A Review on Effectiveness of Numerous Technologies by Utilizing Hydrogen

Mohd Syafiq Sharip[1], Norazlianie Sazali[1,2]*, Haziqatulhanis Ibrahim[1], Ahmad Shahir Jamaludin[1], and Farhana Aziz[3]

[1]Faculty of Mechanical Engineering, Universiti Malaysia Pahang, 26600 Pekan, Pahang, Malaysia.
[2]Centre of Excellence for Advanced Research in Fluid Flow (CARIFF), Universiti Malaysia Pahang, Lebuhraya Tun Razak, 26300 Gambang, Kuantan, Pahang, Malaysia.
[3]Advanced Membrane Technology Research Centre (AMTEC), School of Chemical and Energy, Faculty of Engineering, Universiti Teknologi Malaysia, 81310 Skudai, Johor Darul Takzim, Malaysia
azlianie@ump.edu.my

Abstract. Numerous technologies for H_2-rich gaseous mixture production has been know through studies. However, most approaches do not satisfy the purity level for certain process such as fuel cell technology that demands a high-purity hydrogen supply (>99.99 vol%). Therefore, purification technology to purify hydrogen is taken into consideration in order to meet purity requirement by certain applications, and it is a key factor to efficient hydrogen supply. In addition, CO_2 capture in pre-combustion of integrated gasification combined cycle (IGCC) power plants include the separation of H_2-CO_2 to generate electricity at a lower hydrogen purity. Advantage of hydrogen gaseous are its low volumetric energy density compared to other materials and the storage is essential for wider applications using hydrogen as well as hydrogen purification.

Keywords: Hydrogen purifications, fuel cell technologies, hydrogen storage, and selectives membrane.

1 Introduction

Abundance and longer lifetime of natural gas has initiated the idea of using it as primary feedstock in most petrochemical processing industries. Compared to other energy sources available, natural gas is the cleanest sources, generating low pollution than fuel. According to literature, it is expected that worldwide natural gas consumption will reach 182 trillion cubic feet in 2030, increasing from 95 trillion cubic feet in 2003 [1]. However, raw natural gas contains impurities such as methane (CH4), and other hydrocarbons such as ethane (C2H6), propane (C3H8), butane (C4H10), CO2 coexists and other impurities such as hydrogen sulphide (H2S), sulphur dioxide (SO2) and nitrogen (N2) are also present [2]. Therefore, it needs to undergo purification prior to the usage to prevent and minimized the fouling effect, corrosion, as well as pipeline rupture [3]. In addition, calorific value and transportability of natural gas would increase when carbon dioxide is removed from the gas mixture [4]. This separation can be achieved by employing thin barriers called membranes to remove the unwanted components and the technique was proven to be economically and technically excellent by past researchers [5]. Currently, performance H_2-selective membranes have been widely studied for separation of gas mixture H_2-CO_2. Molecules of H_2 are known to possess smallest kinetic diameter compared to other types of gases molecules, thus, it has a large diffusion coefficient which is suitable for permeation through membranes. Despite the reported achievements of hydrogen, gas separation via membrane technology still require lot of intensive investigations before being able to practice in a large-scale industrial application [6]. This is due to low quality hydrogen production from the reported H_2–CO_2 separation that unable to satisfy the requirement. To improve competitivity of membrane-based separation in terms of technology and economy, few challenges that need to be addressed by both scientific and engineering community has been outlined below [7]:

I. Materials' ability to develop a perfect, crack-free thin layer on porous supports or a self-standing thin film with enough mechanical strength, is the most essential factor in order to reach successful practical application, but are rarely investigated [8]. Even though the chosen materials possess a high permeability, it is unable to be practiced in industrial sector if it cannot be easily synthesized into a thin-selective layer. Therefore, fabrication of thin membrane with large area need to be handled alongside the advancements in advanced membrane materials. It should be noted that pre-requisite for a membrane to be successfully applied commercially are the stability of its separation performance under different practical conditions (i.e. pressure, temperature and impurities).

II. Development in materials science since the past decades has also shows improvement in performance of conventional membrane materials via structural optimization. Introduction to several advanced materials for novel membrane fabrication include metal organic frameworks (MOFs), graphene-based materials, thermal rearranged (TR) polymers, polymers of intrinsic microporosity (PIMs), ionic liquids (ILs) and functionalized polymers, which are specialized for hydrogen purification and produced from thermochemical and biotechnological method. Membranes for H_2–CO_2 separation can be classified as H_2-selective membranes or CO_2-selective membrane depending on its favorable gas species permeations. Alternatively, the gas mixture can be separated according to type of membrane materials, specifically inorganics membranes; polymeric and mixed matrix membranes. The only well-known H_2-selective membrane is molecular sieving mechanism for microporous membranes which resulted in high-efficiency gas transport. To achieve molecular sieving effects, complete control of pore structures need to be achieved first [9]. It includes pore size, shape of pores and pore size distribution. MOFs shows all the aforementioned requirements and thus, became the potential candidate for molecular sieving H_2-selective membranes. It is predicted that investigations for new fabrication approaches can produced a highly molecular-sieving MOF membrane.

2 Fuel Cell Development

Fuel cells advancement as well as environmental strains for example climate change concern lead to increasing global attention of hydrogen as clean energy carrier of high-quality in the recent years [10,11] . Purification and separation technologies are crucial in thermochemical operations of transforming fossil fuels into hydrogen. Membrane reactors demonstrate exceptional potential in equilibrium shift involving water–gas shift reaction in forming hydrogen from carbon monoxide. Membranes are also significant in hydrogen purification. There are two classification of inorganic membranes for hydrogen purification and production which are porous ceramic as well as metal alloys and dense phase metal membranes. Hydrothermal technique and sol-gel are usually used in preparing the porous ceramic membranes with qualities such as high durability and stability in elevated temperature, severe contamination as well as hydrothermal surroundings [12] . Particularly, microporous membranes exhibit potentials in water gas shift reaction at elevated temperatures. Registry of membrane technology importance and relevance to recent creation of zero-emission power technologies is necessary in order to study the vital concerns involved with these membranes according to economic and technical benefits as well as shortcomings. Hydrogen economy concept can be defined as hydrogen utilization as the primary energy carrier. This concept is already well-known among the policy makers and futurists for several decades. Promising prospective brought by hydrogen is widely recognized for nearly two centuries. Hydrogen was used as fuel in the first combustion engine build by Isaac de Rivaz in 1805 [13] . Fig. 1 illustrates hydrogen as fuel system [10].

[Fig. 1 here]

Nevertheless, steam and petroleum preceded hydrogen in powering engines until now. Implications of shifting to hydrogen economy are seriously considered by various countries. Increasing attention gained by hydrogen is attributed to its potential in solving two main concerns faced by the global economies which are achieving independence in energy while reducing the effect of economic activity on the environment [11]. Realization of hydrogen economy needs to be preceded by the development of four crucial technologies which are:

1. Cost effective hydrogen manufacture in carbon restricted system of global energy. This area comes with a few trials such as hydrogen production from fossil fuels with inclusion of carbon sequestration as well as growing employment of renewable sources.
2. Hydrogen storage and purification technologies with abilities to separate as well as refine hydrogen streams according to subsequent usage and storage systems essentials. US DOE target of 6.5 wt% needs to be achieved in developing practical and efficient hydrogen storage devices.
3. An effective, broadly accessible with sound management hydrogen distribution and delivery structures.

4. Effective fuel cells as well as other energy transformation technologies utilizing hydrogen (Fig. 2).

[Fig. 2 here]

3 Generation of H_2 and Purification Needs

Separation and purification technology are very crucial for H_2 derived from fossil fuels. In the process, water-gas shift reaction occurs and carbon monoxide is converted to H_2 inside a membrane reactor. In this context, membrane reactor shows a great potential in shifting the equilibrium. It should be noted that membranes also play an important role in purification mechanism of H_2. Economical way to produce H_2 is by stream reforming, where steam reacted with hydrocarbons and nickel are added to accelerate the process [14,15]. Example of competitive separating technology for H_2 from the streams is amine absorption, pressure swing adsorption (PSA), and membrane separation [16]. Among the list, gas separation using membrane system are more cost-effective than PSA in comparison to the relative capital investment and unit recovery cost [17]. Selective removal of H_2 from the reaction system shifted the reaction equilibrium to the products side, resulting in higher conversion of CH_4 to H_2 and carbon dioxide, and it can be obtained at lower temperatures. A simulation study which employed Pd-based disk membrane with 100µm of thickness proved the enhancement of steam reforming performance in a real membrane catalytic system [18,19]. From their study, the production of H_2 was increased but at high temperature range of 700 or 800°C. However, available commercial membrane for Pd-based membrane are too thick and does not work effectively at temperature suggested. Few properties of a good membrane reactors include high separation selectivity, high gas permeance, and the durability and stability of the membrane itself. There are two inorganic membrane classes for production and purification of H_2 which are dense phase metal, metal alloys and ceramics, and porous ceramic membranes [20].

4 Conclusion

Currently hydrogen-based technology is used in various gas separation processes such as H_2 recovery, H_2 purification, as well as H_2 storage. Although H_2 have been extensively applied for gas separation process and fuel cell development, these technologies are less competitive as compared to the conventional processes concerning to their performance and the durability. Few challenges that need to be addressed has been outlined in order to achieve a high-quality gas separation performance. Purification technology is essential, and it is a key factor to efficient hydrogen supply.

Acknowledgement

The authors would also gratefully acknowledge the financial support from the Ministry of Education and Universiti Malaysia Pahang under the Fundamental Research Grant Scheme (Project Number: Rdu1703253 and RDU191105).

References

1. Yeo ZY, Chew TL, Zhu PW, Mohamed AR, Chai SP. (2012). Conventional processes and membrane technology for carbon dioxide removal from natural gas: A review. Journal of Natural Gas Chemistry 21:282-298.
2. Scholes CA, Stevens GW, Kentish SE (2012). Membrane gas separation applications in natural gas processing. Fuel 96: 15-28
3. Chua ML, Xiao YC, Chung TS. (2013). Modifying the molecular structure and gas separation performance of thermally labile polyimide-based membranes for enhanced natural gas purification. Chemical Engineering Science 104: 1056-1064.
4. Ahmad AL, Adewole JK, Leo CP, Ismail S, Sultan AS, Olatunji SO. (2015). Prediction of plasticization pressure of polymeric membranes for CO_2 removal from natural gas. Journal of Membrane Science 480: 39-46
5. Adewole JK, Ahmad AL, Ismail S, Leo CP. (2013). Current challenges in membrane separation of CO_2 from natural gas: A review. International Journal of Greenhouse Gas Control 17: 46-65.
6. Lu GQ, Diniz da Costa JC, Duke M, Giessler S, Socolow R, Williams RH, et al. (2007). Inorganic membranes for hydrogen production and purification: A critical review and perspective. Journal of Colloid and Interface Science 314(2):589-603.
7. Sazali N, Norharyati W, Md. Nordin NAH, Mohamed M, Ismail A, Yusof N, et al. (2017). Influence of Carbonisation Temperature on Gas Permeation Properties of Matrimid-based Carbon Membrane.
8. Sazali N, Salleh WNW, Ismail AF. (2017). Carbon tubular membranes from nanocrystalline cellulose blended with P84 co-polyimide for H_2 and He separation. International Journal of Hydrogen Energy 42(15):9952-7.
9. Sazali N, Norharyati W, Nur Izwanne M, Harun Z, Kadirgama K. (2018). Precursor Selection for Carbon Membrane Fabrication: A Review
10. Hames Y, Kaya K, Baltacioglu E, Turksoy A. (2018). Analysis of the control strategies for fuel saving in the hydrogen fuel cell vehicles. International Journal of Hydrogen Energy 43(23):10810-21.
11. Ma C, Yu J, Wang B, Song Z, Xiang J, Hu S, et al. (2016). Chemical recycling of brominated flame retarded plastics from e-waste for clean fuels production: A re-view. Renewable and Sustainable Energy Reviews 61:433-50.
12. Wei Q, Wang F, Nie Z-R, Song C-L, Wang Y-L, Li Q-Y. (2008). Highly Hydrothermally Stable Microporous Silica Membranes for Hydrogen Separation. The Journal of Physical Chemistry B 112(31):9354-9.
13. Schemme S, Breuer JL, Samsun RC, Peters R, Stolten D. (2018). Promising catalytic synthesis pathways towards higher alcohols as suitable transport fuels based on H_2 and CO_2. Journal of CO_2 Utilization 27:223-37.
14. Acar C, Dincer I. (2018). The potential role of hydrogen as a sustainable transportation fuel to combat global warming. International Journal of Hydrogen Energy.

15. Ismail NH, Salleh WNW, Sazali N, Ismail AF. (2017). Effect of intermediate layer on gas separation performance of disk supported carbon membrane. Separation Science and Technology 52 (13): 2137-2149
16. Ismail NH, Salleh WNW, Sazali N, Ismail AF, Yusof N, Aziz F. (2018). Disk supported carbon membrane via spray coating method: Effect of carbonization temperature and atmosphere. Separation and Purification Technology 195: 295-304
17. Tseng H-H, Wang C-T, Zhuang G-L, Uchytil P, Reznickova J, Setnickova K. (2016). Enhanced H_2/CH_4 and H_2/CO_2 separation by carbon molecular sieve membrane coated on titania modified alumina support: Effects of TiO_2 intermediate layer preparation variables on interfacial adhesion. Journal of Membrane Science 510(Supplement C):391-404.
18. Sridhar S, Smitha B, Shaik A. (2005). Pervaporation a-Based Separation of Meth nol/MTBE Mixtures—A Review. Separation & Purification Reviews 34(1):1-33.
19. Lu H, Zhu L, Wang W, Yang W, Tong J. (2015). Pd and Pd–Ni alloy composite membranes fabricated by electroless plating method on capillary α-Al_2O_3 substrates. International Journal of Hydrogen Energy 40(8):3548-3556.
20. Wu W, Yang Q, Su B. (2018). Centimeter-scale continuous silica isoporous membranes for molecular sieving. Journal of Membrane Science 558:86-93.