Cooling System Design for a Fuel Cell Powered Pleasure Boat

Yasemin Arikan*, Ümit Güneş, Fahri Çelik***

Dept. of Naval Architecture and Marine Eng., Yildiz Technical University, Turkey, yarikan@yildiz.edu.tr, fcelik@yildiz.edu.tr, BSc Student, umitgunes87@gmail.com

Abstract

The decrease of the sources for fossil based fuels and the increase of environmental awareness gives rise to the widespread use of renewable energy sources. Among renewable energies especially fuel cell systems find challenging applications for mobile practice. Because of the low power supply, renewable energy systems offer restricted application areas for ship propulsion. There are applications where renewable energy systems are used as prime energy sources and applications where they are used as secondary energy sources. Marine applications of fuel cells give also rises to the design of convenient auxiliary systems like the fuel cell cooling system. The excess heat produced by the fuel cell must be removed by a cooling system. In this study the cooling system of an 8.5 kW fuel cell is investigated for a pleasure boat which is built in the scope of a student project in the Yıldız Technical University. A water cooling system is designed and analyses are made by the computational fluid dynamics code Fluent.

Keywords: Fuel cell, cooling system, pleasure boat design

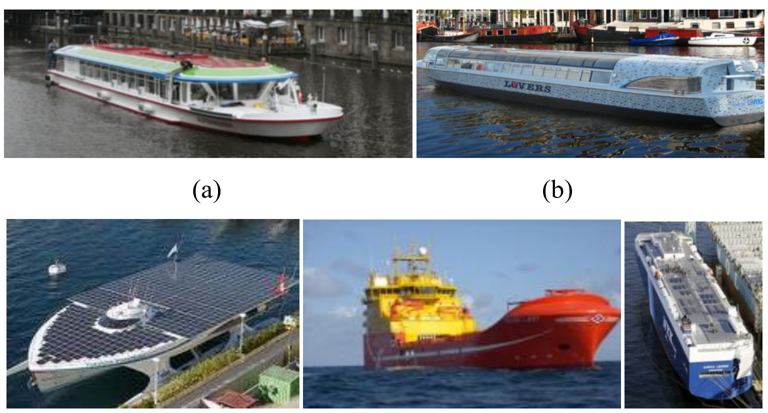
1. Introduction:

Limited reserves of fossil fuels and a growing environmental sensibility bring along the use of renewable energy sources. The most outstanding applications with renewable energies are those with solar energy and fuel cells. While solar energy is used principally in local applications because of the large area need, fuel cell systems offer also a widely use in mobile applications. Principle advantages of fuel cell systems are fuel savings, reduced exhaust emission, lower operating costs, quieter and cleaner propulsion (Sattler, 2000). While there are interesting designs with alternative energies in the automotive industry there are also exemplary marine applications of solar energy and fuel cell systems. There are applications where renewable energies are used as a prime energy source and applications where they are used as auxiliary energy sources (Table 1). While project based applications aim the full propulsion with renewable energies, commercial applications take advantage of renewable energies as a secondary energy source. Zemship, H_2-Nemo, Auriga Leader and Viking Lady Projects are exemplary designs with solar energy or fuel cell applications (Arıkan et. al., 2011, web 1) (Fig.1).

Energy is leaving the fuel cell in three forms: as electricity, as ordinary sensible heat, and as the latent heat of water vapour (Larminie & Dicks, 2003). According to the current range, the fuel cell has optimum temperatures and the coolant outlet temperature needs to be regulated to the appropriate temperature for the current drawn (Table 2). The operating temperature of a fuel cell must be controlled for optimize the performance and maximize the system life. For this purpose a cooling system must be designed (Fig. 2).

Table 1. Marine applications with renewable energy sources

PROJECT NAME	SHIP LENGTH	POWER SOURCE	PURPOSE	POWER
Duffy Boat	9.14 m.	Hydrogen	Prime energy source	1.5x4=6 kW
Planet Solar	31.00 m.	Solar energy	Prime energy source	93.5 kW
Alstersonne	26.53 m.	Solar energy	Prime energy source	24 kW + 8.2 kW (gen.)
Alsterwasser	25.50 m.	Hydrogen	Prime energy source	100 kW
H_2-Nemo	21.95 m.	Hydrogen	Prime energy source	2x30 kW + 70 kW (bat.)
Viking Lady	92.20 m.	Hydrogen	Auxiliary energy source	320 kW
Auriga Leader	199.00 m.	Solar energy	Auxiliary energy source	40 kW



(a) (b) (c) (d) (e)

Fig 1. (a) The hydrogen powered ship “Alsterwasser” (b) The canal vessel powered by fuel cell “H2-Nemo” (c) The solar powered ship “Planet Solar” (d) The offshore supply vessel “Viking Lady” (e) The car carrier “Auriga Leader” (Web 2-8)

Table 2. Current- Temperature Correlation

Current (A)	Temperature (°C) [± 2°C]
>325	60
225-325	55
125-225	50
38-125	45
<38	40

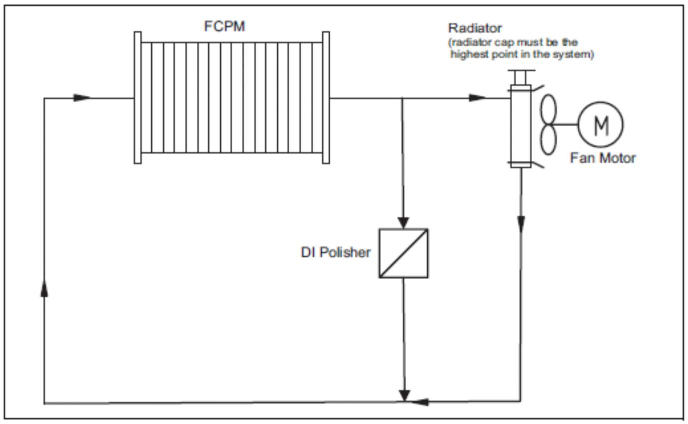


Fig. 2. Typical coolant flow system (HyPM HD 8 Installation and Operation Manual)

The heat can be taken from the fuel cell by air cooling or water cooling. The open water cooling system and the closed water cooling system are the two types of cooling systems for marine applications. In this study a closed water cooling system is investigated for a hydrogen powered boat equipped with an 8.5 kW fuel cell. 13 kW heat energy must be taken from the fuel cell for adequate operating conditions. The coolant inlet temperatures are between 36-55 degrees and the outlet temperatures must be between 40-60 degrees. The maximum pressure drop should be 20 kPa. With this information a convenient length for a pipe which will be used in the cooling system is searched with the use of the computational fluid dynamics code Fluent 6.2.16.

2. Cooling System

The cooling system design of an 8.5 kW fuel cell is carried out for a pressure drop of 20 kPa and 13 kW heat rejections (Fig. 3). As the coolant, distillated water is used and the pipe material is selected as chrome. The pipe diameter is selected as 1” (2.54 cm) with 2 mm thickness according to the outlet of the fuel cell. In numerical computations, the pipe is modelled as wall with no thickness. A two dimensional approach is considered for the solution of the problem. The length of the pipe is selected as 5 m which is longer than assumed to determine the optimum pipe length (Fig. 4).

The external flow is modelled as seawater with 20°C as well as the internal flow with 60°C. Steady calculations are made for different grid densities. The mesh is generated by using Fluent pre-processor Gambit. The first model consists of 317500 cells while the last model consists of 1390000 cells (Fig. 5-6). The velocity inlet conditions are determined according to 30 L/min flow rate, as 0.987 m/s and the velocity of the seawater is taken as the boat speed; 6 knots (Fig. 7). The calculations are made for laminar flow.

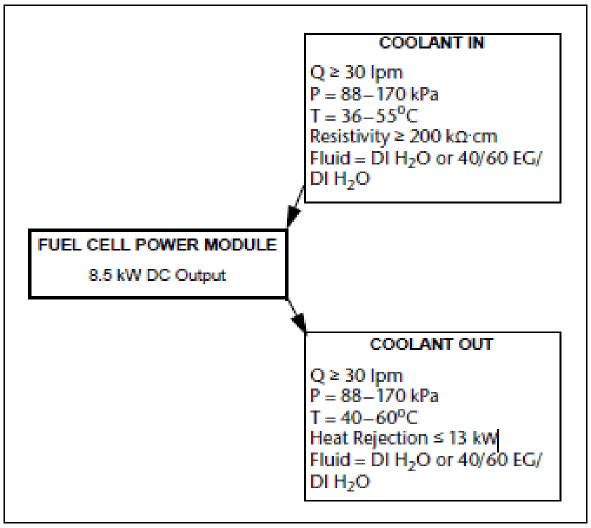


Fig. 3. Coolant specifications

(HyPM HD 8 Installation and Operation Manual)

Fig. 4. Cooling pipe

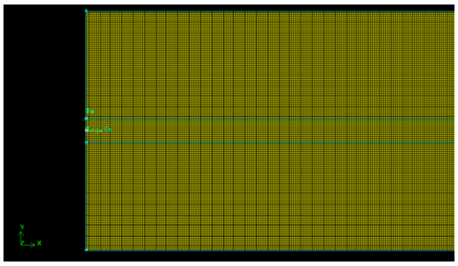


Fig. 5. Model 1 with 317500 cells

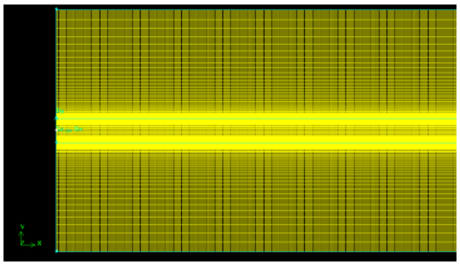


Fig. 6. Model 2 with 1390000 cells

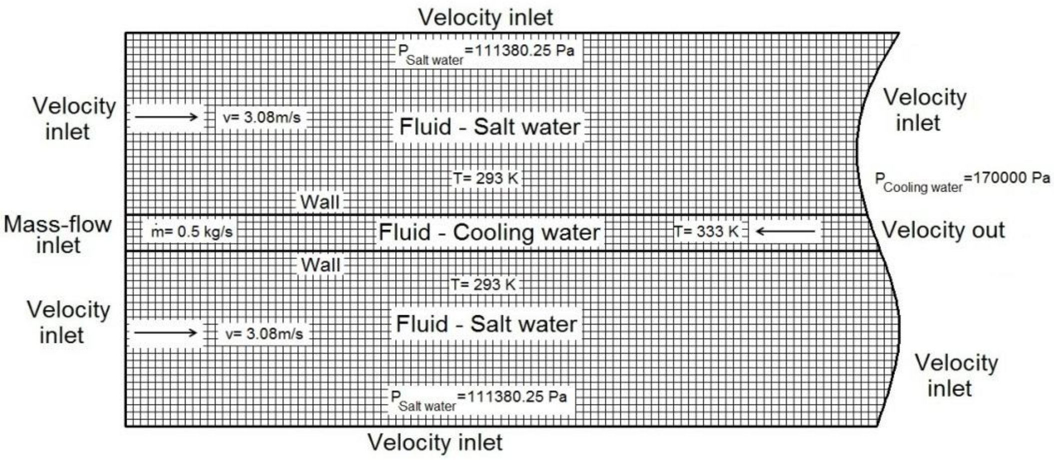


Fig. 7. İnitial and boundary conditions

The temperature variation is investigated along the pipe length. The expected temperature variation is calculated according to Eq. 1 as 6.22°C. And the pipe length is determined according to the temperature variation.

$$Q = m * c * \Delta t \tag{1}$$

$$13[kW] = 13000[W]$$

$$m = V * \rho = 0.00005 * 10000 = 0.5 \ [kg/s]$$

$$\text{Internal pipe surface} = \frac{\pi D^2}{4} = \frac{\pi * 0.0254^2}{4} = 0.0005[m^2]$$

$$V = A * V \rightarrow V = \frac{m}{A} = \frac{0.0005}{0.0005067} = 0.987[m/s]$$

$$C_{p\ water} = 4.18 \ KJ/kg * K \ \rightarrow C_{p\ su} = 4180 \ J/kg * K$$

$$13000 \ W = 0.5 \ kg * 4180 \ J/kg.K * \Delta t$$

$$\Delta t = 6.22 \ [^{\circ} C] \ , t_i = 60 \ [^{\circ} C]$$

$$\Delta t = t_i - t_S \rightarrow 6.22 = 60 - t_S \rightarrow t_S = 53.77[^{\circ}C]$$

3. Results and Discussions

The temperature variations along the pipe are shown for the coarsest and finest mesh densities (Fig. 8-9). For the absorption of 13 kW heat from the system, the pipe length required is specified as 4 m. These results are also in agreement with the length recommended by (Reinke et al., 1988) where a pipe of 4 m is calculated for 13.6 kW heat absorption.

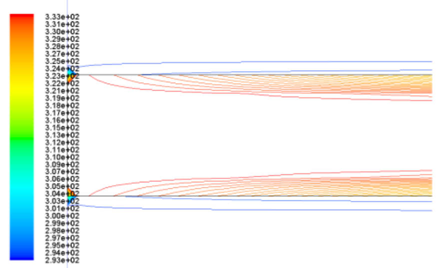


Fig. 8. Temperature contours

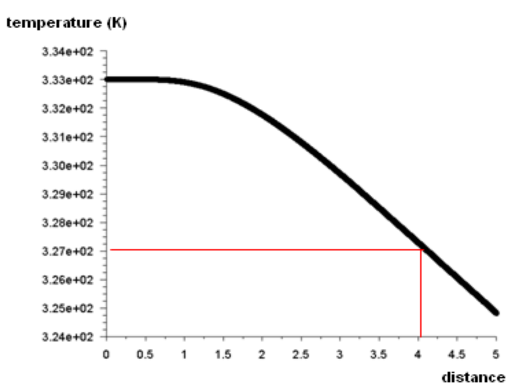


Fig. 9. Total heat variation along the pipe

4. Conclusions

A cooling system design is made for a pleasure boat powered by an 8.5 kW fuel cell. A closed water cooling system is selected and numerical calculations are made with a CFD code Fluent for determine the convenient pipe length for supply the required temperature decrease. For this purpose a 2D model is created with different mesh densities. The difference between the results obtained from the model with finest grid and previous one show little variation. So the optimum pipe length is determined as 4 m. Although the flow is turbulent, the laminar flow condition is selected which shows a worse condition since the heat exchange rate of laminar flow is smaller. Consequently the pipe length is obtained from the calculations of the worst case.

Acknowledgment

The hydrogen powered boat project is a project carried out at Yıldız Technical University with the support of UNIDO-ICHET the International Centre for Hydrogen Energy Technologies (the United Nations Industrial Development Organization.

References

Arıkan, Y., Doğrul, A., Çelik, F., (2011), Energy Efficient Hull Form Design for a Pleasure Boat Powered by a Solar-Hydrogen Energy System, IX HSMV Naples 25-27 May 2011

HyPM HD 8 Installation and Operation Manual, (2010), Hydrogenics.

Larminie, J., Dicks A., (2003), Fuel Cell Systems Explained, Second Edition, Wiley, England

Reinke, Lütjen, Muhs, (1988), Yachtbau, 3. Edition, Delius Klasing Verlag, Germany

Sattler, G., (2000), Fuel Cells going on-board, Journal of Power Sources, Vol. 86, p. 61-67.

Web 1 http://www.duffyboats.com/duffyfacts/duffy-creates-first-hydrogen-powered-passenger-boat/

Web 2 http://www.zemships.eu/

Web 3 http://www.lovers.nl/co2zero/

Web 4 http://en.wikipedia.org/wiki/Nemo_H2

Web 5 http://www.planetsolar.org/

Web 6 http://vikinglady.no/

Web 7 http://www.allcarselectric.com/image/100225887_solar-panels-on-auriga-leader

Web 8 http://www.crunchgear.com/2008/12/23/auriga-leader-japan-launches-first-solar-cargo-ship/