H2D[ee]P

FUEL CELL DIVER PROPULSION VEHICLE

Submission to the Hydrogen Ambassadors International Competition

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Introduction

Today's Diver Propulsion Vehicles consist of a battery operated motor, contained within a waterproof housing, which spins a shaft connected to a propeller. A diver holds onto the device as shown in Figure 1. Diver Propulsion Vehicles (DPV) are used by divers to move a large amount of equipment, minimize gas consumption, or to reach a destination faster. Underwater mobility technologies are used by professional divers for commercial, scientific, or military purposes, and by recreational divers for personal use [1]. Thus, depending on the application for which the end users purchase a DPV, the selection criteria can include maximum diving depth, weight, operating speed, battery lifetime, and cost.

Figure 1: Typical diver propulsion vehicle configuration [2]

The current state of DPV technology makes it an ideal candidate for a polymer electrolyte membrane (PEM) fuel cell application with true commercial potential. The purpose of this document is to highlight the advantages that a fuel cell powered DPV offers over conventional battery operated DPVs. The proposed design will be referred to as the H_2D[ee]P: the Hydrogen Diver Propulsion vehicle.

H_2D[ee]P Design

The fuel cell powered DPV design outlined here is a preliminary analysis of the fuel cell stack selection, fuel delivery options, as well as electrical and gas consumption requirements. The H_2D[ee]P design improves the key features of the energy storage and conversion system of the Sea-Doo® Seascooter™ Explorer, manufactured by DAKA [3] by replacing the current battery operated equipment with a hydrogen polymer electrolyte fuel cell.

Assuming that the H_2D[ee]P uses the same 170 W at 12V motor as the Sea-Doo® Seascooter™ Explorer, a fuel cell stack containing twenty 25 cm^2 active area cells, weighing 7.3 kg, is designed to take advantage of the single operating point and maximize efficiency. A target dive duration of 3 hours can be met using hydrogen stored in compressed gas cylinders. A comparison of the fuel cell and traditional battery operated DPV is provided in Table 1 below.

Table 1: H_2D[ee]P vs. Battery powered DVP

Metric	**H_2D[ee]P**	**Seascooter**
Range (h)	3	1.5
Recharge (minutes)	5	4200 (8h)
Estimated Weight (lbs)	29	32
Fuel Options	Compressed air or recycled air / H_2	N/A
Price (short term) $CND	1,000 – 1,500 (without mark up)	900

For the design proposed above, air is primarily delivered to the fuel cell from a supplementary (not diver's air) pressurized air tank. It is also possible to use the air exhaled by the diver to power the fuel cell. Such an air recycling option would lead to an advantageous weight reduction and efficiency improvement. Figure 2 shows a simple overview of the recycled air option functionality.

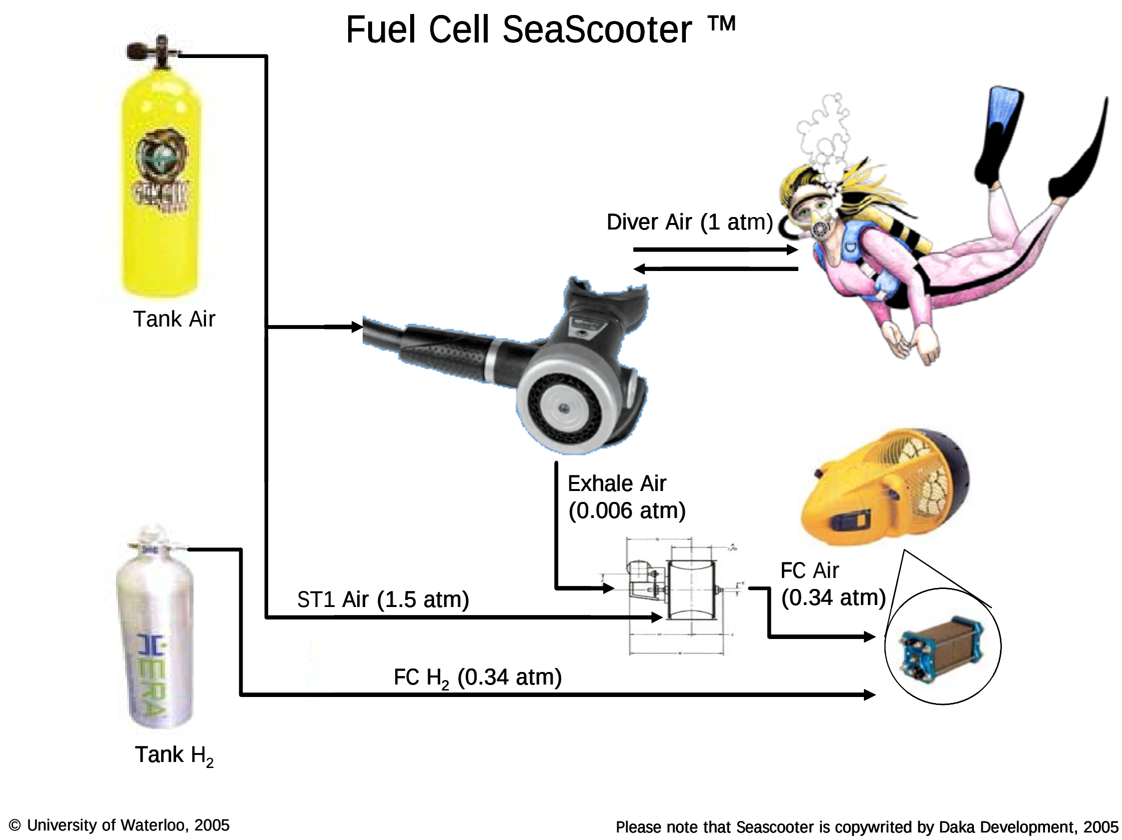

Figure 2: H_2D[ee]P Recycled Air Option Functionality

With regards to the recycling option, it is important to note that the air exhaled by a diver contains approximately 16% oxygen per unit volume and is humidified, which makes it a favorable fuel cell reactant. The air exhaled by the diver must be compressed before being fed to the fuel cell. A novel pressure-assist compressor should accomplish this without affecting the diver's ease of breathing. Additionally, an air tank would be used to compensate for the diver's inhalation cycles.

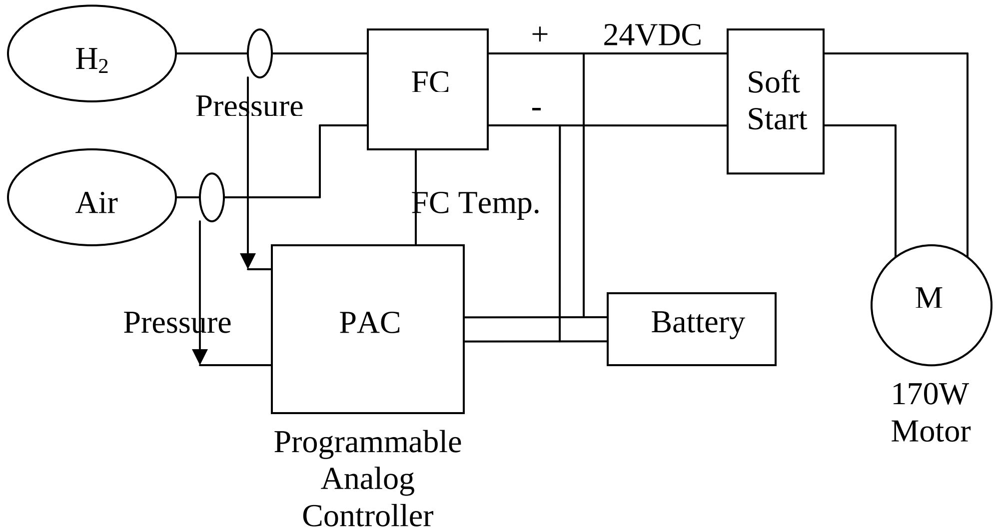

Figure 3: H_2D[ee]P electrical overview.

By constraining the H_2D[ee]P to a single operating point, the fuel cell can operate by using feedback control on its temperature and reactants' pressure as shown in Figure 3. Table 2 outlines the main specifications on the H_2D[ee]P.

Table 2: H_2D[ee]P specifications based on the Sea-Doo® Seascooter™ Explorer [3]

Specifications		H2D[ee]P
Size	597 x 366 x 311 mm (15" x 16" x 9")	
Weight	29 lbs / 13 kg	
Buoyancy	For snorkeling it is usual to have about 2 lbs buoyancy. For diving, it is usual to have about 5 oz buoyancy (150 grammes). In both cases, the H2D[ee]P will rise to the surface if released at depth.	
Performance	Speed	The maximum attainable speed when using the H2D[ee]P depends on body position, but 3.3 mph (4.8 kph) is typical.
	Operating time	Target value: 3 hours with standard hydrogen canisters.
	Depth rating	160 feet / 53 m
	Power to weight ratio	1.1 kgf/kg 1.1 lbf/lb
Motor	12 V DC -170 W continuous	
Fuel cell	PEM - 20 cell, 25 cmsq. 10 kPa, 65 C	
Materials	Housing:	Polypropylene
	Gears:	Acetal
	Levers:	Nylon
	Seals:	PTFE impregnated NBR

	Fuel cell:	Graphite, Nafion	
	Gas storage:	Stainless steel YST130N	4
Operation	Master switch:	Is used to disable the normal on/off trigger. When in the off position, the H2D[ee]P can be safely handled without fear of mistakenly enabling the motor.	
	Trigger:	The H2D[ee]P has a finger-operated trigger, which, when depressed, accelerates for a moment using a "soft start" before max speed is requested from the motor	
Safety	Safety grille	The safety grilles must be kept on the frame at all times and be removed for maintenance only	
	Obstruction sensor	Is fitted on the H2D[ee]P to protect both the user and the motor.	
	Hydrogen supply	Follow the hydrogen supply user manual instructions carefully.	
Maintenance	Rinse with tap water after use. Do not open housing divider leading to fuel cell, service may only be performed by authorized personnel		

H_2D[ee]P Economics and Market

A review of the current market revealed that the price for a battery operated DPV ranges from $200 CND for a very basic recreational model [4] to over $10,000 CND for larger military units. The battery lifetime, the tow capacity, the depth capacity, and the weight of the DPV dictates its price. It is estimated that a H_2D[ee]P prototype would cost approximately $4,000 CND using current off-the-shelf components. This cost is almost exclusively due to the fuel cell stack cost, which includes a large OEM profit margin. It is believed that a realistic production cost for the H_2D[ee]P would range between $1,000 to $1,500 CND, assuming that mass production could reduce its current off-the-shelf price by 5 times, which is reasonable considering that automotive applications require a much higher cost reduction. Nonetheless, the premium price of the H_2D[ee]P can be justified by its advantages over the currently available DPVs.

Environmental and Social Benefits

The main environmental benefit of the H_2D[ee]P is greater energy efficiency, which translates into less waste. This technology also prevents large amount of battery waste from reaching landfills. From a larger perspective, DPVs are a doorway to the wide scale introduction of fuel cells in the marine industry as a replacement for environmentally unfriendly technologies such as diesel generators and gasoline motors. The H_2D[ee]P will help further marine science and security allowing research and military divers to dive for longer periods and cover greater distances. Finally, the H_2D[ee]P is an ideal technology for introducing fuel cells to the larger public, pushing forward the hydrogen economy. Divers, the users of the H_2D[ee]P, are already familiar with compressed gas technologies and therefore will likely accept the product more readily.

Conclusion

The H_2D[ee]P design presented in this document consists of a fuel cell powered Diver Propulsion Vehicle. A PEM fuel cell stack provides power to the propeller's 170W motor based on the Seadoo® SeaScooter™ Explorer design. Hydrogen and air are provided to the fuel cell by small compressed gas cylinders attached to the unit. It is also proposed to recycle air exhaled by the diver and reuse it as a reactant supply. The H_2D[ee]P design would offer four main advantages over the traditional battery operated DPV:

1) Longer/Customizable Lifetime Range
2) Shorter Refuelling Time
3) Lower Weight
4) Recycled Air Option

The targeted production cost for the H_2D[ee]P is between \$1,000 and \$1,500 CND, which assumes that mass production of fuel cells would result in a 5 fold cost reduction.

From a wider perspective, penetration into the DPV market can lead to wider fuel cell technology acceptance throughout the marine sector.

Bibliography

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