Preparation of polysilsesquioxane-based CO_2 separation membrane with thermally degradable succinic anhydride and urea units

Katsuhiro Horata,[1] Tsubasa Yoshio,[1] Ryuto Miyazaki,[1] Yohei Adachi,[1] Masakoto Kanezashi,[2] Toshinori Tsuru,*[,2] Joji Ohshita*[,1,3]

[1]*Smart Innovation Program, Graduate School of Advanced Science and Engineering, Hiroshima University, Higashi-Hiroshima 739-8527, Japan*

[2]*Chemical Engineering Program, Graduate School of Advanced Science and Engineering, Hiroshima University, Higashi-Hiroshima 739-8527, Japan*

[3]*Division of Materials Model-Based Research, Digital Monozukuri (Manufacturing) Education and Research Center, Hiroshima University, Higashi-Hiroshima 739-0046, Japan*

Supporting Information

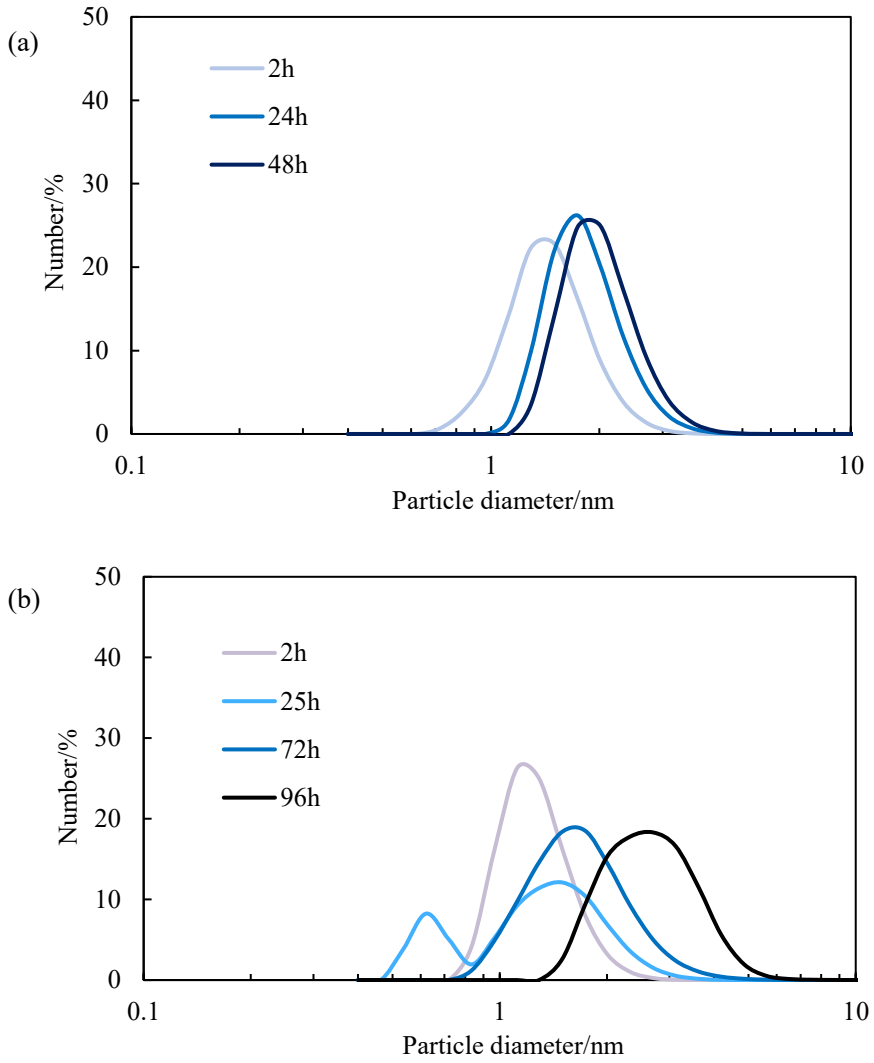

Figure S1. Progress of sol formation from (a) TESPS/BTESE and (b) TESPU/BTESE 1/1 mixtures monitored by DLS measurements at different reaction times.

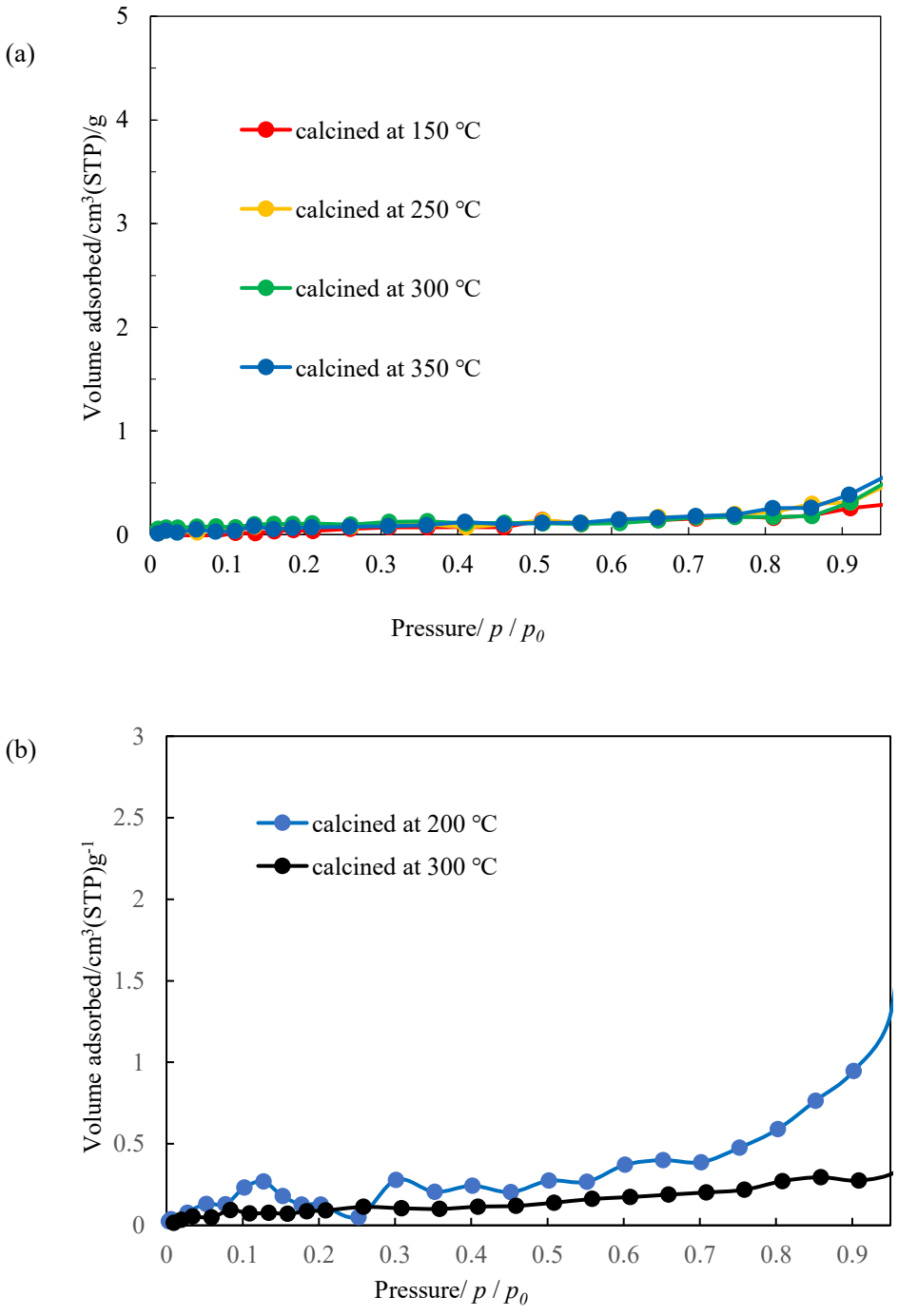

Figure S2. Nitrogen adsorption isotherms for (a) TESPS/BTESE and (b) TESPU/BTESE gels calcined at different temperatures.

(a)

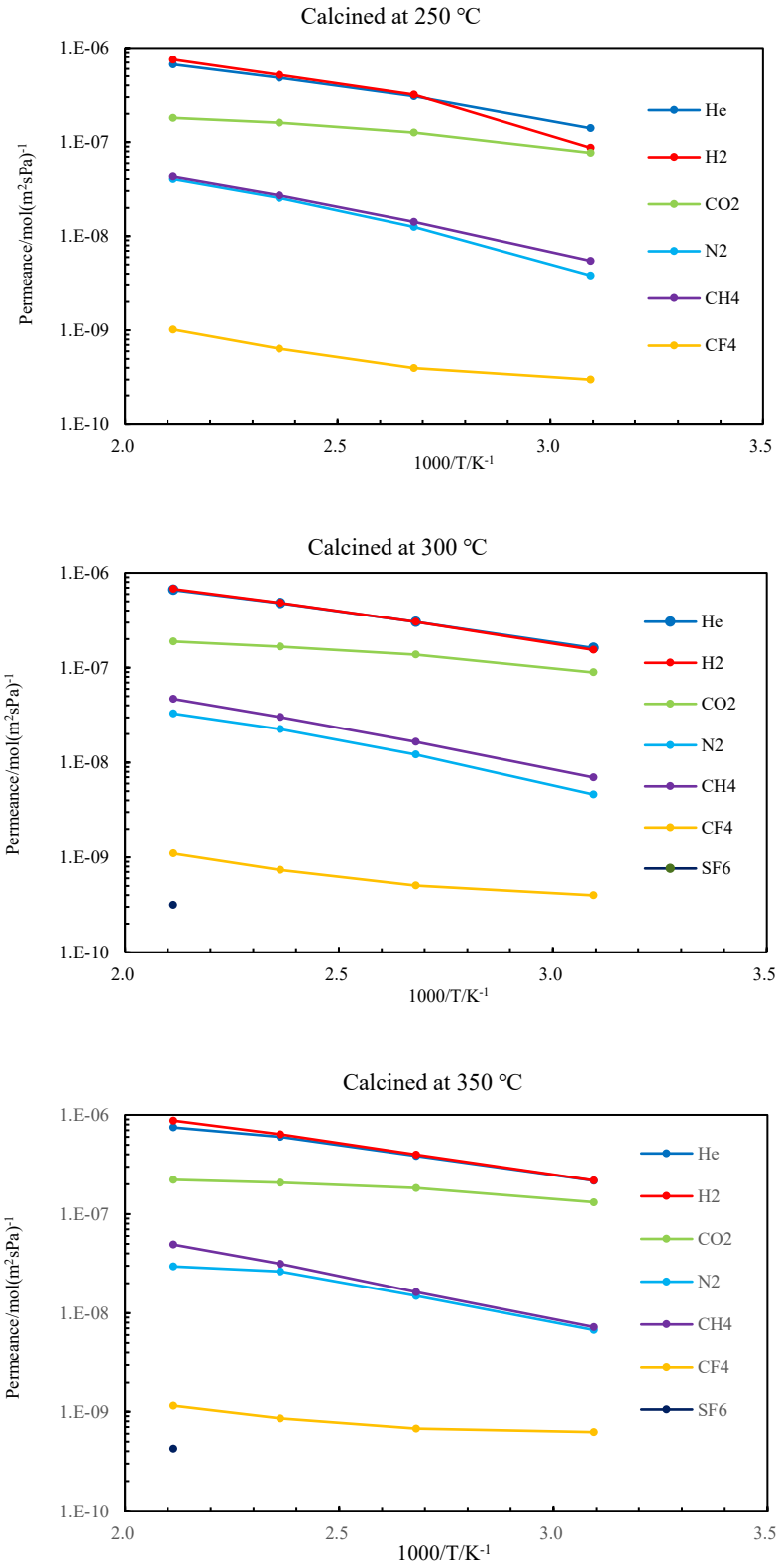

Figure S3. Temperature dependent gas permeances of (a) TESPS/BTESE and (b) TESPU/BTESE membranes calcined at different temperatures.

(b)

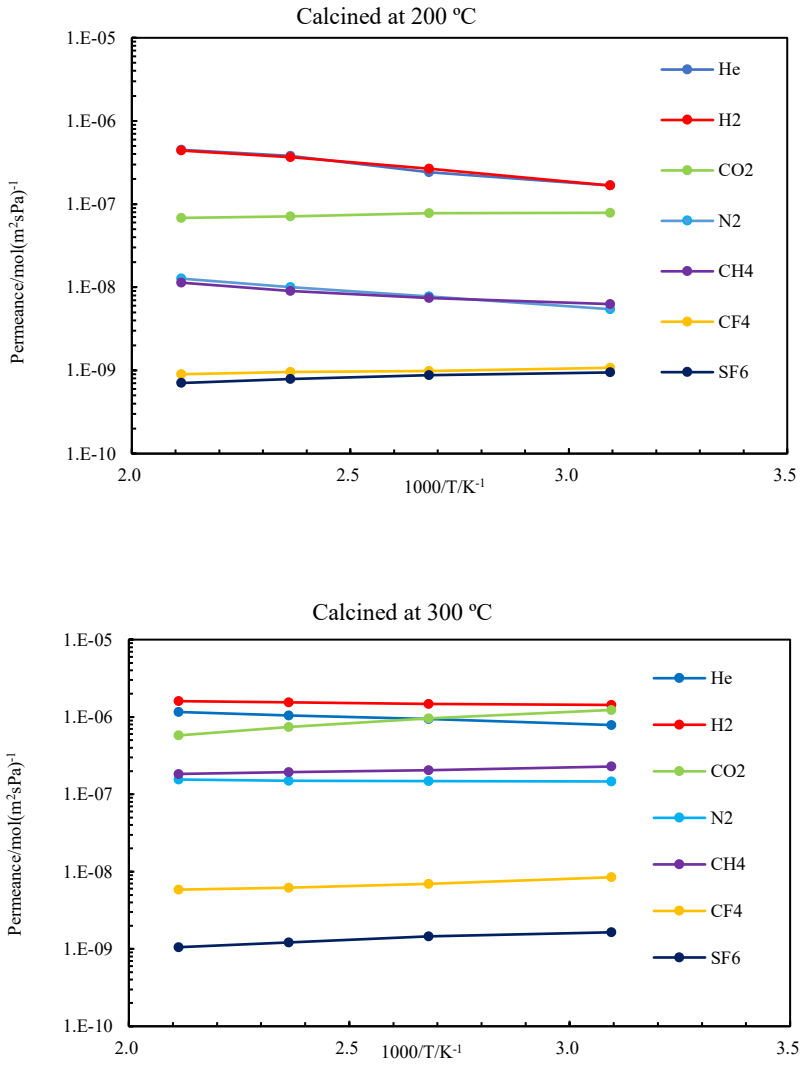

Figure S3. Temperature dependent gas permeances of (a) TESPS/BTESE and (b) TESPU/BTESE membranes calcined at different temperatures (continued).

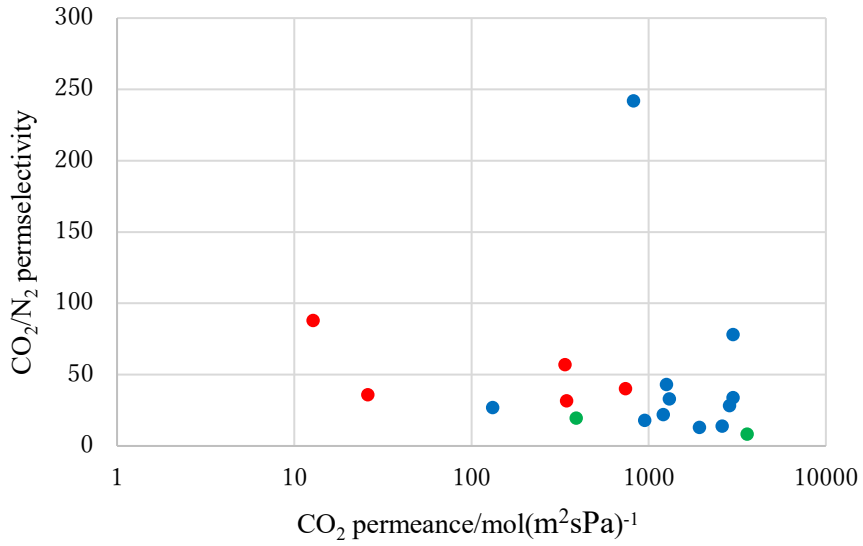

Figure S4. Comparison of performance of TESPS/BTESE (350) and TESPU/BTESE (300) membranes (green) and that of mix-matrix-membranes (red) [1-5] and polymer-based membranes (blue) [6-12], reported previously (GPU = gas permeation unit).

Table S1. Activation energies for gas permeation

precursor	calcination temp/ºC	E_{act}/kJmol^{-1} H_2	He	CO_2	N_2	CH_4	CF_4	SF_6
TESPS	250	18.1	13.2	7.3	17.2	17.5	10.3	-
/BTESE	300	12.5	12.0	6.4	14.7	16.2	8.5	-
	350	11.9	10.7	4.4	10.3	16.4	5.1	-
TESPU	200	8.3	8.7	-1.2	7.1	4.9	-1.4	-2.5
/BTESE	300	1.0	3.2	-6.4	0.5	-1.9	-3.2	-3.8

References

1. P.D. Sutrisna, J. Hou, M.Y. Zulkifli, H. Li, Y. Zhang, W. Liang, D.M. D'Alessandro, V. Chen, Surface functionalized UiO-66/Pebax-based ultrathin composite hollow fiber gas separation membranes, J. Mater. Chem. A, 6 (2018) 918-931
2. A. Ahmad, Z. Jawad, S. Low, S. Zein, A cellulose acetate/multi-walled carbon nanotube mixed matrix membrane for CO2/N2 separation, J. Membr. Sci., 451 (2014) 55-66.
3. Y. Dai, J. Johnson, O. Karvan, D.S. Sholl, W. Koros, Ultem®/ZIF-8 mixed matrix hollow fiber membranes for CO_2/N_2 separations, J. Membr. Sci., 401 (2012) 76-82.
4. G. Dong, X. Zhang, Y. Zhang, T. Tsuru, Enhanced permeation through CO_2-stable dual-inorganic composite membranes with tunable nanoarchitectured channels, ACS Sustain. Chem. Eng., 6 (2018) 8515-8524.
5. Q. Fu, J. Kim, P.A. Gurr, J.M. Scofield, S.E. Kentish, G.G. Qiao, A novel cross-linked nano-coating for carbon dioxide capture, Energy Environ. Sci., 9 (2016) 434-440.
6. K. Xie, Q. Fu, C. Xu, H. Lu, Q. Zhao, R. Curtain, D. Gu, P.A. Webley, G.G. Qiao, Continuous assembly of a polymer on a metal–organic framework (CAP on MOF): a 30 nm thick polymeric gas separation membrane, Energy Environ. Sci., 11 (2018) 544-550.
7. S. Li, Z. Wang, C. Zhang, M. Wang, F. Yuan, J. Wang, S. Wang, Interfacially polymerized thin film composite membranes containing ethylene oxide groups for CO_2 separation, J. Membr. Sci., 436 (2013) 121-131.
8. S. Kim, S.H. Han, Y.M. Lee, Thermally rearranged (TR) polybenzoxazole hollow fiber membranes for CO_2 capture, J. Membr. Sci., 403 (2012) 169-178.
9. D. Nikolaeva, I. Azcune, E. Sheridan, M. Sandru, A. Genua, M. Tanczyk, M. Jaschik, K. Warmuzinski, J. Jansen, I. Vankelecom, Poly (vinylbenzyl chloride)-based poly (ionic liquids) as membranes for CO_2 capture from flue gas, J. Mater. Chem. A, 5 (2017) 19808-19818.
10. Y. Ji, M. Zhang, K. Guan, J. Zhao, G. Liu, W. Jin, High-performance CO_2 capture through polymer-based ultrathin membranes, Adv. Funct. Mater., 29 (2019) 1900735.
11. B. Wang, Z. Qiao, J. Xu, J. Wang, X. Liu, S. Zhao, Z. Wang, M.D. Guiver, Unobstructed Ultrathin Gas Transport Channels in Composite Membranes by Interfacial Self-Assembly, Adv. Mater., (2020) 1907701.
12. Z. Qiao, S. Zhao, M. Sheng, J. Wang, S. Wang, Z. Wang, C. Zhong, M.D. Guiver, Metal-induced ordered microporous polymers for fabricating large-area gas separation membranes, Nat. Mater., 18 (2019) 163-168.