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Preparation and characterization of low cost porous ceramic membrane support from kaolin using phase inversion/sintering technique for gas separation: Effect of kaolin content and non-solvent coagulant bath

Siti Khadijah Hubadillah[a,b,*], Zawati Harun[b,c], Mohd Hafiz Dzarfan Othman[a], A.F. Ismail[a], Wan Norharyati Wan Salleh[a], Hatijah Basri[d], Muhamad Zaini Yunos[b,c], Paran Gani[e]

[a] Advanced Membrane Technology Research Centre (AMTEC), Universiti Teknologi Malaysia, 81310 Skudai, Johor, Malaysia

[b] Integrated Material and Process, Advanced Materials and Manufacturing Centre (AMMC), Faculty of Mechanical and Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia, 86400 Parit Raja, Batu Pahat, Johor Darul Takzim, Malaysia

[c] Department of Material and Design, Faculty of Mechanical and Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia, 86400 Parit Raja, Batu Pahat, Johor, Malaysia

[d] Department of Technology and Heritage, Faculty of Science, Technology and Human Development, Universiti Tun Hussein Onn Malaysia, 86400 Parit Raja, Batu Pahat, Johor Darul Takzim, Malaysia

[e] Department of Water and Environmental Engineering, Faculty of Civil and Environmental Engineering, Universiti Tun Hussein Onn Malaysia, 86400 Parit Raja, Batu Pahat, Johor, Malaysia

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ABSTRACT

The aim of this study is to investigate the feasibility of using kaolin as a starting material in ceramic membrane support preparation using phase inversion/sintering technique at different kaolin content and non-solvent coagulant bath. The ceramic suspension was prepared by mixing the kaolin, polyethersulfone (PESf) as binder, N-methyl-2-pyrrolidone (NMP) as solvent and Arlacel as dispersant using a magnetic stirrer; drying and sintering process at temperature of 1200 °C. By varying the kaolin contents, different morphologies of ceramic support were obtained due to the variations in viscosity of ceramic suspensions. Similarly, different non-solvent coagulant bath was found to affect the membrane support structure through liquid–liquid demixing process and at the same time affected membrane support's roughness, porosity, pore size distribution and strength. All ceramic supports possessed high gas permeation with no separation capability, proven the suitability as ceramic membrane support. The cost for the prepared ceramic membrane support in this work is as low as $5.97, prepared at 54.0 g kaolin content and immersed into distilled water.

* *Corresponding author at*: Integrated Material Process, Advanced Materials and Manufacturing Center, Universiti Tun Hussein Onn Malaysia, 86400 Parit Raja, Batu Pahat, Johor Darul Takzim, Malaysia. Tel.: +60 74537608; fax: +60 74536080.
E-mail address: ctkhadeeja@gmail.com (S.K. Hubadillah).

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1. Introduction

The combination of excellent thermal and chemical stabilities has made ceramic membranes as an attractive alternative to polymeric membranes (Fung and Wang, 2014; Harun et al., 2014; Hubadillah et al., 2014; Kingsbury and Li, 2009; Othman et al., 2010; Paiman et al., 2015). These advantages have resulted in ceramic membranes to show better durability under harsh condition such as gas separation application (Donelson et al., 2014; Isobe et al., 2007; Li and Hwang, 1992). Consequently, porous ceramic membrane support has received intensive attentions because of their advantages being used in a broad range of applications (Bouzerara et al., 2006; Isobe et al., 2013; Miao, 1999; Smart et al., 2013). Pore size distribution, total porosity ratio, surface quality and mechanical strength are among the major properties of the development of ceramic membrane support. The addition of top layer on the support which will be applied in the subsequent preparation steps is of crucial importance to the integrity of ceramic membrane.

Conventionally, most ceramic membrane support are usually made from expensive metal oxides such as alumina, zirconia, titania or a combination of these oxides. However, significant efforts have been made in recent years in membrane technology to develop new porous ceramic support from kaolin (Bouzerara et al., 2006; Bouzerara et al., 2012; Emani et al., 2014; Sarbatly, 2011). Kaolin is one of the most widely clay materials and has an important role in numerous industrial applications, such as provides low plasticity and high refractory properties (Bouzerara et al., 2006); and preferred raw material for porous ceramics (Ganesh and Ferreira, 2009). It may however be noted that most of the studies on kaolin were aimed at water and wastewater application (Bouzerara et al., 2006; Sahnoun and Baklouti, 2013) and no attempt has been made for gas separation.

Preparation of ceramic membrane using phase inversion technique is an emerging method for producing asymmetric ceramic membrane. In 2009, Li et al. had reported on the formation of macrostructures in a ceramic membrane from alumina using phase inversion technique is due to the hydrodynamically unstable viscous fingering (Kingsbury and Li, 2009). Three years later, Wang and Lai extended this work by investigating the effect of different non-solvent coagulant bath to distinguish characteristics according to the rules of the viscous fingering theory (Wang and Lai, 2012). In 2011, Sarbatly discovered that ceramic membrane from kaolin can be successfully prepared by phase inversion technique (Sarbatly, 2011).

Concerning to the costing problem in fabrication of porous ceramic membrane support toward gas separation application, therefore, this work aims to provide a thorough investigation on two important fabrication parameters toward the quality of prepared porous ceramic membrane support from kaolin material. Firstly, this paper continues the effort of two works (Sarbatly, 2011; Wang and Lai, 2012) to investigate the effect of non-solvent coagulant bath toward the fabrication of low cost ceramic membrane support using phase inversion technique. The composition for ceramic membrane support was adapted by work of Sarbatly (Sarbatly, 2011). Secondly, this study was also examined the effect of non-solvent coagulant bath. In this regard, it shall be noted that all supports will promote different morphologies according to previous studies. In this study, ceramic membrane support's characteristics which are surface roughness, pore size distribution, porosity and mechanical strength have been investigated. The gas separation performance will also be investigated in term of gas permeation and selectivity.

Table 1 – Composition of the ceramic dope suspension for ceramic membrane support.

Membranes	Composition (g)				Non-solvent coagulant bath
	Kaolin	NMP	PESf	Arlacel	
M1	54.0	150.75	27	1	Distilled water
M2	67.5	150.75	27	1	
M3	81.0	150.75	27	1	
M4	94.5	150.75	27	1	
E1	54.0	150.75	27	1	Ethanol
E2	67.5	150.75	27	1	
E3	81.0	150.75	27	1	
E4	94.5	150.75	27	1	
N1	54.0	150.75	27	1	70% NMP + 30% water
N2	67.5	150.75	27	1	
N3	81.0	150.75	27	1	
N4	94.5	150.75	27	1	

2. Experimental

2.1. *Materials*

Kaolin powder with particle size ranging from 0.3 μm to 0.8 μm purchased from BG Oil Chem Sdn Bhd was used as the ceramic particles. Polyethersulfone (PESf) (UDEL) was used as the polymer binder, while N-methylpyrrolidone (NMP, QRëC^{TM}) was used as the solvent.

2.2. *Preparation of ceramic suspension*

The kaolin powder and PESf were dried in an oven overnight at 60 °C to remove all moisture. Then, NMP and Arlacel was stirred at temperature of 60 °C prior to the addition of the kaolin powder. The suspension was then stirred for 48 h by using magnetic stirrer Yellow MAG HS 7 S2 (IKA) with a hot plate stirrer was set at 60 °C to ensure that the ceramic particles, solvent and additive were mixed well. The stirring was continued for another 48 h after the addition of PESf to ensure that the polymer binder was fully dissolved. After that, the suspension was degassed with slow stirring at 80 rpm under vacuum at room temperature until no bubbles were observed. Removing bubbles from the ceramic suspension was important to avoid defects, which usually forming small holes on the precursors.

2.3. *Fabrication of ceramic support from kaolin*

Fig. 1 and Table 1 show the preparation of flat-sheet ceramic precursor from kaolin by phase inversion technique and its composition, respectively. Precursor is sample before sinter to obtain final ceramic support. The prepared ceramic suspension was poured onto a clean and smooth glass plate of 15 cm × 15 cm at room temperature using a casting knife. The thickness of the ceramic support was controlled by using adhesive tape that sticked on the glass plate. The cast film was then immediately immersed into non-solvent coagulant bath. In this study, three different types of non-solvent coagulant bath were used which are distilled water, ethanol and mixture of 70% NMP and 30% distilled water for 24 h to complete