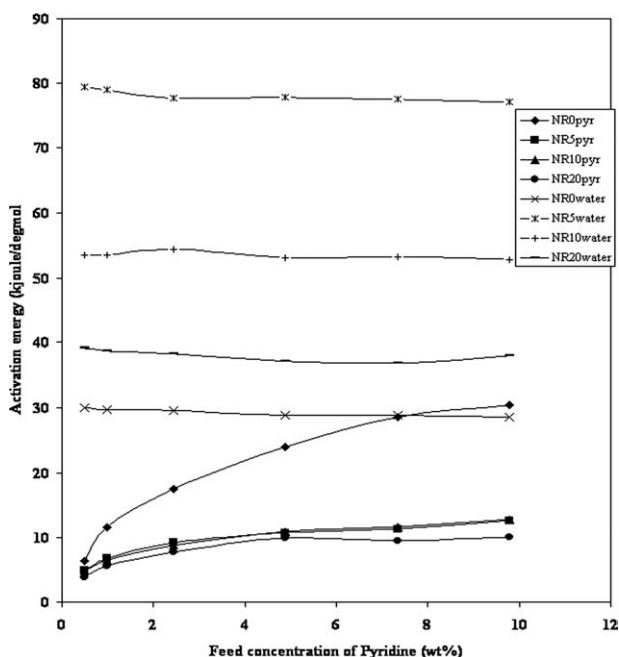


Figure 7 Feed concentration and activation energy of NR membranes.

rubber chains show extensive mobility at higher temperature and hence an increased rate of flux with temperature.

Effect of feed concentration on permeation factor

Permeation factor [eq. (5)] quantifies the effect of one component on the permeation rate of the other component.<sup>11</sup> From Figure 8(a), it is observed that for NR membranes, at very low concentration of pyridine in water (~ 0.5 wt %), permeation factor for all the membranes are much higher than unity

signifying positive coupling effect of water on pyridine flux. It is also observed that for the same feed concentration, permeation factor also increases with increase in filler loading from NR0 to NR20. As the feed concentration of pyridine increases, permeation factor for pyridine drastically decreases and approaches unity. The permeation factor of water is shown in Figure 8(b). In this case, permeation factor of the filled membranes for water are observed to be much lower than pyridine [Fig. 8(a)] and it remains marginally constant over the used concentration range of pyridine in water. However, the unfilled NR0 membrane shows much higher permeation factor of water than pyridine. The very high permeation factor, even for pyridine with unfilled NR0 membrane, may be ascribed to permeation of large amount of water through these membranes at very high concentration of water in feed.

Comparison of permeation through NR and SBR membranes

From Table I, it is observed that unfilled and filled SBR membranes<sup>6</sup> with similar filler loading and state of crosslinking showed higher selectivity but lower flux for same feed pyridine concentration and temperature. SBR is more rigid than NR because of the presence of aromatic benzene ring in its structure.<sup>9,13</sup> Thus, NR membranes yielded higher flux but lower selectivity at similar feed concentration and temperature. For filled membrane, transport of permeant depends on filler-rubber compatibility. If the filler is compatible, it occupies the free volume in the rubber matrix and transport of permeant occurs through a tortuous path of the filled membrane resulting in

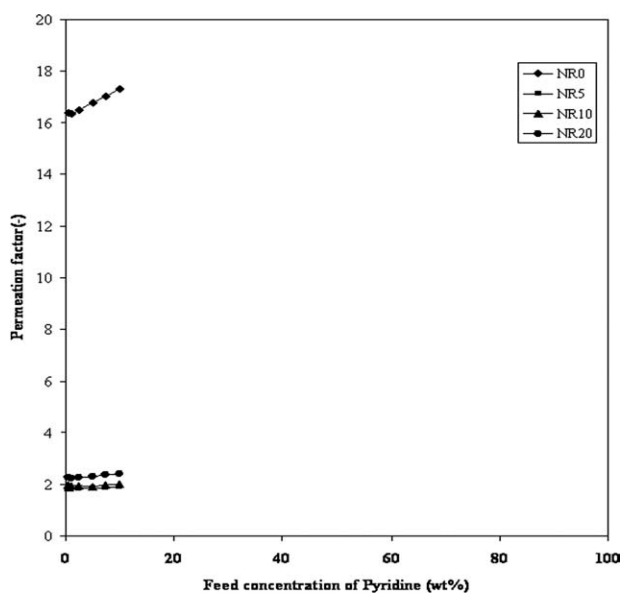
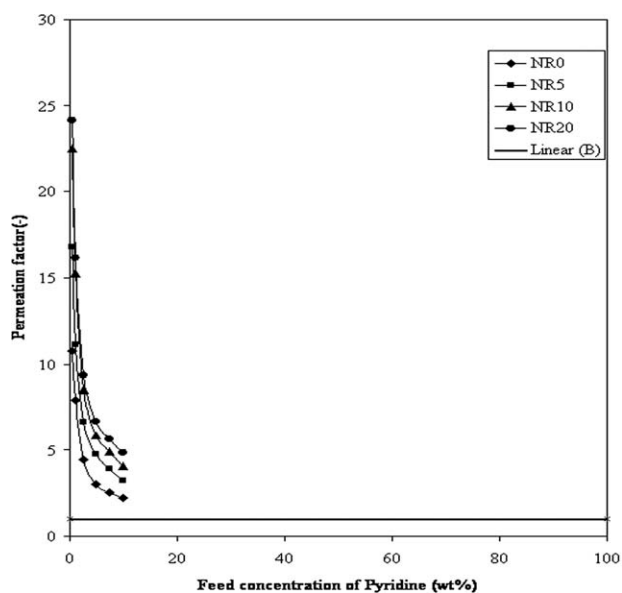


Figure 8 Permeation factor of NR membranes for (a) pyridine and (b) water at 40°C.

**TABLE I**  
**Comparison of Performance of Pyridine Separation by Various Pervaporation Membranes**

Membrane	Feed concentration of pyridine in water (wt %)	Total flux (g m <sup>-2</sup> h <sup>-1</sup> )	Pyridine selectivity	Temperature (°C)	Reference
PERVAP1160 of GFT (modified PDMS membrane)	7.86	1,440	23	50	2
Silicalite-filled silicone composite membrane	5.0	428	34	50	7
Poly(ether- <i>block</i> -amide) membrane	7.0	69.0	14.5	60	8
TS605 (crosslinked PDMS on polyester support from Rhone Poulence)	0.1		70	35	16
Unfilled SBR0 and filled SBR membrane	7.34	SBR-91.545 SBR5-46.182 SBR10-53.36 SBR20-43.73	SBR0-93.64 SBR5-138.29 SBR10-156.4 SBR20-169.5	40	6
Unfilled SBR0 and filled SBR membrane	0.48	SBR0-151.19 SBR5-88.40 SBR10-72.55 SBR20-58.65	SBR0-19 SBR5-28.77 SBR10-33.1 SBR20-36.99	40	6
Unfilled NR0 and filled NR membrane	7.34	NR0-156.18 NR5-84.42 NR10-55.96 NR20-49.21	NR0-15.07 NR5-27.45 NR10-31.71 NR20-36.99	40	This work
Unfilled NR0 and filled NR membrane	0.48	NR0-97.55 NR5-44.12 NR10-29.15 NR20-23.42	NR0-66.33 NR5-121.96 NR10-144.1 NR20-162.81	40	This work

high selectivity and comparatively a lower flux as observed for SBR. When rubber–filler compatibility is not good, void spaces are generated in the rubber–polymer interfaces and transport occurs through these void spaces resulting in higher flux and lower selectivity. For similar filler loading with N330 carbon black, filler–rubber compatibility for SBR has been reported to be better than NR.<sup>10</sup> Thus, filled NR membranes also yielded higher flux but lower selectivity than filled SBR membranes as shown in Table I.

#### Comparison of performances with reported data

Because of hazardous nature of pyridine and lack of suitable membrane, few reports are available on the separation of pyridine–water mixtures by PV. Furthermore, most of the reported membranes are hydrophilic and selectively permeate water from high concentration of pyridine in water. However, for removal of low concentration of pyridine from water by PV, organophilic and pyridine-selective membranes are required. The relative performances of different membranes used for the separation of pyridine from its mixtures with water are given in Table I. From these results, it transpires that the performance of the filled NR membranes used for the studies shows high separation factor for pyridine with reasonable flux in comparison with other membranes reported for the same system.

#### CONCLUSION

Efficiently crosslinked NR rubber membranes filled with N330 carbon black filler was prepared. These crosslinked and filled rubber membranes were studied for pervaporative removal of pyridine from water at different feed concentrations and temperatures. With increasing filler loading from NR5 to NR20, physical crosslinking of the NR membranes were found to increase manifold, resulting in increased tensile strength and pyridine selectivities of the membranes. Among all the membranes, NR5 membrane was observed to show optimum performance in terms of flux and selectivity. These rubber membranes will be extremely effective for separation of any organic having similar solubility parameter with these rubbers while the other component (not to be separated) is completely insoluble in these rubbers.

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#### NOMENCLATURE

<i>A</i>	Effective membrane area (m <sup>2</sup> )
<i>W</i>	Amount of total permeate (g)
<i>J</i>	Flux (g m <sup>-2</sup> h <sup>-1</sup> )
<i>J<sub>P</sub></i>	Pyridine flux (g m <sup>-2</sup> h <sup>-1</sup> )
<i>t</i>	Time of experiment (h)



$y$	Weight fraction of component $i$ in permeate (-)
$x$	Weight fraction of component $i$ in feed (-)
$\alpha$	Permeation selectivity
$\beta$	Enrichment factor (-)
$\theta$	Permeation factor (-)
PSI	Permeation separation index
$B$	Pre-exponential factor
$R$	Universal gas constant (cal degree <sup>-1</sup> mol <sup>-1</sup> )
$T$	Absolute temperature (K)
$E_p$	Activation energy for permeation (cal degree <sup>-1</sup> mol <sup>-1</sup> )

### Subscripts and superscripts

$i$	$i$ th component
$j$	$j$ th component
$p$	Permeation
Py	Pyridine
$w$	Water
$\alpha_{PV}$	Pervaporation selectivity

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