Remotely Operated Vehicle (ROV) Design and Fuel Cell Applicability

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Abstract

Underwater vehicles are counted as one of the most important aspect for marine technology and science. Increasing fuel prices, emissions restrictions, sustainability and environmental regulations are forcing international maritime industry for energy efficient vehicles. MARPOL (International Convention for the Prevention of Pollution from Ships) and IMO (International Maritime Organization) has urged its member countries on marine pollution from operational or accidental causes.

Underwater vehicles require long time power to operate efficiently and continuously. Fuel cell systems promises sustainable technology to power generation for maritime industry. In this study, a fuel cell powered remotely operated vehicle (ROV) is designed and also mass, size, and energy balance of system components are considered. Due to high efficiency and low operation temperatures, proton exchange membrane (PEM) type fuel cell is used. Aim of this study; investigate environmentally friendly fuel cell applicability on ROV with an efficient and perpetual design.

Keywords— ***ROV, fuel cell, electric propulsion, PEM***

I. INTRODUCTION

Underwater vehicles are operated manned and unmanned. Unmanned underwater vehicle is divided remotely operated vehicle (ROV) and Autonomous underwater vehicle (AUV) by its connection type [1]. Remotely operated underwater vehicle have a tethered operation [1]. ROVs are used for many different purposes such as underwater observation, maintenance and inspector. Nowadays, most of underwater vehicles are thrusted by diesel fuel [2]. However remotely operated vehicle can be powered by three categories: Surface powered, vehicle-powered, or a hybrid system [1]. Due to the fact that electrical power in ROV is required for moving with cable, there are tendency to use electrical power source such as fuel cells [3].

In the present work, underwater operated vehicle design is powered by polymer electrolyte membrane (PEM) fuel cell. PEM fuel cells have been developed for many vehicles [4]. Due to the fact that fuel cells have many advantages such as high efficiency, high power capacity, low emissions and low operation temperatures [4], Fuel cell technology is also not only green and environmentally source but also not limited energy compared with other energy sources. Therefore, it is one of the most active energy sources and fuel cell technology is studied by many scientific and researches [5].

II. PREVIOUS STUDY

There are many different studies about ROV in the world. ROV was designed and manufactured by Bayramoğlu and Öncel [6] with TUBITAK 2241/A support for undergraduate thesis. The manufactured ROV has moved all maneuverability such as Figure 1.

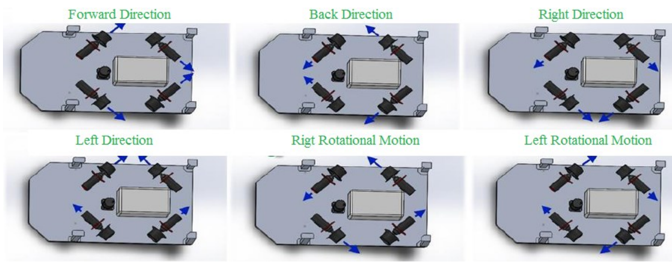

Fig. 1. Maneuverability for ROV

Project owners [6] have also implement their manufactured ROV camera for discovery, observation, searching and survey activities. Authors have selected applicable materials can be seen in Figure 2 so as to calculate best stability and hydrostatic value.

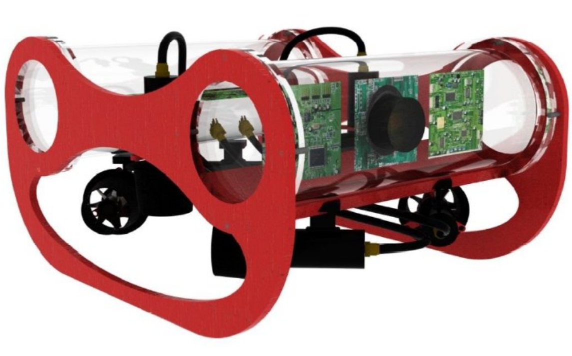

Fig. 2. Designed ROV

Hasvold and Storkersen [7] have studied electrochemical power sources for underwater vehicle operations. When working on marine vehicle, they have expressed that fuel cell is charming energy source for marine operations.

Fuel cell is used in different applications like transportation, stationary power generation, residential power generation, cogeneration and portable power [13]. Authors have also expressed that portable fuel cell is used as battery replacement which has facilitated longer operations for many electronic vehicle like ROV.

Fuel cells have different types that are recognized by operation temperature and electrolyte type. Besides that proton exchange membrane (PEM) fuel cells have been taken a great interest by scientists for its low temperature and high efficiency. PEM fuel cells have simple operations. Hydrogen and oxygen react electrochemically to generate electricity. As a result of reaction results, water and heat is obtained. The PEM fuel cell reactions are given in below:

$$\begin{aligned} &2H_2 \rightarrow 4H^+ + 4e^- \\ &O_2 + 4H^+ + 4e^- \rightarrow 2H_2O \end{aligned} \qquad (1)$$

PEM fuel cell working mechanism can be shown in Figure 3 [19].

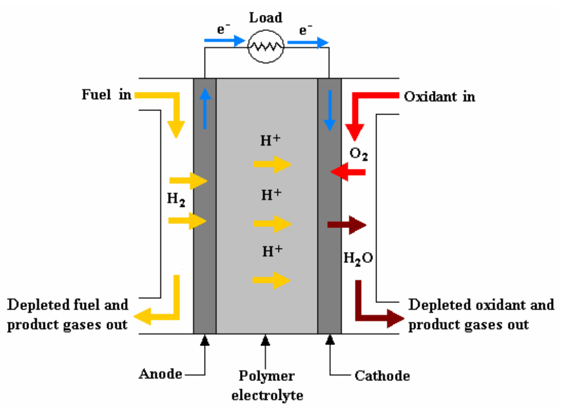

Fig. 3. PEM fuel cell working mechanisms

On the other hand Yılmaz and Nuran [14] are carried out fuel cell application for a boat design that is showed in Figure 4. In that study [14], the authors have purposed that marine industry has increasing awareness on advantages of fuel cell technology.

Fig. 4. Hydrogen powered boat

III. METHODOLOGY

Remotely operated vehicles have several properties for ocean exploration, offshore engineering and maintenance, and maritime recovery [8-9]. Therefore ROVs has crucial specifications for these applications above.

Our research object in this study is applicability of polymer electrolyte membrane (PEM) fuel cell system for using ROVs and the working methodology is showed as below in Figure 5.

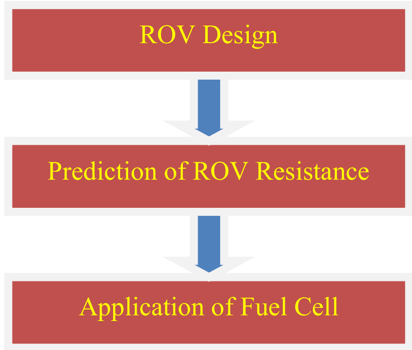

Fig. 5. Methodology of study

ROVs have several components such as tether, volume for buoyancy, frame which is prevention against collision, sensor, and camera (see. Figure 6) [10].

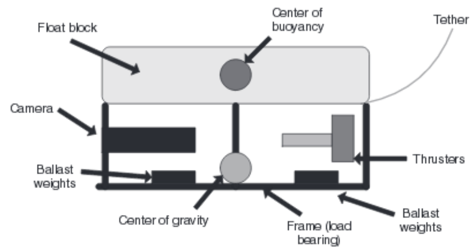

Fig. 6. Components of ROV

Remotely operated vehicles may be in range from 20 cm to a few meters and in mass from a few kilograms to thousand kilograms [11]. The vehicle design has following dimension below in Table I.

TABLE I. MAIN DIMENSION OF REMOTELY OPERATED VEHICLE

Vehicle Specification	Dimensions [mm]
Length	850
Width	560
Draft	410

Developments of computer science and technology, Computational Fluid Dynamics (CFD) methods allow to solve complex problems for marine vehicles [12]. Using this method, ROV resistance can be obtained by calculation in calm seawater conditions.

Then, geometry of ROV is calculated in the ANSYS® FLUENT software [17] to determine vehicle total water resistance. Fuel cell is selected according to required total power which is related to vehicle speed.

In this study, total ROV resistance is calculated using CFD. ROV preliminary design, resistance is calculated by numerical methods. On account of motion in real fluid which is described as viscous fluid, ROVs have friction resistance, appendage resistance and viscous resistance. Appendage resistance is counted in friction resistance.

The total force component along the specified force vector on ROV wall zone is computed by summing the dot product of the pressure and viscous forces on each face with the specified force vector. The terms in this summation represent the pressure and viscous force components in the direction of the vector $\vec{k}$ as described below [18]:

$$F_T = \vec{k} \cdot \vec{F}_p + k \cdot \vec{F}_v \qquad (2)$$

The force coefficient is defined as below where ρ, V, A are the density, velocity, and wet surface area respectively.

$$C_F = \frac{F_T}{\frac{1}{2}\rho V^2 A} \qquad (3)$$

The seawater flow around the ROV has been modeled with CFD. The model is calculated using incompressible flow and using Reynolds-averaged-Navier Stokes RANS equations to determine analysis results. The shape of the flow domain geometry is rectangle prism as shown in Figure 7.

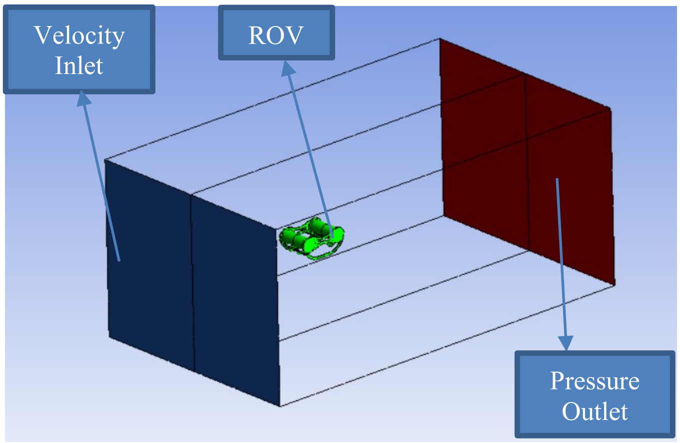

Fig. 7. Flow domain geometry

According to our approach, computational domain has been discretized by suitable mesh in Figure 8. Tetrahedral elements are used in meshing operation and inflation is applied with smooth transition for 5 layers on surface body of ROV.

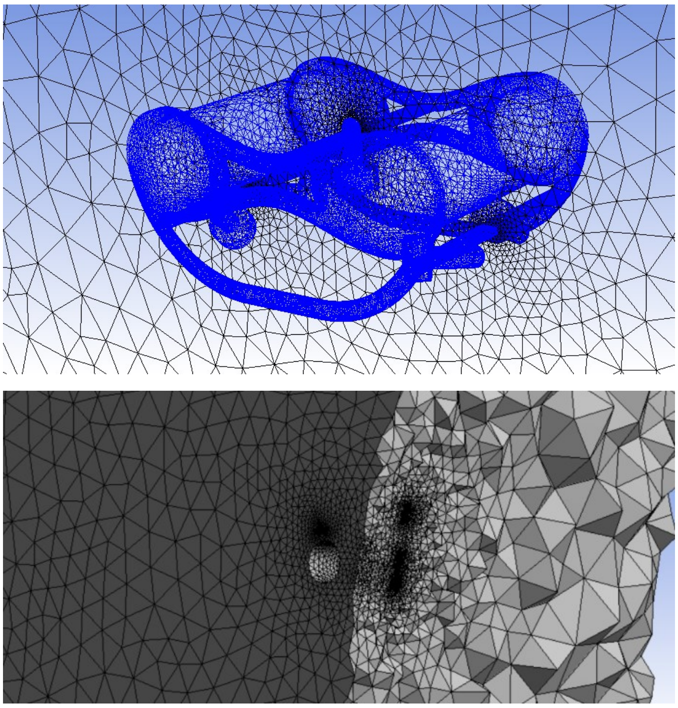

Fig. 8. Computational mesh

Mesh information is given at Table II below. According to mesh independency study, 200 K, 800 K, 1.5 M. and 3 M. meshed analyses are applied and 822513 element mesh is chosen for suitable element quality and computational time.

TABLE II. MESH INFORMATION

Mesh Information	**Values**
Dimension of Domain	2000 x 3000 x 7000 mm
Number of Elements	822513
Number of Nodes	148779
Element Quality	0.83742

IV. RESULTS

The net values of the pressure, viscous, total forces and drag coefficient are computed with CFD analysis according to 1 m/s velocity of ROV. Table III shows calculated values as below.

TABLE III. DRAG FORCES AND COEFFICIENTS

Drag Forces (N)		
Pressure	***Viscous***	***Total***
69.677	2.805	72.482
Drag Coefficients		
Pressure	***Viscous***	***Total***
0.813	0.033	0.846

According to CFD analysis results, obtained velocity streamlines and vectors are shown in Figure 9.

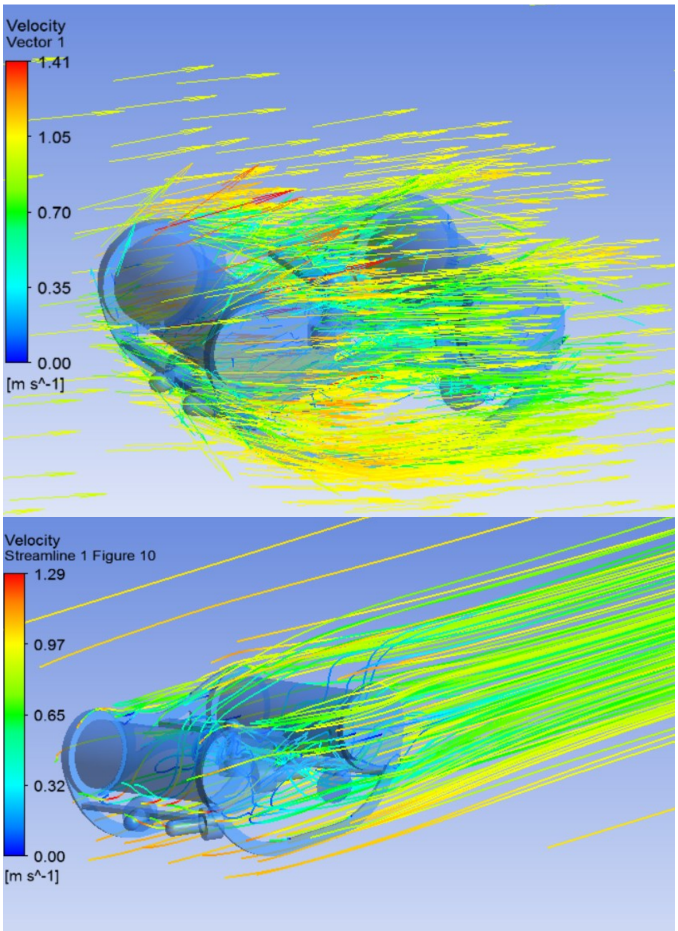

Fig. 9. Velocity Streamlines and Vectors

ROV pressure and velocity distribution of symmetry plane contour plots are given in Figure 10 and 11 respectively.

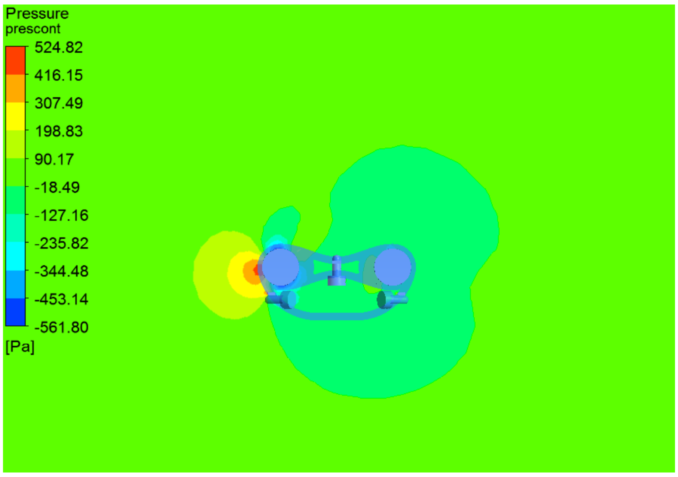

Fig. 10. Pressure Distribution

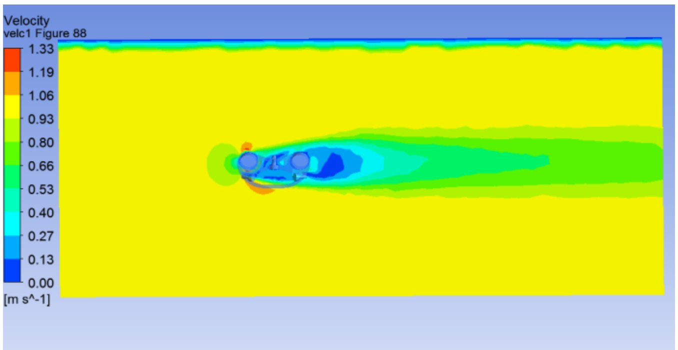

Fig. 11. Velocity Distribution

According to CFD solutions, ROV total drag force is determined approximately 75 N.

Required thrust will be supplied with five thruster which has 50 N thrust maximum for each (see Figure 12 [18]). Power requirement of these thrusters 350 W each and two of them can be used simultaneously. That's why PEM fuel cell is selected as 1 kW power according to this power necessity. PEM fuel cell is specifications Table IV.

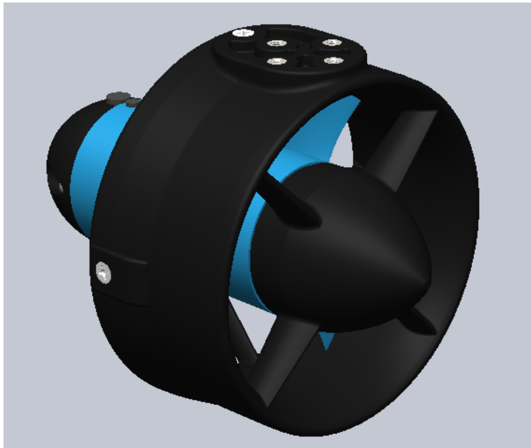

Fig. 12. Thruster for designed ROV

TABLE IV. THRUSTER AND FUEL CELL SPECIFICATIONS

THRUSTER	
Dimension of Thruster (L x D)	131 x 100 mm
Max. Forward Thrust	50 N
Operation Voltage	6-20 V
FUEL CELL	
Rated Power	1000 W
Rated Performance	20 V @15 A
Dimension of Fuel Cell (L x W x H)	203 x 104 x 264 mm
Weight	6 kg

ROV design with all components are shown in Figure 13. In this figure ROV, PEM fuel cell, control panel, camera, control box, thrusters and tethers are given. Control panel, fuel cell and other required system are thought to be on board inside a control ship.

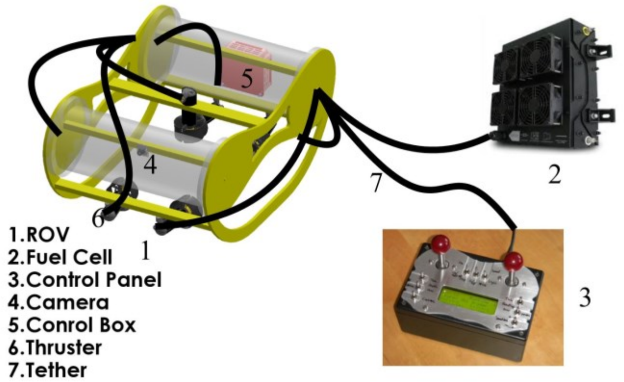

Fig. 13. ROV design with components

V. CONCLUSION

Fuel cells provide many advantages for different areas such as marine industry. Maritime industry has been complied with new regulations and rules by IMO for protecting environment. Therefore, new energy methods required to thrust these kinds of vehicles. In this project, ROV is thrusted by fuel cell instead of battery systems. Therefore, aim of the study is increasing awareness of new energy source applications for marine vehicles. According to calculated total resistance and determined velocity value, fuel cell is selected for this project. Hereby, fuel cell application for ROVs could be a good alternative comparing with conventionally systems.

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