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Wildan Baina Iedai El Islami and Asep Handaya Saputra

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Wildan Baina Iedai El Islami[1], Asep Handaya Saputra[2]

[1,2)] Chemistry of Engineering, Universitas Indonesia, Depok 16424, Indonesia
e-mail: wildan.baina@ui.ac.id, sasep@che.ui.ac.id

Abstract.
The rising concern about climate change coupled with the depletion of fossil fuels and energy security are major worldwide challenges. For this reason, scientists are trying to find affective and sustainable energy sources to overcome this issue. Hydrogen is regarded as an excellent energy vector to replace fossil fuels future as it offers a wide range of advantages. In this study, the selection of electrolysis technology for effective and efficient hydrogen production are observed in order to get a reference in the development of hydrogen plants. Three main electrolyser technologies are used or being developed today. This section provides a brief overview of the technology outlook for electrolysers, or detailed modelling of their performance. The selection of the electrolyzer will be based on several technical criteria by a weighting system. The scoring pattern in this weighting system is given a range of values from 0 to 10 with the decision making value. The electrolyzer technology selected based on the results of the weighting (scoring) is PEM (proton exchange membrane) technology with a weighting value of 8.32. Meanwhile, the alkaline electrolyzer and solid oxide electrolyser technology obtained a weighting value of 7.55 and 3.05.

Keywords: Hydrogen Production, Alkaline, Electroliser, PEM, Solid Oxide

Introduction

Environmental regulations such as the Paris agreement or the intergovernmental panel on climate change, the United Nations Framework Convention on Climate Change (UNFCCC) related to CO_2 emissions, are becoming increasingly stringent around the world, creating a trend of shifting energy use towards renewable energy. There are various kinds of alternative energy from renewable energy sources, one of which is hydrogen energy. The development of hydrogen energy is growing rapidly in recent years as green energy sources have become much more important in various industries and can replace natural gas in the future. Countries in the world that have massively developed hydrogen energy such as Japan, Korea, Italy, Saudi Arabia, China, Turkey have started researching and pioneering the development of technology to produce hydrogen from renewable energy sources with competitive hydrogen production costs and have also begun to develop utilization of hydrogen energy in the transportation sector. Hydrogen production technology based on renewable energy can be produced through electrolysis with electrical energy sources from renewable energy. The choice of the best option for hydrogen production depend on various criteria (such as resource availability, technology maturity, cost…), besides, the consideration of hydrogen as green energy carrier depends on how its produced. Consequently, only renewable sources of energy must be considered for a sustainable hydrogen production. One of the most promising and sustainable technology to produce hydrogen is water electrolysis. Water electrolysis is the process of using electricity in two electrodes to split water molecule via the following reaction: $2H_2O \longrightarrow 2H_2+O_2$. Water electrolysis has many advantages: a high energy conversion efficiency; it can produce hydrogen with high purity which is required for the fuel cells; it's a wellestablished technology, and perfectly compatible with renewable energies.

Materials and Methods

Three main electrolyser technologies are used or being developed today. This section provides a brief overview of the technology outlook for electrolysers, or detailed modelling of their performance and related impact on the cost of hydrogen production. Alkaline (ALK) electrolysers have been used by industry for nearly a century. Proton exchange membrane (PEM) electrolysers are commercially

available today and are rapidly gaining market traction as, among other factors, they are more flexible and tend to have a smaller footprint. Solid oxide electrolysers hold the potential of improved energy efficiency but are still in the development phase and, unlike ALK and PEM, work at high temperatures (FCH JU, 2017a; FCH JU, 2014). ALK electrolyser technology is fully mature. It has been used by industry since the 1920s for non-energy purposes, particularly in the chemicals industry (e. g. chlorine manufacture). The lifetime of an ALK electrolyser is currently twice as long, and is expected to remain significantly longer for the next decade. Table 1 below provides a general overview of the techno-economic characteristics of ALK and PEM electrolysers today and their expected future improvements. State-of-the-art PEM electrolysers can operate more flexibly and reactively than current ALK technology. This offers a significant advantage in allowing flexible operation to capture revenues from multiple electricity markets, as PEM technology offers a wider operating range and has a shorter response time (NREL, 2016a; NREL, 2016b).
The selection of electrolyser technology considers several technical. The parameters that are considered in the selection of electrolyser technology are the dimensions of the electrolyser, efficiency of electricity to hydrogen, low investment costs, optimum production capacity, reliability in operation, easy maintenance and can be used at Cirata floating solar photovoltaic locations. How to choose technology is to use criteria and specifications of the advantages and disadvantages of each technology. Assessment in the selection of technology is carried out with a weighting system where the weighting value scale is 1-5 with minimum and maximum value parameters. The criteria and parameters that will be weighted in the technology selection (Grigoriev, S. A., Et.al, 2006)

Results and Discussion

There are 3 methods to choose the technology for hydrogen production from electrical energy (electrolysis). The selection of the electrolyzer will be based on several technical criteria and economic criteria determined by a weighting system. The scoring pattern in this weighting system is given a range of values from 0 to 10 with the decision making value based on the references listed in the three tables below. The comparison of electrolyzer technology that will be selected according to the point value and the largest weight system from the comparison of technical specifications and the economic value of each technology is shown in Table 1, Table 2 and Table 3 below.

Table 1 Assessment Criteria and Weighting for PEM Electrolyzer Technology

No	Assessment criteria	Proton Exchange Membrane Electroliser			
		Description of Weighting Factors	Value	Percen-tage(%)	Sco-Ring
1	**Dimension**	Design simplicity dan Compact System	10	5	**0,5**
2	**Stack Lifetime**	The lifetime of the stack can reach 40,000 operation hours	4	5	**0,2**
3	**Start up/ shutdown**	Time required for start up and shutdown 1 - 5 seconds	10	5	**0,5**
4	**System Efficiency**	Reaches 80%	8	5	**0,4**
5	**Durability (hours)**	Able to operate up to 50,000 hours	5	5	**0,25**
6	**Output Pressure**	15-30 Bar	10	5	**0,5**
7	**Specific system energy consumption**	3,8 - 5,0 kWh/Nm3	6,8	5	**0,34**
8	**System Lifetime**	10-20 years	5	5	**0,25**
9	**Maturity Technology**	Early Commercial	7,5	5	**0,375**
10	**Annual Degradation**	Range 2%-4%	10	5	**0,5**
	Total Scoring				**3,815**

Table 2 Assessment Criteria and Weighting for Alkaline Electrolyzer Technology

No	Assessment criteria	Alkaline Electroliser			
		Description of Weighting Factors	Value	Percen-tage(%)	Sco-Ring
1	Dimension	Large stack size and relatively large area required	5	5	0,25
2	Stack Lifetime	The lifetime of the stack can reach 90,000 operation hours	9	5	0,45
3	Start up/ shutdown	Time required for start up and shutdown 1 - 10 minutes	2,5	5	0,125
4	System Efficiency	Reach 60%	6	5	0,3
5	Durability (hours)	Able to operate up to 100,000 hours	10	5	0,5
6	Output Pressure	2-10 Bar	3,5	5	0,175
7	Specific system energy consumption	Range 4,5 - 5,5 kWh/Nm3	2,5	5	0,125
8	System Lifetime	20-30 years	10	5	0,5
9	Maturity Technology	Commercial	10	5	0,5
10	Annual Degradation	Range 8%-10%	5	5	0,25
	Total Scoring				3,175

Table 3 Assessment Criteria and Weighting of Solid Oxide Electrolyzer Technology

No	Assessment criteria	Solid Oxide Electroliser			
		Description of Weighting Factors	Value	Percen-tage(%)	Sco-Ring
1	Dimension	No commercial designs yet	0	5	0
2	Stack Lifetime	The lifetime of the stack can reach 4,000 operation hours	0,4	5	0,02
3	Start up/ shutdown	The time required for start up and shutdown is about 5 minutes	5	5	0,25
4	System Efficiency	Reach 90%	9	5	0,45
5	Durability (hours)	Able to operate up to 2.000 hours	2	5	0,1
6	Output Pressure	Maximum 20 Bar	7	5	0,35
7	Specific system energy consumption	Range 2,6 - 3,6 kWh/Nm3	10	5	0,5
8	System Lifetime	There is no commercial design yet and production is still on a lab scale.	0	5	0
9	Maturity Technology	Still in the research and development stage	2,5	5	0,125
10	Annual Degradation	Reach 17%	2,5	5	0,125
	Total Scoring				1,92

The electrolyzer technology selected based on the results of the weighting (scoring) as shown in Table 1, Table 2 and Table 3 above is PEM technology with a weighting value of 8.32. Meanwhile, the alkaline electrolyzer and solid oxide electrolyser technology obtained a weighting value of 7.55 and 3.05, respectively. This scoring result shows that the comparison between PEM technology and Alkaline has a relatively small difference in value, but the difference in the scoring ratio between PEM and alkaline electrolyzer and solid oxide electrolyser technology is too large. This difference in solid oxide occurs because the technology is fundamental, namely it is still in the research and development stage or is still in the laboratory-scale research stage, so there is no definite data regarding dimensions and commercial lifetime. In addition, solid oxide electrolyzer has not been developed into a commercial stage because this technology requires high temperature conditions of around 800 – 1000 ^{0}C so that large electrical energy is needed to produce this temperature. This is a consideration in the development to the commercial stage because it is considered less effective and efficient than alkaline technology or PEM electrolyzer.

The difference in technical specifications that most influence the weight value between PEM technology and alkaline electrolyzer are several variables, including the dimensions and design of the electrolyzer system. The dimensions and design of the PEM electrolyzer are simpler and the system design is more compact so that it requires a relatively small area. Meanwhile, the separate stack design in alkaline electrolyte technology causes the required area to be relatively large compared to PEM electrolyzer technology. The second technique variable that is very influential on the weighting is the start up and shutdown of the electrolyzer operation where in PEM technology the electrolyzer takes 1 to 5 seconds for the start up and shutdown process. Meanwhile, the alkaline electrolyzer technology takes 1 to 10 minutes. The next variable that makes the alkaline electrolyser score lower than the PEM electrolyzer is the efficiency of the system. The efficiency of PEM electrolyzer in producing hydrogen reaches 80%, whereas in alkaline electrolyser the efficiency is only capable of a maximum of 60%. The next variable that influences is the specific system Energy Consumption, where the PEM electrolyzer technology only requires energy in the range of 3.8 – 5 kWh/Nm3 in producing hydrogen. While the alkaline electrolyzer requires energy ranging from 4.5 to 5.5 kWh/Nm3 in producing hydrogen. The last variable that is considered as a technique that causes the alkaline electrolyser to have a lower score than the PEM electrolyzer is Annual Degradation. The value of decreasing operating performance each year for alkaline electrolyzers is in the range of 8% - 10%, while PEM electrolyzer only experiences a decrease in operating performance every year in the range of 2% - 4%.

Conclusions

According to the Results and Discussion, PEM electroliser technology is preferable from a technical point of view for electrolyzer operation. The relevance of technical in dynamic operation is striking, which are generally higher for other technology. The focus is on the mere utilization of renewable electricity, PEM electroliser offers advantages. However, due to the higher calculated efficiency for the other technology, these advantages necessarily result in higher hydrogen production quantities.

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