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Riview Article

An Overview of the Development of Fluidized Bed Membrane Reactors in Hydrogen Production via Natural Gas Reforming

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1. ABSTRACT

Due to the problems associated with fossil fuels, much attention has been given to hydrogen as a renewable energy source. Hydrogen can be produced through various methods and materials. However, currently, the majority of hydrogen production is achieved through methane reforming. The development of membrane processes and membrane reactor technologies has led to a greater focus on the possibility of producing high-purity hydrogen through reforming processes. Based on research conducted on hydrogen production using fluidized bed membrane reactors and fixed bed membrane reactors, it is evident that fluidized bed membrane reactors necessitate a higher membrane surface area, approximately 20 to 25%. This is primarily due to the dominant temperature profile in packed bed reactors. Therefore, this article reviews and analyzes the research conducted on the development of fluidized bed membrane reactors for hydrogen production. The results of the steam methane reforming process in a fluidized bed membrane reactor demonstrate achieving hydrogen product purity levels up to 99.994%. When comparing steam reforming and autothermal reforming processes in fluidized bed membrane reactors, the hydrogen production rate ranges from $4.8 - 12\frac{\mathrm{N\ m^3}}{\mathrm{m^2\ h}}$ for steam reforming and $9 - 18\frac{\mathrm{N\ m^3}}{\mathrm{m^2\ h}}$ for autothermal reforming. Hence, hydrogen production using fluidized bed membrane reactor technology, which offers lower costs and higher efficiency, can be a suitable substitute for fossil fuels.

Keywords: Hydrogen Production, Membrane Technology, Fluidized Bed, Methane, Reforming Process.

2. INTRODUCTION

The process of supplying energy has traditionally relied on hydrocarbon energy sources (fossil fuels), which are geographically distributed and easily extractable but limited. The methods we have employed since the Industrial Revolution for production, conversion, and consumption of fossil fuels as our primary energy source have resulted in numerous environmental problems, such as a significant increase in CO_2 levels and other greenhouse gases in the Earth's atmosphere, which are the main contributors to global warming, acid rain, ozone layer depletion, and climate change. Recently, various solutions have evolved to address the current environmental problems associated with harmful emissions[1, 2]. It seems that hydrogen energy systems are one of the most effective solutions, and in recent years, there has been great interest in H_2 as an alternative fuel for energy supply due to its clean nature, ease of use, and high energy efficiency compared to hydrocarbon fuels[3, 4]. Hydrogen can be produced from a wide range of sources using various raw materials, including fossil fuels and renewable energy sources, as well as different pathways and technologies[1].

3. Methodology

In recent years, the use of selective membranes for hydrogen conversion has garnered significant attention from researchers and industrial communities in order to increase the conversion of hydrocarbons for hydrogen production and synthesis gas[5]. The use of membrane reactors containing selective membranes for hydrogen is promising because it allows simultaneous transport to occur in equilibrium and facilitates the purification of pure hydrogen. To achieve a high-purity hydrogen permeate stream, dense metal membranes that are selectively permeable to hydrogen are employed. In

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general, a fluidized bed membrane reactor consists of a set of membranes immersed in a catalytic bed and operates under a bubbling or turbulent regime. In fluidized bed membrane reactors, mass transfer limitations (concentration polarization) from the bed to the membrane surface are reduced, and the intense movement and circulation of the catalyst inside the reactor increase the rate of mass and heat transfer.

4. RESULTS AND DISCUSSION

The operational temperature and pressure play a crucial role in the steam methane reforming process conducted within a fluidized bed membrane reactor. The overall efficiency of this reaction is significantly enhanced by higher temperatures and pressures, resulting in increased conversion of methane and higher yields of hydrogen. The selection of appropriate temperature and pressure for the steam methane reforming process in the fluidized bed membrane reactor depends on several factors, including the catalyst used, membrane specifications, and desired composition of the end product.

Differentiating between autothermal reforming and steam reforming lies in their heat supply mechanisms. In the context of a fluidized bed membrane reactor, autothermal reforming offers distinct advantages due to its ability to generate internal heat. This characteristic contributes to enhanced efficiency and increased hydrogen production, setting it apart from steam reforming of methane.

The conducted research indicates significant potential for the application of combined steam and CO2 reforming reactions in both fluidized bed membrane reactors and specialized fluidized bed membrane systems designed for dry methane reforming. The environmental benefits of converting CO2 into usable hydrogen are noteworthy. However, it is anticipated that this method may yield lower quantities of hydrogen compared to alternative reforming approaches. The catalysts, operating conditions and feed conditions used in various research studies on different reforming processes in fluidized bed membrane reactors are shown in Table 1, Table 2, and Table 3.

Table 1. Common catalysts studied in the fluidized bed reactor system for hydrogen production through methane steam reforming process

References	Operating conditions	Feed conditions	catalyst
Mahecha-Botero et al. (2009)	P=0.5-3 MPa T=500-900˚C	$\frac{S}{C}=3$ $F_{CH_4}=4.465\frac{kmol}{h}$	Nickel on Alumina
Mahecha-Botero et al. (2008)	P=650-900 kPa	$\frac{S}{C}=3$ feed rate=0.896,0.448,0.298$\frac{Nm^3}{min}$	A nickel oxide catalyst supported on alumina
Medrano et al. (2016)	P=2-5 bar T=500-600˚C	$\frac{S}{C}=2-4$ feed rate =3.5-5.2 $\frac{L}{min}$	Ni/$\mathbf{CaAl_2O_4}$ reforming catalyst
Xie et al. (2010)	P=0.5-3 MPa T=400-800˚C	$F_{CH_4}=1000\frac{mol}{h}$ $\frac{S}{C}=0.5-5$	Nickel based catalyst
Dehkordi et al. (2009)	P=1.8-2.6 MPa T=700-1200˚C	$\frac{S}{C}=0-6$ $F_{CH_4}=175\frac{kmol}{h}$	Nickel based catalyst
Abashar et al. (2003)	P=1.8-2.6 MPa T=700-1200˚C	$\frac{S}{C}=0-6$ $F_{CH_4}=175\frac{kmol}{h}$	Ni/$\mathbf{MgAl_2O_4}$

Table 2. Common catalysts studied in the fluidized bed reactor system for hydrogen production through methane autothermal reforming process

References	Operating conditions	Feed conditions	catalyst
Mahecha-Botero et al. (2008)	P=650-900 kPa	$\frac{S}{C}=3$ feed rate =0.896,0.448,0.298$\frac{Nm^3}{min}$	A precious metal catalyst supported on alumina
Lu et al. (2018)	P=1 bar T=900˚C	$F_{CH_4}=373.4\frac{kmol}{h}$ $\frac{S}{C}=2$	Pt/$\mathbf{AL_2O_3}$
Chen et al. (2007)	P=1500-2600 kPa T=500-600˚C	$\frac{S}{C}=2-3.5$ Feed rate=0.8-1.2 $\frac{kg}{h}$	commercial autothermal reforming catalyst

Table 3. Common catalysts studied in the fluidized bed reactor system for hydrogen production through methane dry reforming process

References	Operating conditions	Feed conditions	catalyst
Shahkarami et al. (2015)	P=0.1-1 MPa T=650-1000 K	$\frac{S}{C}=0-3$ $\frac{CO_2}{CO}=0-3$	$\mathbf{Ni}/\mathbf{La_2O_3}$
Duran et al. (2019)	T=475-575˚C	feed rate =235.5 $\frac{mL}{min}$ Gas composition= (CH_4:30), (CO_2:30), (N_2:5), (O_2:10), (Ar:25)	$\mathbf{Ni(5\%)-Ce(10\%)}/\mathbf{Al_2O_3}$
Abashar(2004)	P=1 MPa T=650-850	$\frac{S}{C}=1.6-10$ $F_{CH_4}=30\frac{mol}{h}$	$\mathbf{Ni}/\mathbf{La_2O_3}$

5. CONCLUSION

Hydrogen is a suitable solution to fossil fuel issues and can be produced through various methods. Membrane reactors demonstrate better performance compared to traditional reactors for hydrogen production. Based on various studies, it can be concluded that dry methane reforming is not the optimal option for hydrogen production in a fluidized bed membrane reactor. Among the two processes, autothermal reforming and steam methane reforming, the latter appears to be more suitable for hydrogen production in a fluidized bed membrane reactor. Additionally, it provides better energy efficiency due to lower external heat requirements.

6. REFERENCES

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