

### Membrane Gas Separation

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# Microporous Polyamide Membranes for Molecular Sieving of Nitrogen from Volatile Organic Compounds

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**Abstract:** Microporous polymer membranes continue to receive tremendous attention for energy-efficient gas separation processes owing to their high separation performances. A new network microporous polyamide membrane with good molecular-sieving performance for the separation of  $N_2$  from a volatile organic compound (VOC) mixture is described. Triple-substituted triptycene was used as the main monomer to form a fisherman's net-shaped polymer, which readily forms a composite membrane by solution casting. This membrane exhibited outstanding separation performance and good stability for the molecular-sieving separation of  $N_2$  over VOCs such as cyclohexane. The rejection rate of the membrane reached 99.2% with 2098 Barrer  $N_2$  permeability at 24°C under 4 kPa. This approach promotes development of microporous membranes for separation of condensable gases.

n nature materials tend to avoid forming vacuums because of their enthalpy effects, indicating that the formation of pores is energetically unfavorable.<sup>[1]</sup> Synthesis of microporous materials is thus a complicated process, while the existence of micropores in materials has potential technological significance for molecular separation (for example, catalysis, gas storage, and so on).<sup>[2]</sup> Therefore, great effort have been devoted to developing varied approaches for obtaining such materials, including polymers of intrinsic microporosity (PIMs),<sup>[3]</sup> thermally rearranged (TR) polymers,<sup>[4]</sup> and covalent organic frameworks (COFs).<sup>[5]</sup> However, although many microporous organic materials have been synthesized, one significant challenge is the handful of microporous organic polymers to be processed into membranes for chemical separation, because most of the materials synthesized to date have been produced as intractable solids, which greatly limits their functionalization or post-processing into useful forms.<sup>[6]</sup> Furthermore, even though the produced microporous materials such as PIMs-1 are solution processable, and the separation performance of the prepared PIMs-1 membrane is

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excellent for gas separation (for example,  $\rm CO_2/N_2$  separation) because of its molecular-sieving ability and preferential adsorption,<sup>[7]</sup> their solubility in a range of solvents may result in the formation of membranes with volatile organic compound (VOC) permselectivity when these membranes are used for the separation of N<sub>2</sub>/VOC mixtures.<sup>[8]</sup>

The recovery of VOCs is an important task in industry because escaping VOCs are not only harmful to people and the environment, but also cause a lot of waste.<sup>[9]</sup> Therefore, many different technologies have been employed to treat this problem.<sup>[9,10]</sup> Energy-efficient membrane technology is regarded as more attractive than other traditional methods.<sup>[7,10,11]</sup> Many membrane materials with VOC permselectivity have been developed, and significant progress has also been made in their industrial applications.<sup>[12]</sup> However, the requirement of a high driving force to obtain intrinsic membrane performance would increase the operating cost, and the plasticization phenomenon would weaken the separation performance. Furthermore, this kind of membrane technology is referred to as an end-of-the-pipe treatment.

In contrast to current VOC permselective membranes, herein we report a new triptycene-based three-dimensional (3D) network microporous polyamide membrane with N<sub>2</sub> permselectivity for the separation of N2/VOC mixtures (Scheme 1 a). This kind of membrane can ensure the source control of VOC emissions. It was reported that polymer chain flexibility affects pore size, which could consequently impact on size-selectivity.<sup>[7]</sup> Moreover, it is difficult for a polymer with a backbone of fused rings to experience large-scale conformational change without breakage of bonds.<sup>[13]</sup> In this study, rigid 3D-contorted triptycene was selected as the primary monomer, which has already been recognized as an interesting building block for new microporous polymers.<sup>[14]</sup> Its 3D structure could enhance the microporosity of the membranes, leading to higher permeance,<sup>[14c, 15]</sup> and materials made of the 3D structure can form 3D-interconnected pores, which are not easily blocked.<sup>[11]</sup> However, most studies using triptycene note only two or four latent reaction sites, resulting in the formation of linear polymers.<sup>[15,16]</sup> Some studies report the synthesis of network polymers derived from triptycene monomers.<sup>[17]</sup> Few previous works have employed triptycene with three latent reaction sites in the synthesis of network polymers. To the best of our knowledge, there are no reports about using this kind of polymer to fabricate membranes for N<sub>2</sub>/VOC separation. Therefore, a triptycene derivative (2,6,14-triaminotriptycene) was synthesized for the first time in this study (see the Supporting Information for synthetic details, Fourier transform infrared spectroscopy (FTIR; Figure S3), and <sup>1</sup>H NMR spectroscopy (Figure S4)). SubseGDCh

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**Scheme 1.** a) Diagram of a microporous polyamide composite membrane used as a  $N_2$  permselective membrane for  $N_2/VOC$  mixture separation. b) Synthesis of triptycene-based polyamides by solution polymerization.

quently, a simple amidation reaction using triaminotriptycene and acyl chlorides as monomers was employed to synthesize polyamides; the method is quick and can be operated at low temperature and pressure. Solution polymerization instead of interfacial polymerization was used to synthesize polymers. Co-condensation reactions of the contorted rigid monomer (2,6,14-triaminotriptycene) and linear non-contorted monomers (acyl chloride compounds, including glutaryl chloride, adipoyl chloride, suberoyl chloride, and sebacoyl chloride) provided polyamides (termed HT-PA1, HT-PA2, HT-PA3, and HT-PA4, respectively), as illustrated in Scheme 1b. Scanning electron microscopy (SEM) images (Supporting Information, Figure S5) show the particle patterns of the synthesized polyamides. Analyses of the FTIR (Supporting Information, Figure S6), <sup>1</sup>H NMR (Supporting Information, Figure S7) and <sup>13</sup>C NMR (Supporting Information, Figure S8) spectroscopies were used to confirm their amide structures and the existence of triptycene. X-ray photoelectron spectroscopy (XPS) analysis (Supporting Information, Figures S9-S12 and Table S1) was employed to predict their structures<sup>[18]</sup> and both network structures and linear structures existed in the synthesized polyamides (Supporting Information, Table S1) where the network structures resulted from a repeat unit, as shown in Scheme 1b (termed M4).<sup>[5,6]</sup> Powder X-ray diffraction (PXRD) images (Supporting Information, Figure S13) show the amorphous structure of the synthesized polyamides, and their d-spacing ranges from 0.438 to 0.527 nm. Thermal gravimetric analysis (TGA; Supporting Information, Figure S14) indicates good thermal stability. The Brunauer-Emmett-Teller areas (BET) for these network polymers under N<sub>2</sub> adsorption (Supporting Information, Figure S15 and Table S2) are from approximately 20- $60 \text{ m}^2\text{g}^{-1}$ , and higher BET areas under CO<sub>2</sub> adsorption are observed. A similar phenomenon was also reported by Livingston et al.<sup>[19]</sup>

The solubility of synthesized polyamides in common solvents would effectively affect the membrane preparation through solution casting. Thus, solubility of synthesized polyamides in different solvents was evaluated (Supporting Information, Table S3); the insolubility of the synthesized polyamides in alkane solvents, aromatic solvents, and alcohol solvents was expected, which could greatly enhance the plasticization resistance induced by the swelling of adsorbed solvents, resulting in increased stability.[20] The partial solubility of the synthesized polyamides in the aprotic organic solvents, such as dimethylformamide (DMF) (Supporting Information, Figure S16 and Table S3) could enhance postprocessing into membranes, which readily form a composite

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membrane or a free-standing membrane with no visible defects (Figure 1 a; Supporting Information, Figures S17 and S18), indicating good film-forming properties. The insolubility of the free-standing polyamide membrane in the cyclohexane solution is also expected (Figure 1 b). Additionally, a constant rejection rate (the reason for choosing rejection rate is given in the Supporting Information) with decreasing membrane thickness also suggests good film-forming properties of the synthesized polyamides (Supporting Information, Figure S19).

Four membranes composed of different chloride compounds were evaluated for separation of smaller N2 molecules over larger cyclohexane molecules. A rejection rate of more than 98.5% (Figure 2a) indicates an outstanding molecularsieving performance and the degree of network cross-linking of the synthesized polyamide may not affect size-selectivity significantly under these separation conditions.<sup>[1]</sup> This also suggests that a significant proportion of micropores are of a diameter that is dimensioned between  $N_2 (0.364 \text{ nm})^{[19]}$  and cyclohexane (0.6 nm),<sup>[21]</sup> which has already been confirmed by XRD. To further characterize the size and shape of the micropores in these membranes, TEM (Figure 1c) and positron annihilation lifetime spectra (PALS) analyses (Supporting Information, Table S4) were used. Figure 1c presents a "fishing net" structure in the membrane. Additionally, the discrete ortho-positronium (o-Ps) lifetime parameters (Supporting Information, Table S4) show the existence of two types of pores: network pores in the center of each repeat unit in membranes with radii ranging between 0.469-0.587 nm from  $\tau$ 3, and aggregate pores in the interstitial sites in membranes with radii ranging between 0.742-1.048 nm from  $\tau 4$ ,<sup>[6,22]</sup> which are schematically represented in Figure 1e. The network pore is a small pore originating from the amide linkage reaction and is cross-linked as previously reported.<sup>[22]</sup> This verified the existence of a periodic fisherman's net-

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**Figure 1.** a) Digital image of the four prepared polyamide composite membranes; SEM surface image of the HT-PA4 composite membrane. Composite membranes were prepared by coating a 5 wt% polyamides DMF solution on a 0.22 µm Nylon-6 support and cross-linking in a vacuum oven at 80 °C for three days. b) Solubility of HT-PA2 free-standing HT-PA2 membrane in cyclohexane solution at room temperature for 20 days. The free-standing membrane was prepared by coating 5 wt% HT-PA2 polyamide DMF solution on a polytetrafluoroethylene (PTFE) plate and crosslinking in a vacuum oven at 80 °C for three days. c) TEM images of the prepared HT-PA2 membrane. d) Diagram of the periodic fisherman's net-shaped structure of the membrane. e) Representation of the possible molecular structure of the network and aggregate pores in the membrane.



**Figure 2.** a) Rejection rate of cyclohexane for the prepared polyamide composite membranes coated on PA-6 support. b) Rejection rate of different organic molecules using HT-PA1 and HT-PA2 composite membranes. Separation was conducted in a crossflow mode at about  $30000 \pm 1500$  ppm feed VOC concentration (flux of 20 Lm<sup>-2</sup>h<sup>-1</sup>) and temperature of 24 °C.

shaped structure in the membrane (Figure 1d,e), which is formed from the repeat unit (M4). This unit also makes the synthesis of 2D-polymer membranes possible in the near future.<sup>[1,23]</sup> Furthermore, although it has been reported that the chemical environment caused by polar atoms and groups can affect the *o*-Ps lifetime, the similar backbone structures of all the membranes in this work indicate that the intensity component is correlated to the relative concentration of the free volume holes.<sup>[22]</sup> Periodic microporosities with correct sizes and continuity across the membrane play an important role in gas separation.<sup>[6,11]</sup> Therefore, the PALS results clearly show that intensity of aggregate pores is low, which indicates the main portion of network pores exist in the membranes, resulting in a high rejection rate owing to the molecular-sieving mechanism. The reason for the decreasing size of network pores (Supporting Information, Table S4) with increasing length of the acyl chloride chain is due to enhanced chain flexibility (Supporting Information, Figure S20), because higher chain flexibility would strengthen the stacking density of the polymer, reducing the pore size or free volume.<sup>[24]</sup>

Figure 2b shows a rejection rate for the separation of different binary mixtures using HT-PA1 and HT-PA2 membranes. Rejection rates for cyclohexane, hexane, and heptane are all around 99%, with the exception of acetone (although the kinetic diameter of acetone is a little higher than that of hexane).<sup>[21]</sup> Therefore, excepting the effect of size selectivity, shape selectivity must also be taken into consideration in the separation. Molecular dimensions of these organic molecules were compared (Supporting Information, Table S5), and the lowest molecular dimension and excluded area for the acetone molecule led to its lowest rejection rate. Furthermore, molecular dynamic simulation also confirms these results because of the different number and connectivity of accessible pathways or pores, and the fractional accessible volume for the permeation of VOC molecules through membranes compared to that for N<sub>2</sub> molecules (Supporting Information, Figures S21 and S22).

Good membranes should not only possess a high rejection rate but also high permeability. A comparison of single-gas permeation at 25 °C with different gas molecules, including O<sub>2</sub> (0.346 nm), N<sub>2</sub> (0.364 nm), and CH<sub>4</sub> (0.38 nm)<sup>[19]</sup> was thus conducted (Supporting Information, Table S6). The N<sub>2</sub> permeabilities of the prepared membranes are higher than most previously reported examples. This is because the kinetic diameter of a N<sub>2</sub> molecule is about 0.364 nm, which is less than that of a network pore. Thus, N<sub>2</sub> permeation can take place in both types of pores, leading to high N<sub>2</sub> permeation. Furthermore, the 3D fisherman's net-shaped structure across the membrane (formed by rigid 3D-contorted triptycene) also promotes the permeation of N<sub>2</sub>. Similar results were also obtained by Pinnau et al.,<sup>[15]</sup> stating that the incorporation of triptycene would enhance membrane permeability. Livingston et al.<sup>[18]</sup> also reported that membranes composed of network polymers will express ultrafast permeance in contrast to those composed of linear polymers. Thus, although a membrane is theoretically uneconomic for removing a major component, high permeability and the requirement of lower energy input offsets this weakness, suggesting great potential in industrial applications.

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A relatively low feed pressure is needed to drive this separation owing to the 3D fisherman's net-shaped structures in the membranes. High pressure leads to low rejection rates (Supporting Information, Figure S23a), because high feed pressure pushes more organic molecules through the membrane. More pores are therefore occupied by these sorbed molecules, hindering the transportation of N<sub>2</sub> molecules through the membrane, and resulting in lower N2 permeabilities (Supporting Information, Figure S23b). Furthermore, higher rejection rates for the separation of the N<sub>2</sub>/ cyclohexane mixture than for the N2/hexane mixture (Supporting Information, Figure S23a) further verified the importance of the molecule-sieving mechanism. Adsorption has only a slight effect on the separation performance. This is because, although the mass loading of cyclohexane is higher than that of hexane (Supporting Information, Figure S24), which means that cyclohexane has a higher affinity than hexane to the membrane, the rejection rate of cyclohexane is still higher than that of hexane because of cyclohexane's higher kinetic diameter. A higher feed concentration of condensable gas leads to a higher rejection rate, and a rejection rate as high as 99.2% with N<sub>2</sub> permeability up to about 2098 Barrer (Supporting Information, Figure S25) can be obtained. This is because the rigid 3D-contorted triptycene, which is connected by strong covalent bonds, formed a rigid periodic fisherman's net-shaped structure that restricted the free movement of polymer chains in the membrane and helped to prevent polymer swelling induced by VOC molecules. Finally, the rejection rate increases with higher feed concentrations of condensable gas. The highest rejection rate, using the HT-PA2 composite membrane, was compared to that of the reverse osmosis (RO), nanofiltration (NF), and ultrafiltration (UF) membranes (Supporting Information, Figure S26). The result further indicates the importance of a rigid 3D-contorted triptycene, which prevents efficient packing of the polymer network and forms interconnected network pores (Supporting Information, Figure S21), leading to low feed pressures and higher rejection rates.<sup>[14c,25]</sup>

Consequently, we further studied the evaluation of the stability of the prepared composite membranes (Figure 3), and good stability of the membrane's rejection rate during 30 days of operation was observed. This is because, as hypothesized by Pinnau et al., [16b] chain architecture and conformation play an important role in physical aging. Herein, the synthesized polyamides have a more stable fisherman's net-shaped structure owing to the introduction of rigid 3D-contorted triptycene, which greatly restricts the mobility of the chains.<sup>[25]</sup> Furthermore, the built-in free volume in triptycene is already in an equilibrium state, preventing it from evolving towards equilibrium over time as other microporous membranes do.[16b,26] This indicates the hard reorganization of the "intrinsic" microporosity and good stability. It also confirms the importance of chain architecture and conformation in the mitigation of physical aging.

In summary, novel membranes were successfully fabricated using rigid 3D-contorted triptycene as a monomer and have been used for  $N_2/VOC$  separation. Molecular-sieving ability and a periodic fisherman's net-shaped structure were



Figure 3. Stability of the prepared HT-PA2 composite membranes for separation of a  $N_2$ /cyclohexane mixture. Separation was conducted in a crossflow mode at 24 °C under 4 kPa.

demonstrated. Furthermore, good stability and higher rejection rates at higher feed concentrations suggest the importance of chain structure and conformation in the mitigation of physical aging in organic vapors. Thus, the prepared membranes offer outstanding separation performance, where a rejection rate as high as 99.2% with high permeability can be obtained for molecular-sieving separation of mixtures, such as an N<sub>2</sub>/cyclohexane mixture. Furthermore, the low feed operating pressure needed to drive this separation suggests a new operation mode applicable for the membrane-based separation of N<sub>2</sub>/VOC mixture and an economical operating cost and therefore good commercial feasibility. This work provides an important contribution to the preparation and application of microporous polymer membranes and can bring about a revolutionary change for the membrane-based separation of N<sub>2</sub>/VOC mixtures.

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#### Conflict of interest

The authors declare no conflict of interest.

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- [1] Z. Zheng, R. Grünker, X. Feng, Adv. Mater. 2016, 28, 6529–6545.
- [2] Q. Song, S. Jiang, T. Hasell, M. Liu, S. Sun, A. K. Cheetham, E. Sivaniah, A. I. Cooper, *Adv. Mater.* 2016, 28, 2629–2637.
- [3] P. M. Budd, E. S. Elabas, B. S. Ghanem, S. Makhseed, N. B. McKeown, K. J. Msayib, C. E. Tattershall, D. Wang, *Adv. Mater.* 2004, *16*, 456–459.
- [4] H. B. Park, C. H. Jung, Y. M. Lee, A. J. Hill, S. J. Pas, S. T. Mudie, E. Van Wagner, B. D. Freeman, D. J. Cookson, *Science* 2007, *318*, 254–258.
- [5] H. M. El-Kaderi, J. R. Hunt, J. L. Mendoza-Cortés, A. P. Côté, R. E. Taylor, M. O'Keeffe, O. M. Yaghi, *Science* 2007, 316, 268 – 272.
- [6] J. Sakamoto, J. van Heijst, O. Lukin, A. D. Schlüter, Angew. Chem. Int. Ed. 2009, 48, 1030–1069; Angew. Chem. 2009, 121, 1048–1089.
- [7] M. Carta, R. Malpass-Evans, M. Croad, Y. Rogan, J. C. Jansen, P. Bernardo, F. Bazzarelli, N. B. McKeown, *Science* 2013, 339, 303 – 307.
- [8] S. Thomas, I. Pinnau, N. Du, M. D. Guiver, J. Membr. Sci. 2009, 338, 1–4.
- [9] M. J. Salar-García, V. M. Ortiz-Martínez, F. J. Hernández-Fernández, A. P. de los Ríos, J. Quesada-Medina, J. Hazard. Mater. 2017, 321, 484–499.
- [10] C. K. Yeom, S. H. Lee, H. Y. Song, J. M. Lee, J. Membr. Sci. 2002, 198, 129–143.
- [11] D. L. Gin, R. D. Noble, Science 2011, 332, 674-676.
- [12] C. Wylock, P. P. Eloundou Mballa, C. Heilporn, F. Debaste, M. L. Fauconnier, *Trends Food Sci. Technol.* 2015, 46, 68-74.
   [13] P.M. Pudd, N. P. McKaown, *Polym. Cham.* 2010, 1, 62, 68
- [13] P. M. Budd, N. B. McKeown, *Polym. Chem.* **2010**, *1*, 63–68.
- [14] a) C. Zhang, Y. Liu, B. Li, B. Tan, C.-F. Chen, H.-B. Xu, X.-L. Yang, ACS Macro Lett. 2012, 1, 190–193; b) T. M. Swager, Acc. Chem. Res. 2008, 41, 1181–1189; c) B. S. Ghanem, R. Swaidan, E. Litwiller, I. Pinnau, Adv. Mater. 2014, 26, 3688–3692; d) C. Zhang, Z. Wang, J.-J. Wang, L. Tan, J.-M. Liu, B. Tan, X.-L. Yang, H.-B. Xu, Polymer 2013, 54, 6942–6946.

- [15] R. J. Swaidan, B. Ghanem, R. Swaidan, E. Litwiller, I. Pinnau, J. Membr. Sci. 2015, 492, 116–122.
- [16] a) J. R. Wiegand, Z. P. Smith, Q. Liu, C. T. Patterson, B. D. Freeman, R. Guo, *J. Mater. Chem. A* 2014, *2*, 13309–13320; b) R. Swaidan, B. Ghanem, E. Litwiller, I. Pinnau, *Macromolecules* 2015, *48*, 6553–6561.
- [17] a) B. S. Ghanem, M. Hashem, K. D. M. Harris, K. J. Msayib, M. Xu, P. M. Budd, N. Chaukura, D. Book, S. Tedds, A. Walton, N. B. McKeown, *Macromolecules* 2010, 43, 5287-5294; b) A. Del Regno, A. Gonciaruk, L. Leay, M. Carta, M. Croad, R. Malpass-Evans, N. B. McKeown, F. R. Siperstein, *Ind. Eng. Chem. Res.* 2013, 52, 16939-16950.
- [18] S. Karan, Z. Jiang, A. G. Livingston, Science 2015, 348, 1347– 1351.
- [19] M. F. Jimenez-Solomon, Q. Song, K. E. Jelfs, M. Munoz-Ibanez, A. G. Livingston, *Nat. Mater.* 2016, 15, 760–767.
- [20] J. E. Bachman, Z. P. Smith, T. Li, T. Xu, J. R. Long, Nat. Mater. 2016, 15, 845–849.
- [21] M. Jahandar Lashaki, M. Fayaz, S. Niknaddaf, Z. Hashisho, J. Hazard. Mater. 2012, 241–242, 154–163.
- [22] S. H. Kim, S.-Y. Kwak, T. Suzuki, Environ. Sci. Technol. 2005, 39, 1764–1770.
- [23] D. J. Murray, D. D. Patterson, P. Payamyar, R. Bhola, W. Song,
  M. Lackinger, A. D. Schlüter, B. T. King, *J. Am. Chem. Soc.* 2015, *137*, 3450–3453.
- [24] B. Li, D. Xu, X. Zhang, Z. Jiang, Y. Wang, J. Ma, X. Dong, H. Wu, Ind. Eng. Chem. Res. 2010, 49, 12444–12451.
- [25] N. B. McKeown, Nat. Mater. 2016, 15, 706-707.
- [26] R. R. Tiwari, Z. P. Smith, H. Lin, B. D. Freeman, D. R. Paul, *Polymer* 2014, 55, 5788–5800.

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Microporous Polyamide Membranes for Molecular Sieving of Nitrogen from Volatile Organic Compounds



A triple-substituted triptycene microporous polyamide membrane, featuring a fisherman's net-shaped structure, imparts the microporous material with molecular-sieving network pores and a low driving force. The membrane displays preferential nitrogen permeation over volatile organic compounds such as cyclohexane.

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