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THE EFFECT OF HYDROGEN GAS PREHEATING ON THE EFFECTIVE PERFORMANCE OF A FUEL CELL

BUDAPESTI MŰSZAKI ÉS GAZDASÁGTUDOMÁNYI EGYETEM
GÉPÉSZMÉRNÖKI KAR
ENERGETIKAI GÉPEK ÉS RENDSZEREK TANSZÉK TANSZÉK

SZAKDOLGOZATOK vagy DIPLOMATERVEK

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# INDIVIDUAL PROJECT

PEMFC SUPPORT SYSTEM: HYDROGEN & THERMAL CONTROL DESIGN

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**ZÁRADÉK**

**Ez a szakdolgozat/diplomaterv elzártan kezelendő és őrzendő, a hozzáférése a vonatkozó szabályok szerint korlátozott, a dolgozat tartalmát csak az arra feljogosított személyek ismerhetik.**

**A korlátozott hozzáférés időtartamának lejártáig az arra feljogosítottakon kívül csak a korlátozást kérelmező személy vagy gazdálkodó szervezet írásos engedélyéjével rendelkező személy nyerhet betekintést a dolgozat tartalmába.**

**A hozzáférés korlátozása és a zárt kezelés 201x. év … hónap … napján ér véget.**

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The table contains the names of the symbols that occur several times, as well as their units of measure in the case of physical quantities. The designation of the individual quantities - where possible - is the same as the designations accepted in the domestic and international literature. Explanations of rarely used symbols can be found at their first place of occurrence.

Latin letters

| Notation | Name, comment, value | Unit of measure |
|---|---|---|
| $m$ | Mass flow rate | $m^3/s$ |
| $P$ | pressure | Pa |
| $t$ | time | s |
| $T$ | temperature | °c |

Greek letters

| Notation | Name, comment, value | Unit of measure |
|---|---|---|
| $\lambda$ | Stoichiometry | 1 |

# 1. INTRODUCTION

## *1.1. Objectives*

Fuel cells have emerged as a leading technology for clean and efficient energy conversion, offering transformative potential across sectors such as transportation, stationary power generation, and portable electronics. Among these, Proton Exchange Membrane Fuel Cells (PEMFCs) are particularly prominent due to their high efficiency, fast start-up, low operating temperatures, and minimal emissions—making them ideal for automotive and residential applications.

To ensure optimal PEMFC performance, dedicated support systems are crucial—specifically, the hydrogen delivery and thermal management subsystems. These systems directly impact efficiency, reliability, and operational flexibility across varying environmental conditions.

A key aspect of hydrogen support is the preheating of hydrogen gas before it enters the fuel cell stack. Elevated hydrogen temperature can enhance electrochemical reaction rates, reduce activation losses, improve membrane conductivity, and facilitate better water management. These benefits also improve cold-start behavior, expanding the fuel cell's applicability.

In parallel, maintaining thermal stability within the PEMFC is essential. Effective cooling ensures uniform temperature distribution, prevents dehydration of the membrane, and extends system longevity.

This project focuses on the design and integration of the hydrogen supply and thermal control subsystems within a PEMFC support architecture. Instead of merely analyzing performance, the aim is to engineer a robust, efficient system infrastructure that enhances the operability of the fuel cell stack.

The subsequent sections detail the design, operation, and technical implementation of these two primary support domains: hydrogen supply & preheating, and cooling system design.

## *1.2. Overview*

This report includes the design principles used in designing a complete working system to generate electrical power using the PEMFC and hydrogen as fuel, and the parts and mechanisms used to operate the PEMFC.

# 2. TASK 1

The first part of the task is choosing the PEMFC to be used and determine the operating temperature.

## *2.1. PEMFC selection*

Selecting PEMFC:

The selected PEMFC is manufactured by EH group Engineering AG.

The product code of PEMFC is EH81, the following tables show some of the information made available by the manufacturer:

| Electrical Specs | EH81 - 20kW | EH81 - 40kW | EH81 - 60kW | EH81 - 100kW |
|---|---|---|---|---|
| Nominal Power [kWe] | 20.0 | 40.0 | 60.0 | 100.0 |
| Peak Power [kWe] | 22.0 | 44.0 | 66.0 | 110.0 |
| Current Range [A] | 0 – 450 | | | |
| Voltage Range [V] | 46 – 103 | 93 – 206 | 139 – 308 | 231 – 513 |

| Mechanical Specs | | | | |
|---|---|---|---|---|
| Dimensions [mm] *(with manifolds and connection ports)*[1] | 400 x 120 x 260 | *400 x 120 x 320* | *400 x 120 x 450* | *400 x 120 x 610* |
| Weight [kg] (with manifolds and connection ports) | ~ 32 | ~ 48 | ~ 66 | ~ 78 |

| Operating Conditions - Cathode side | |
|---|---|
| Quality | Filtered, no impurities |
| Inlet Temp. [°C] | 65 – 70 |
| Outlet Temp. [°C] | 76 – 80 (85 short run) |
| RH [%] – No condensation | 35 – 80 |
| Stoichiometry [λ] | 1.5 – 2.0 |
| Pressure level [kPa g] | < 150 |
| Pressure drop [kPa] *(@ 0.6V operation)* | < 35 |

| Operating Conditions - Anode side | |
|---|---|
| Quality | >99.995 (SAE J2719 or ISO 14687:2019 grade D) |
| Inlet Temp. [°C] | 65 – 70 |
| RH [%] – No condensation | 20 – 80 |
| Stoichiometry [λ] | 1.2 – 1.8 |
| Pressure level [kPa g] | < 150 |
| Pressure drop [kPa] *(@ 0.6V operation)* | < 35 |

| Operating Conditions - Coolant side | |
|---|---|
| Quality | DI water, DI + anti-freeze |
| Inlet Temp. [°C] | 65 – 70 |
| ΔT [°C] | 8 – 10 |
| Pressure drop [kPa] | < 100 |
| *Maximum dP between Anode/Cathode [kPa]* | *30* |

## 2.2. optimal temperature

Using the data available by the manufacturer:
Stoichiometry (λ): to maintain a desired relative humidity.

$$\lambda = \frac{42.1 \cdot p_{air}}{RH_{des} \cdot p_{sat-out} \cdot p_{win}} \qquad (1)$$

Where:
$P_{air}$: pressure of inlet air.
$RH_{des}$: desired relative humidity.
$P_{sat-out}$: saturated vapour pressure in output air.
$P_{win}$: sweet water partial pressure.

$$p_{sat} = -0.01751 + 0.016786 \cdot e^{\frac{T}{25.55}} \qquad (2)$$

From equations (1) and (2), obtain the optimal temperature as:

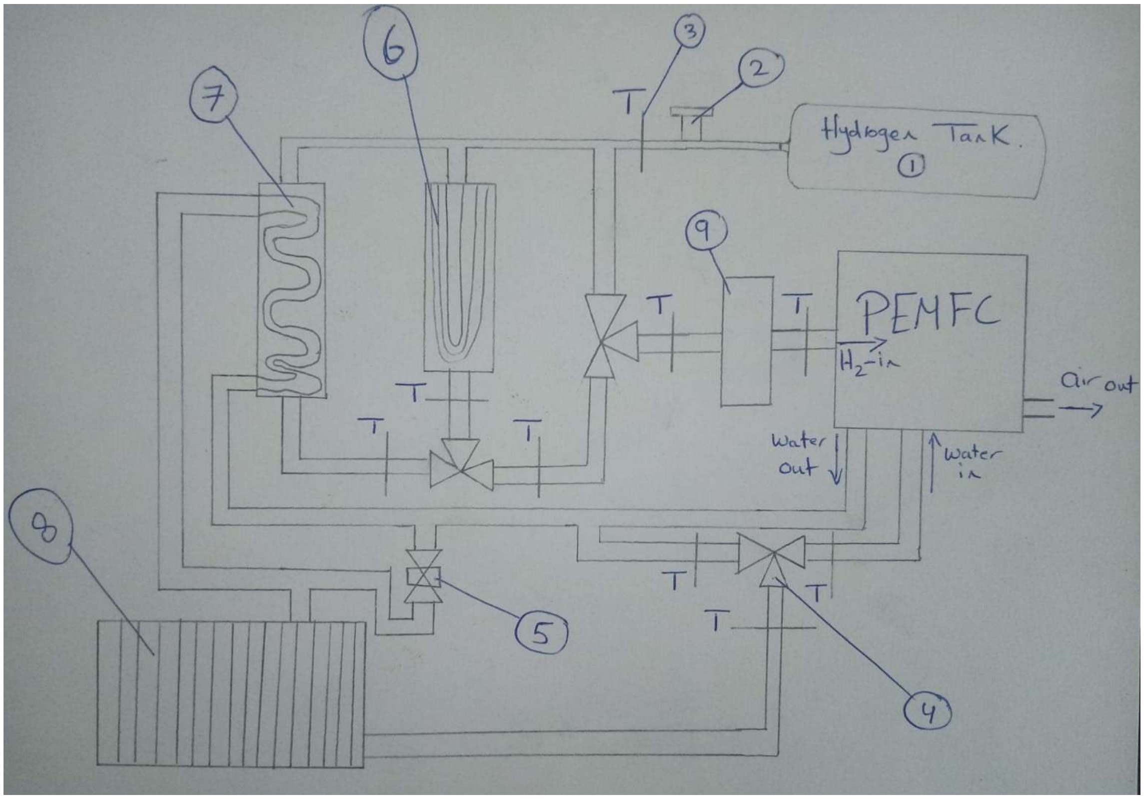
$$T_{opt} = 96.25 + 23.55 \cdot \ln(\frac{1}{RH_{des}} \cdot \left(\frac{0.421 \cdot p_{air}}{\lambda + 0.0188}\right) + p_{win} + 0.01751)$$

$$T_{opt} = 335.97\ K = 62.8\ °C$$

# 3. TASK 2

The second task consists of designing the hydrogen supply and cooling systems.

**Design sketch:**




## *3.1. Hydrogen supply:*

The PEMFC operates using hydrogen gas as fuel, which must be supplied with a specific temperature to keep the PEMFC operating at optimal temperature, to achieve this a hydrogen supply cycle which controls the supplied gas' temperature must be designed, which will be discussed in this section.

The used parts:

| no. | quan-tity | name | purpose |
|---|---|---|---|
| 1 | 1 | hydrogen tank | hydrogen storage |
| 2 | 1 | expansion valve | decrease the temperature and pressure of gas |
| 3 | 5 | thermostat | measure temperature |
| 4 | 2 | three-way modulating valve | control flow rate of gas |
| 6 | 1 | electric heater | heat up the gas |
| 7 | 1 | heat exchanger | heat up the gas |
| 9 | 1 | humidifier | Moisturise gas |

**Boundary conditions:**

System inlet: hydrogen tank
System outlet: PEMFC (fuel intake)

This design is split into two main sections, heating and bypass. Which both feed into the three-way modulating valve, controlling both sections flow to obtain the required flow and temperature of hydrogen gas into the PEMFC.

The heating section is also divided into 2 sections, electric and passive heating, one using an electric heater to heat up the gas, while the other uses a heat exchanger to heat up the hydrogen gas using excess heat from the cooling water passing through the heat exchanger. Both sections feed into a three-way modulating valve to control the flow and temperature of the gas.

At multiple points of the cycle thermostats are used to control the flow and temperature of the gas, as the thermostat can control the flow in the pipes and the turn on/off the electric heater as needed.

After the heating of the gas and obtain the desired flow and temperature leaving the system, a humidifier is added to increase the relative humidity of the gas before entering the PEMFC.

### *3.2 Cooling cycle:*

While the PEMFC is operating it heats up as the chemical reaction occurring inside is exothermic, so it is needed to cool the cell down. The selected PEMFC uses water cooling, so it is needed to design a cooling cycle to cool the cell and the cooling water to be reused.

The used parts:

| no. | quan- tity | name | purpose |
|---|---|---|---|
| 3 | 3 | thermostat | measure temperature |
| 4 | 1 | three-way modulating valve | control flow rate of water |
| 5 | 1 | Check valve | Prevent backflow |
| 7 | 1 | heat exchanger | Cool down the water |
| 8 | 1 | radiator | cool down water |

**Boundary conditions:**

System inlet: PEMFC (cooling water output)
System outlet: PEMFC (cooling water intake)

The cooling cycle design uses a similar abroach to split up the cycle into 2 sections, as the water leaves the cell the flow is spilt using a three-way modulating valve into 2 parts, the first passes by the heat exchanger used in the hydrogen cycle to heat up the hydrogen using the heat produced by the cell, then goes to the radiator to be cooled further.

The second section of the flow splits again into two sections, one being a bypass feeding back to the PEMFC, while the second feeds into the radiator to cool down the water. The flow leaves the radiator going back to the PEMFC.

### *3.3 control*

In this section the equations and functions used to control the temperature and flow for both cycles are written.

Thermostats controlling three-way modulating valves to regulate temperature by mixing different temperature fluids involves a feedback control system. Three-way valves can mix two streams of fluids with different temperatures to achieve a desired outlet temperature. The thermostats measure the temperature of the fluid and adjust the position of the valves to control the proportions of hot and cold fluids being mixed.

**Control Strategy**

1. **Temperature Measurement:**
   - Thermostats are placed at key points to measure the temperature of the fluid. The primary measurement is taken at the outlet where the mixed fluid exits.
2. **Feedback Loop:**
   - The thermostats continuously monitor the temperature of the fluid and compare it to a setpoint temperature (desired temperature).
3. **Control Signal Generation:**
   - Based on the difference (error) between the measured temperature and the setpoint temperature, the thermostat generates a control signal. This signal is typically sent to a PID controller which adjusts the valve positions.
4. **Valve Adjustment:**
   - The three-way modulating valves adjust the mixing ratio of the hot and cold fluids. For example, if the fluid temperature is below the setpoint, the valve will allow more hot fluid to mix in. If the fluid temperature is above the setpoint, the valve will allow more cold fluid to mix in.

**Detailed Steps**

1. **Thermostat Measurement:**

   The thermostat measures the current temperature $T_{measured}$.
2. **Error Calculation:**

   The error e(t) is calculated as:

   $$e(t) = T_{desired} - T_{measured}$$
3. **PID Controller:**

   The PID controller processes the error to generate a control signal u(t):

$$u(t) = K_p \cdot e(t) + K_i \cdot \int e(t)dt + K_d \cdot \frac{de(t)}{dt}$$

where $K_p$, $K_i$, and $K_d$ are the proportional, integral, and derivative gains, respectively.

4. **Control Signal to Valve Position:**

   The control signal u(t) is used to adjust the position of the three-way valve. The valve position θ might be directly proportional to u(t), depending on the valve's design:

$$\theta = f(u(t))$$

   where θ represents the valve's position (ranging from fully allowing hot fluid to fully allowing cold fluid).

5. **Mixing Process:**

   The three-way valve modulates the flow rates of the hot and cold fluids. Let $m_{cold}$ and $m_{hot}$ be the mass flow rates of the hot and cold fluids, respectively. The mixed fluid temperature $T_{mixed}$ can be approximated using an energy balance:

$$T_{mixed} = \frac{\dot{m}_{ho} \cdot T_{hot} + \dot{m}_{cold} \cdot T_{cold}}{\dot{m}_{hot} + \dot{m}_{cold}}$$

# 4. SUMMARY

The designed system is applicable for generating clean energy effectively and efficiently, using hydrogen gas as fuel. The completion of this project proves the effectiveness and viability of such systems and will result in an advanced PEMFC system that contributes to the global efforts in reducing carbon emissions and promoting sustainable energy solutions.

# 5. REFERENCES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