TESTS OF THE VEHICLE'S POWERTRAIN WITH HYDROGEN FUEL CELLS AT A LOW TEMPERATURE

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ABSTRACT

The article discusses issues related to the operation of fuel cells stack fed with hydrogen at low temperature. The test object was a Toyota Mirai passenger car, equipped with this type of powertrain. Tests were carried out in a thermoclimatic chamber at the Cracow University of Technology. They had an initial character, and their aim was to evaluate the work of individual subassemblies of the propulsion system, including the hydrogen supply system in terms of operational safety.

1. INTRODUCTION

There is currently a debate around the world about new sources of vehicle propulsion, which in the near future may replace combustion engines. The problem is very complex, because new sources of propulsion should be competitive in every respect, and additionally they cannot pollute the environment. Vehicles with hybrid propulsion systems fulfil only partially modern requirements and are widely regarded as a transitional stage in relation to the expected, emission-free propulsion systems. On the other hand, battery electric vehicles, currently very preferred, do not meet the expectations and at the current stage of development can only serve as urban vehicles. They are not suitable for further transport as well as for the drive of heavy commercial vehicles or construction machines. In this situation, the only source of vehicle propulsion that can be competitive in relation to reciprocating internal combustion engines is a hydrogen fuel cell. This type of cell is supplied with hydrogen of high chemical purity, stored in composite tanks at a pressure of approx. 70 MPa. During the operation of the cell, water vapour is released, which is the effect of combining hydrogen with oxygen, therefore the operation of fuel cells fed with hydrogen at low ambient temperature requires special procedures. Due to the fact that currently only a few manufacturers offer propulsion systems equipped with hydrogen fuel cells, their common implementation requires proper preparation, the important step of which will be comprehensive research conducted in various conditions to ensure operational safety.

2. THE PURPOSE AND SCOPE OF RESEARCH

Poland belongs to a group of developed European countries where vehicles equipped with a new type of power source will appear first on the market. Therefore, it is necessary to take preparatory measures to facilitate their introduction to the market and guaranteeing operational safety. What matters here is not only the use of a new type of propulsion system, but also the use of hydrogen as a commonly available fuel. An important factor that should be considered here are climate conditions. In Central Europe there is a temperate climate, which is characterized by high variability of temperature and humidity in particular seasons. In the case of operation in this area of vehicles equipped with hydrogen fuel cell drive, it is very important that the vehicle is driving in winter, when the temperature reaches a minimum value of around -20 ° C, and there are large temperature fluctuations in the 24-hour cycle. In low ambient temperature, the working conditions of many structural elements of the vehicle's propulsion system are changed, related to the phenomenon of thermal expansion, and also to the phenomenon of liquefying gas factors and changes in density and even freezing of liquid media. The mentioned phenomena are particularly important in the propulsion system of a vehicle equipped with fuel cells, where the fuel used is hydrogen, which requires appropriate conditions to maintain the tightness of the power supply system. In addition, the water drainage system resulting from the reaction of hydrogen with oxygen in the fuel cell requires special thermal conditions. In connection with the above, before the introduction of this type of vehicles to the market, relevant from the point of view of operational safety, the research will be conducted in various climatic conditions, especially at low ambient temperature. An important issue is to ensure the tightness of the entire hydrogen supply system to the fuel cell when the operating temperature changes. This applies to hydrogen tanks, supply lines and their connections as well as valves and pumps.

This type of preliminary research of a Toyota Mirai car, equipped with hydrogen-fuelled fuel cell drive, was carried out in a thermoclimatic chamber (Fig.1). Their main goal was to gain operational experience, allowing better preparation of the market for the widespread introduction of this type of vehicles into operation. The scope of the research was limited to the analysis of the operation of individual construction parts of the power unit at a reduced temperature, in particular the hydrogen supply system for fuel cells.

Fig. 1. Toyota Mirai during tests in the thermoclimatic chamber

3. RESEARCH METHODOLOGY

The object of the research was a Toyota Mirai car in the standard version, equipped with an electric drive system and fuel cells stack, supplied with hydrogen with a purity of 99.97% H_2 stored under 70 MPa pressure in two tanks made of composite materials. The tests were conducted in an accredited thermoclimatic chamber in the temperature range from -10 ^{o}C to -18 ^{o}C, which corresponds to the temperature range occurring in the winter period in the temperate climate zone. The vehicle was inserted into a chamber with an unheated fuel cells stack and the test time was about 2.5 hours. Measurements of many different physical quantities characterizing the operation of the drive unit were carried out, using signals available in the vehicle's on-board diagnostic system, read from the Toyota factory diagnostic system. Particular attention has been paid to those parameters that have an impact on the operational safety of the hydrogen supply system for fuel cells at a low temperature, such as:

- Hydrogen Pump Motor Temperature
- Smoothed Value of Hydrogen Tank 1 Temperature
- Smoothed Value of Hydrogen Tank 2 Temperature
- FC Stack Coolant Temperature (FC Stack Outlet)
- Smoothed Value of FC Stack Coolant Temperature (Radiator Outlet)
- FC Stack Coolant Temperature (Radiator Outlet)
- Smoothed Value of Intake Air Temperature
- Smoothed Value of FC Stack Air Temperature (FC Stack Inlet)
  and additionally:
- Measurement time
- Temperature in the thermoclimatic chamber.

Figure 2 shows the temperature change of hydrogen tanks along with the temperature change in the thermoclimatic chamber. During the measurements lasting about 2.5 hours, every hour the procedure of checking the condition of fuel cells was switched on, and in addition it was necessary to perform maintenance activities related to the need to enter service inside the chamber. This is manifested by temporary changes in the temperature in the chamber. Therefore, the chart additionally includes a trend line, which indicates a continuous decrease in the temperature in the chamber, which during the tests varied from approx. -11 °C to approx. -18 °C. The sudden increase in temperature in the final part of the graph was related to the activation of fuel cells. The temperature of the hydrogen tanks changes much more slowly than the temperature of the air in the thermoclimatic chamber, while a significant reduction in their temperature occurs with the activation of the fuel cell and the outflow of hydrogen. This is inter alia related to the air movement around the hydrogen tanks.

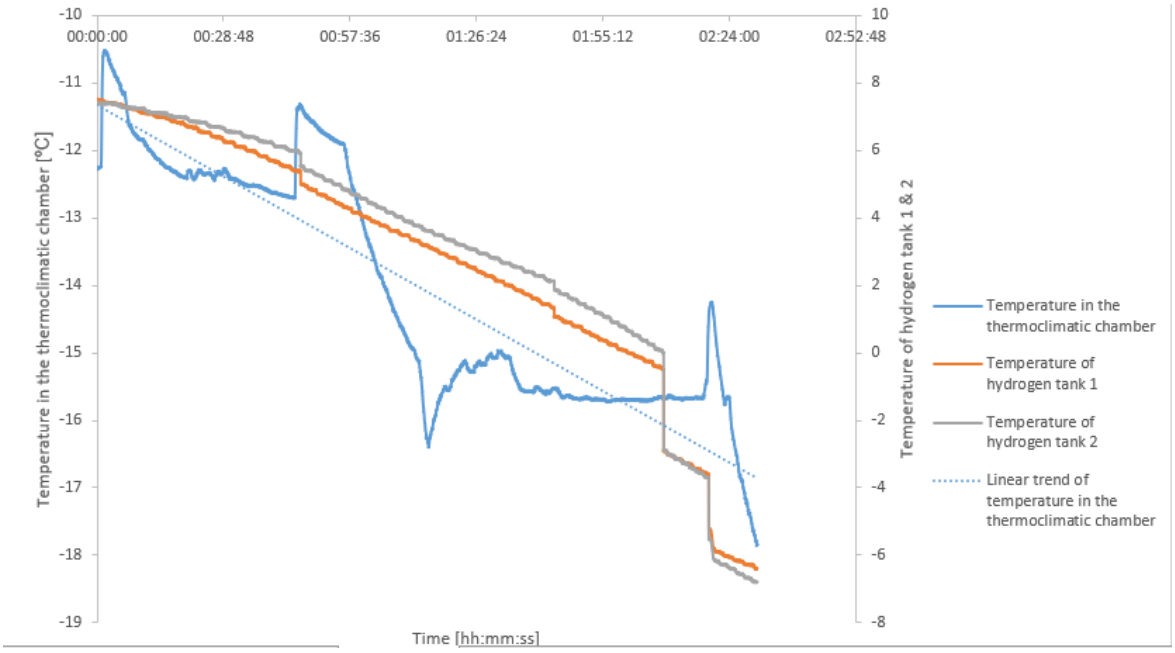

Fig. 2. Temperature of hydrogen tanks during vehicle tests in a thermoclimatic chamber

When the vehicle is stationary at a temperature below 0 °C, the procedure of cleaning the surface of the cells from the water is activated. This is manifested by the periodic switching on of the air compressor and the hydrogen pump in order to dry the surface. In Fig. 3. The temperature change of the engine driving the hydrogen pump is presented along with the temperature decrease in the thermoclimatic chamber. Visible, abrupt temperature changes are associated with the pump switching on, because its operation causes the gases to move and the cooling of its components. The sudden increase in temperature of the hydrogen pump seen in Fig. 3 occurred after switching on the fuel cell.

The most sensitive element of the propulsion system of the Toyota Mirai car for lower temperatures are the individual segments of the fuel cell stack. During the tests in the thermoclimatic chamber carried out in the temperature range from -11 °C to -18 °C in about 2.5 hours, the temperature of the stack cooling liquid decreased very slowly and during the tests was above 0 °C, and its sudden increase took place with activation of cells (Fig. 4). A similar change was shown in the air temperature surrounding the stack of cells, where its value was significantly lower, which resulted from the existing air exchange between the interior of the vehicle and the thermoclimatic chamber (Fig.4).

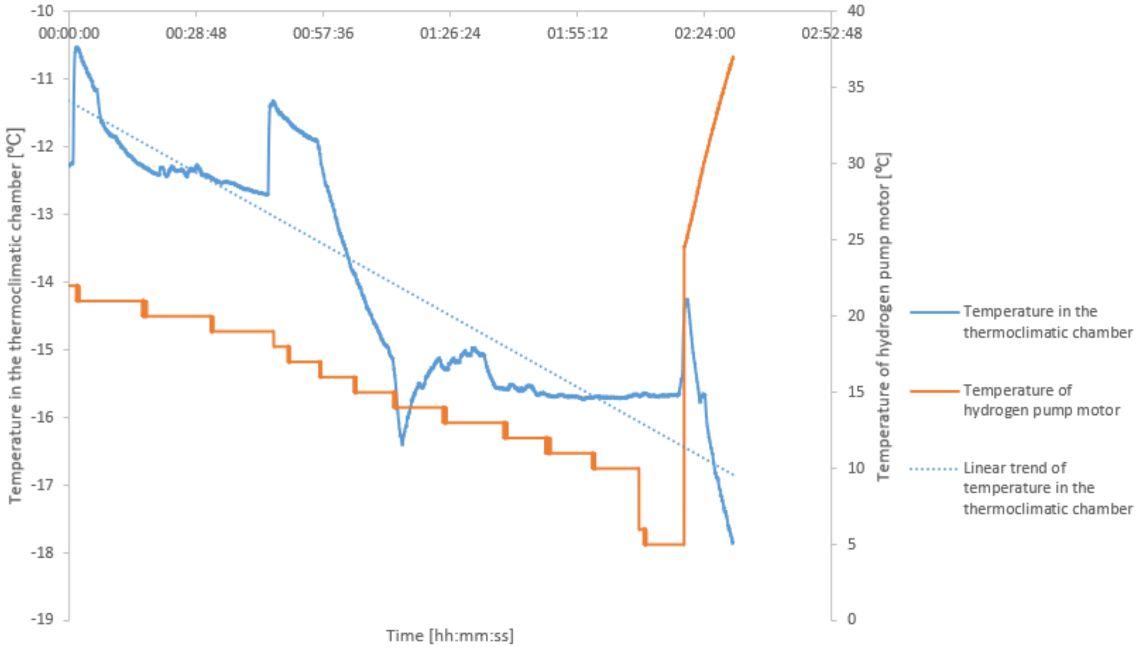

Fig. 3. Temperature of the hydrogen pump during testing of the vehicle in the thermoclimatic chamber

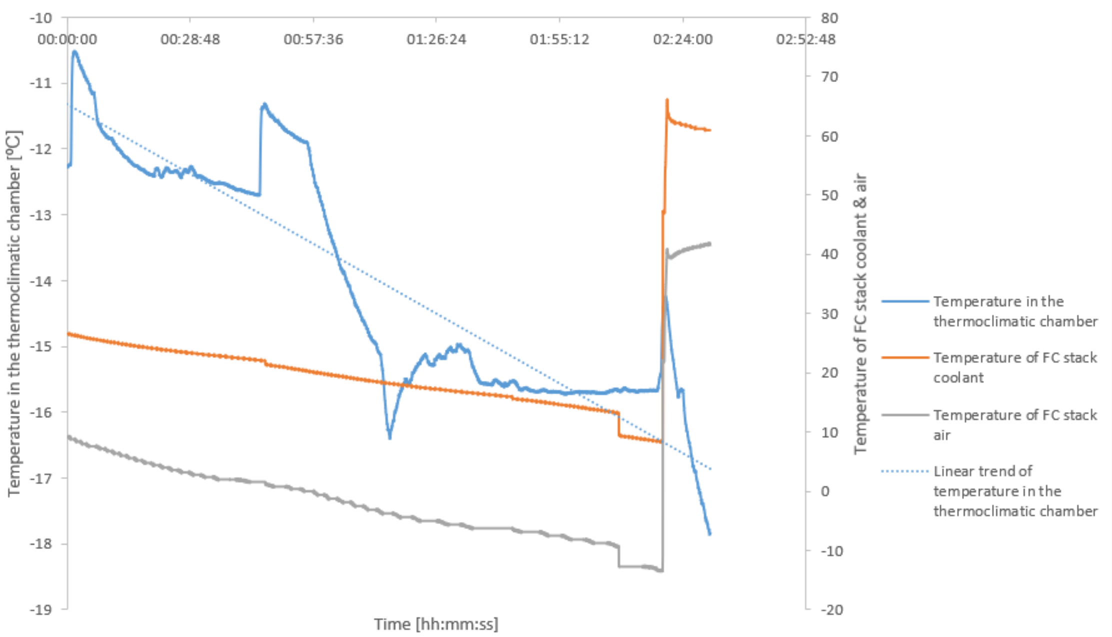

Fig. 4. Temperature of the cooling medium of fuel cells and air in the cell segments during vehicle tests in the thermoclimatic chamber

An important parameter describing the working conditions of the fuel cell is the temperature course in the fuel cell intake system (Fig.5). The changes in the temperature values recorded on the chart are related to the flow of air supplied to the fuel cell, both during its operation and during the purging procedure. The size of this change depends on the value of the air flow which travels from the thermoclimatic chamber to the inside of the cell.

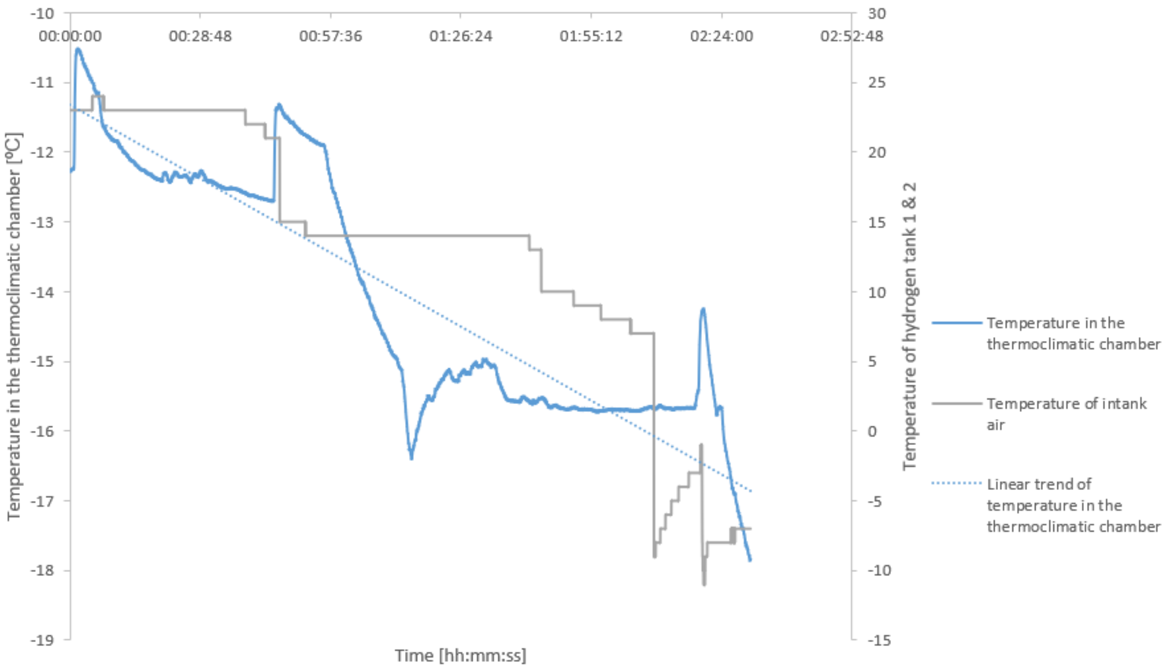

Fig. 5. Air temperature in the fuel cell intake system during vehicle tests in the thermoclimatic chamber

During the conducted tests, and also after their implementation, attention was paid to the phenomenon of condensation of water vapor on individual vehicle systems. After completing the tests in the thermoclimatic chamber, all internal components of the vehicle were covered with water molecules. Therefore, particular attention has been paid to all types of electrical connections and a system for supplying hydrogen from pressure cylinders to the fuel cell. Due to the protection procedures of the fuel cell against the effects of low temperature, many electric circuits of the drive system maintain voltage, and the phenomenon of water condensation on these elements can lead to uncontrolled current flows. In addition, a reduced temperature can affect the tightness of the hydrogen fuel supply system. It should also be remembered that the reduction of the hydrogen temperature accumulated in the composite tanks also reduces the pressure value, which results from the gas state equation. This is important in the process of filling tanks with hydrogen at a low temperature, because after changing the ambient temperature, the permissible pressure value may be exceeded.

Fig. 6. Toyota Mirai after testing in a thermoclimatic chamber

4. CONCLUSIONS

- The tests have initial character and are used to identify phenomena occurring during the operation of a powertrain equipped with a fuel cells fuelled with hydrogen. Their results may indicate the direction of further tests necessary for the proper use of this type of powertrains.
- The tests were carried out in conditions of low ambient temperature, which are the least favourable for fuel cell operation and operation of the whole vehicle propulsion system.
- The operation of the vehicle's power unit, equipped with hydrogen-powered fuel cells, in conditions of low temperature requires the use of new, special procedures that are not used in other vehicle powertrains.
- Particular attention has been paid to the elements of the hydrogen supply system, which during the tests at a reduced temperature were covered with a layer of condensed water. This phenomenon did not affect the safe operation of the vehicle.
- Attention was also paid to the live electrical connections and systems, which were also covered with a layer of condensed water during the tests. In this case, there were also no disturbing symptoms.
- The research shows that the set of hydrogen composite tanks is well insulated, which translates into a slower change in the temperature of the tanks, in relation to changes in the ambient temperature.
- The largest temperature change occurs in all components of the drive system in which the flow of refrigerants occurs. These elements are most exposed to such changes as: thermal expansion of materials, loss of sealing properties or change of electrical conductivity, resulting from the coverage of their surface condensed by water vapour.
- Conclusions from the preliminary tests carried out can contribute to the development of operational indications and instructions for users of vehicles equipped with hydrogen fuel cells and for service stations servicing such vehicles.

5. REFERENCES

1. Instruction manual for the thermoclimatic chamber, Cracow University of Technology, Cracow – Poland 2018
2. Toyota Mirai – Freezing prevention, Toyota Owner’s Manual 2018