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Main factors affecting the lifetime of Proton Exchange Membrane fuel cells in vehicle applications: A review

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HIGHLIGHTS

- Reviewed the PEMFC life degradation during the durability tests and its consequences.
- Reviewed the water management problems: causes, consequence and mitigation methods.
- Reviewed the reactant starvation issues: causes, consequence and mitigation methods.
- Reviewed the effects of the operating parameters on PEMFC dynamic response.
- The conclusion is a guidance for future research of prolong PEM fuel cell life time.

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ABSTRACT

This paper focuses on reviewing the main factors affecting the life time of fuel cells on vehicles. The main difference between fuel cells used in vehicles and fuel cells used as fixed power is the load cycling. Load cycling sometimes leads to water management and gas transport problems, which further leads to degradation of fuel cell performance and attenuation of internal parts. This article is written from the perspective of the fuel cell dynamic cycling as well as its resulting problems of water management and gas starvation, and also analyses the reasons for the degradation of fuel cell life time, and present some mitigation measures during the fuel cell operation.

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1. Introduction

PEM fuel cell system is the main component of a fuel cell vehicle. Compared with other power systems, because of its high power utilization rate and zero emission [1–3], it is considered as one of the most effective power systems for a vehicle [4,5]. To make this technology commercially viable, there are still many challenges. Apart from the high cost of fuel cell systems, high maintenance costs and short lifecycle are the two main issues that need to be addressed [6].

Up to now, while comprehensive studies such as experimental results and reviews have been published in an attempt to understand the degradation mechanisms of fuel cell components such as electro-catalysts [7–9], membranes [10,11], and bipolar plates [12–14], only a relatively small part of studies aimed at real Proton Exchange Membrane (PEM) fuel cell lifetimes have been conducted, due to the high costs and long testing periods required. To increase sample throughput and reduce the experimental time required, several fuel cell developers and companies, such as Ballard Power Systems, Gore, DuPont, and General Motors, have proposed and implemented different accelerated stress tests (ASTs) to determine the durability and performance of current fuel cell components. Papers published in the last decade on PEM fuel cell degradation and lifetimes are shown in Table 1 [15] and Table 2 [15], which presents work on steady state and accelerated lifetime tests, respectively. Prior to commercializing fuel cell technology, more studies of components and analyses of system failure modes are imperative [15].

Table 1 [15] and Table 2 [15] show that the decay rate of the different evaluation methods; the life of the fuel cell under steady-state operation can be very long, up to 26,300 h; the voltage degradation rate is very large during accelerated durability tests, especially during the cold start-up, the voltage degradation reached 22.5 mV. The life time of PEM fuel cell is a prominent problem in its use, and is also one of the main factors hindering its commercialization. The life time of a fuel cell on a vehicle is about 2500–3000 h [42] much shorter than the life time of a fuel cell operating as a fixed power sources which is over 30 thousand hours [43]. Regarding the application of fuel cells in a vehicle, many factors affect its life time, as fuel cells make use of the air

Table 1
Summary of steady state lifetime tests in the literature [15].

Authors	Test time (h)	Degradation rate	Refs.
Ralph	5000	4 μV h^{-1}	[16]
St-Pierre et al.	5000	1 μV h^{-1}	[17]
Washington	4700	6 μV h^{-1}	[18]
	8000	2.2 μV h^{-1}	
Endoh et al.	4000	2 μV h^{-1}	[19]
Yamazaki et al.	8000	2–3 μV h^{-1}	[20]
St-Pierre and Jia	11,000	2 μV h^{-1}	[21]
Fowler et al.	1350	11 μV h^{-1}	[22]
Ahn et al.	1800	>4 mV h^{-1}	[23]
Cheng et al.	4000	3.1 μV h^{-1}	[24]
Scholta et al.	2500	20 μV h^{-1}	[25]
Cleghorn et al.	26,300	4–6 μV h^{-1}	[26]

Table 2
Summary of accelerated durability tests in the literature [15].

Authors	Test time (h)	Degradation rate	Operating conditions	Refs.
Sishtla et al.	5100	6 μV h^{-1}	Reformate fuel	[27]
Nakayama	4000	4.3 μV h^{-1}	Reformate fuel	[28]
Isono et al.	2000	10 μV h^{-1}	Reformate fuel	[29]
Maeda et al.	5000	6 μV h^{-1}	Reformate fuel	[30]
Sakamoto et al.		50–90 μV	Per start/stop cycles	[31]
Fowler et al.	600	120 μV h^{-1}	Humidity cycles	[32]
Cho et al.		4200 μV	Per thermal cycles	[33]
Knights et al.	13,000	0.5 μV h^{-1}	Methane reformate fuel Low humidification	[34]
Oszcipok et al.		22,500 μV	Per cold start-up	[35]
Xie et al.	1916	60 μV h^{-1}	Over-saturated humidification	[36]
	1000	54 μV h^{-1}		
Yu et al.	2700	21 μV h^{-1}	Low humidification	[37]
Endoh et al.	3500	3 μV h^{-1}	High temperature, low humidification	[38]
Du et al.	1900	70–800 μV h^{-1}	Cold start and hot stop	[39]
Xu et al.	1000	<10 μV h^{-1}	High temperature, low humidification	[40]
Owejan et al.		0.212 mV	Per start/stop cycles	[41]

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