

Degradation tests of hydrogen-air fuel cell stack with open cathode during storage with irregular operation

© M.Z. Galin, A.A. Belmesov, L.V. Shmygleva, E.V. Gerasimova, A.V. Levchenko

Federal Research Center of Problems of Chemical Physics and Medical Chemistry, Russian Academy of Sciences, Chernogolovka, Moscow region, Russia
E-mail: shmygleva@icp.ac.ru

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The work presents the results of a study examining the operating and storage characteristics of an open-cathode hydrogen-air fuel cell stack (FCS) with a rated power of 1.1 kW. To approximate real-world operating conditions, the FCS was started without a set periodicity for 0.6–6 h over a period of three years. It is shown that long-term storage of the FCS between starts (over 180 days) results in a reversible decline in its performance characteristics, including maximum power and ramp time (the time to reach rated power).

Keywords: fuel cell battery, hydrogen, degradation, life testing.

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Growing demands for reliable, energy-efficient, and environmentally friendly power sources stimulate the development of backup and autonomous power supply systems based on proton exchange membrane fuel cells (PEMFCs) [1,2]. These devices convert the chemical energy of hydrogen directly into electrical energy with a high efficiency (up to 60%), low noise levels, and no harmful emissions [3]. Unlike batteries, PEMFCs are capable of operating for long time intervals without recharging, providing a quick startup option and power scalability [2,4]. Particular attention is paid to the integration of PEMFCs with renewable energy sources (solar and wind power plants), which provides an opportunity to construct fully autonomous energy complexes [5]. The integration of PEMFCs into solar photovoltaic systems with lithium-ion batteries raises the economic efficiency of such systems [6]. In addition, the introduction of a fuel cell stack (FCS) backup power supply into existing power grids is environmentally advantageous over the use of diesel generators [7].

The use of PEMFCs as backup or auxiliary energy sources often involves long periods of downtime [5,8], and the impact of such operating conditions on the volt- and watt-ampere characteristics of FCSs is unknown. At present, the best-studied factors of degradation changes are the frequency of starts/stops [9] and storage conditions [10]. Thus, tests of the performance of PEMFC stacks under the conditions of long-term storage and irregular starts are important for determining the domain of their applicability. Therefore, the present study was aimed at assembling an open-cathode FCS with a rated power of 1.1 kW, which is designed for backup power supplies, and testing it for three years.

Commercial Pt/C PM-40 (Prometheus R&D, Russia) material, which contains 40 wt.% Pt, was used as a catalyst to fabricate electrodes. Catalytic ink was applied using a PRISM BT (Ultrasonic Systems, Inc.) system by ultrasonic

spraying to a Freudenberg H23C3 gas diffusion layer with a microporous layer in accordance with the procedure detailed in [11]. The platinum load was 0.6 and 0.4 mg/cm² at the cathode and the anode, respectively. Membrane electrode assemblies 18 × 4.5 cm in size with an active region area of 71 cm² were fabricated by cathode–membrane–anode hot pressing at 130 °C; a Nafion XL (Chemours, United States) membrane served as a proton-conducting membrane. Titanium foil 18 × 4.5 cm in size, which was glued with silicone sealant around the perimeter to the anode side of the membrane, was used to form the anode half-space. Silicone washers were introduced between the individual fuel cells (IFCs) to seal the hydrogen gas channel. The FCS with a rated power of 1.1 kW was assembled from 55 IFCs separated by corrugated titanium foil with air supply channels (Fig. 1). Titanium foil with a protective

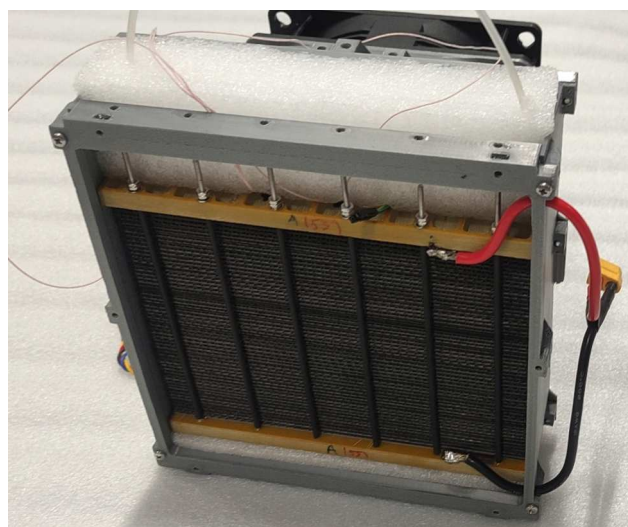


Figure 1. Photographic image of the studied FCS.

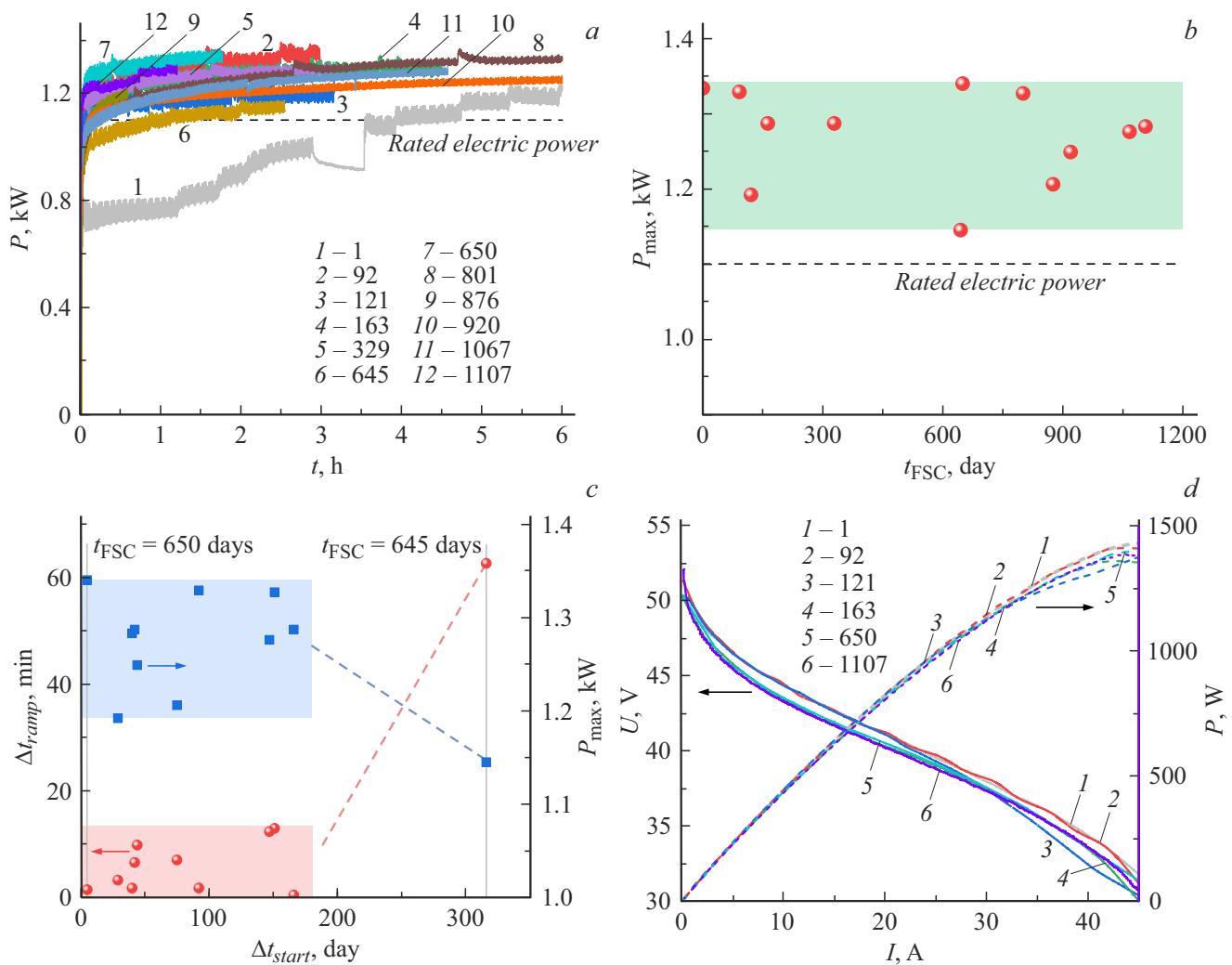


Figure 2. *a* — Dependences of the FCS power on time at each start; *b* — maximum FCS power at each start; *c* — influence of the duration of the interval between starts on the maximum power and the time needed to reach the rated FCS power level; *d* — VACs and power characteristics of the studied FCS. The indicated t_{FSC} values represent the number of days elapsed since the date of FCS fabrication.

coating was used to reduce contact resistance and suppress electrochemical corrosion [12].

A 150x100MPN-1500 (InEnergy, Russia) FCS test unit was used to control the load and monitor/record operating parameters (voltage, current, temperature, anode area purging, etc.). Voltages across each IFC in the stack were measured with a 34980A (Keysight) data acquisition module with a 34924A multiplexer. Over the course of three years, the FCS was started and operated for 0.6–6 h without any specific periodicity in order to approximate real operating conditions. Tests were carried out with self-wetting by means of a controlled pulse load mode (see [13]) at room temperature; air was supplied by a fan from the environment, and hydrogen was fed from a cylinder with an excess pressure of 0.7 atm. The FCS was started in the potentiostatic mode at 0.6 V per IFC; the total voltage was 33 V. With the rated power level reached, volt-ampere characteristics (VACs) were recorded within the current range of 1–45 A. Between the test starts, the FCS was

stored in ordinary conditions: 20–32 °C and a relative humidity of 19–60%. At the end of each test start, the anode half-space inlet/outlet was opened for contact with atmospheric air. No additional purging of the anode area was carried out.

The dependences of power on time obtained at each test start of the FCS are shown in Fig. 2, *a*. The initial start (with $t_{FSC} = 1$ day elapsed since the FCS assembly) is accompanied by extended activation processes during the so-called FCS „ramp,“ which is normally performed for 2–8 h [14]. This long activation with a gradual increase in FCS power is associated with an increase in area of three-phase boundaries, cleaning of the catalyst surface, and uniform wetting of the electrolyte. No direct dependence of the FCS power on temperature and relative humidity of the environment was found.

Over the course of three years, the maximum achieved FCS power P_{max} remained within the range of 1.15–1.34 kW with no pronounced deterioration in the

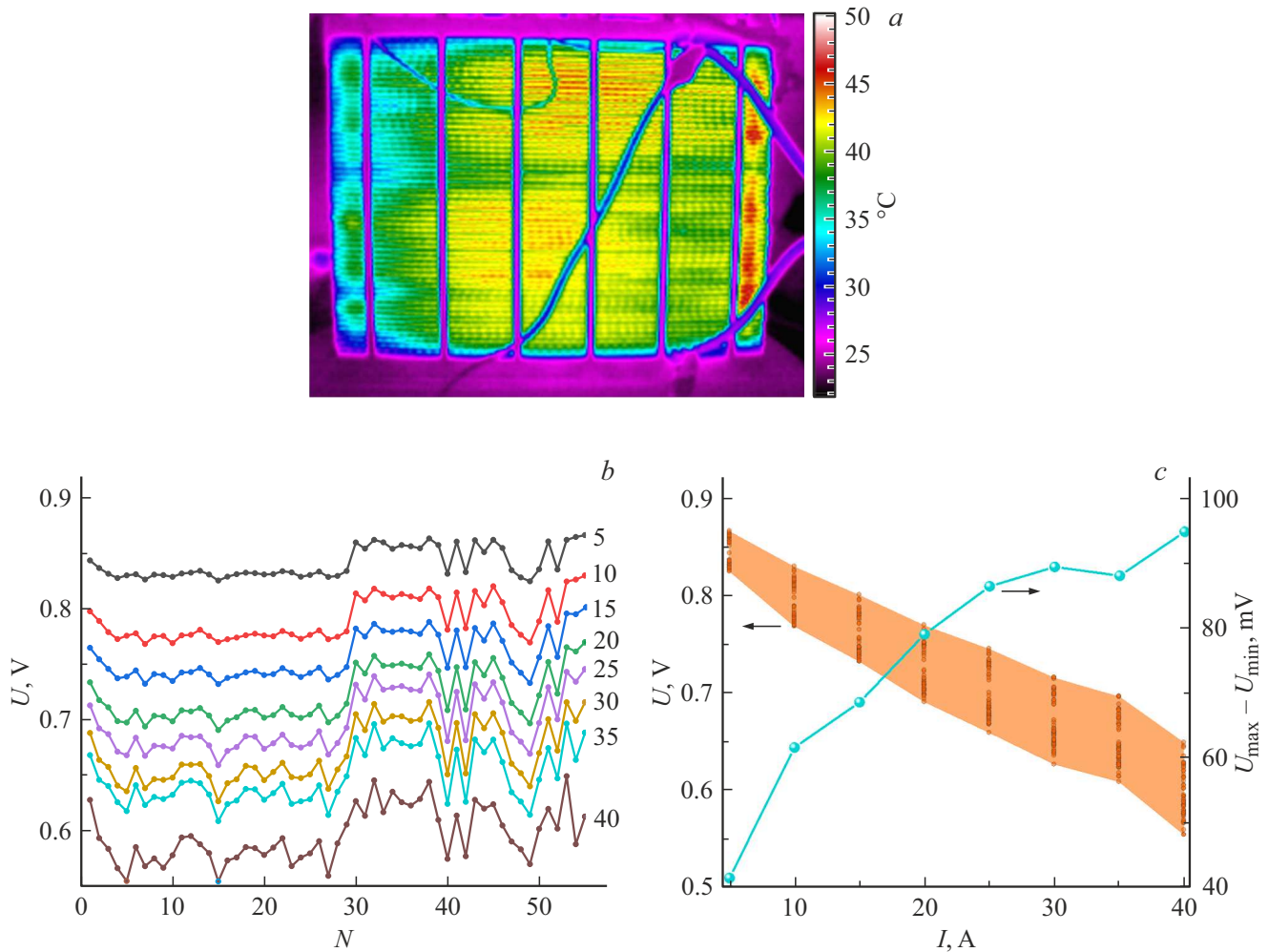


Figure 3. Variation of IFC voltage in the FCS. *a* — Thermal image of the front part of the FCS operating at a voltage of 33 V; *b* — dependences of voltage across an IFC on its number (IFCs are numbered from bottom to top; the load current in A is indicated next to the curves); *c* — dependences of IFC voltage and voltage non-uniformity on the load current.

course of storage (Fig. 2, *b*). However, with long intervals between test starts Δt_{start} ($\Delta t_{start} > 180$ days), a reduction in P_{\max} and an increase in ramp time Δt_{ramp} (time needed to reach the rated power of 1.1 kW) were observed (Fig. 2, *c*). Specifically, Δt_{ramp} at $\Delta t_{start} < 180$ days does not exceed 13 min, while Δt_{ramp} at $\Delta t_{start} = 316$ days extends to 1 h. Therefore, it is recommended for backup power supply systems to start the FCS at least once in every six months.

It should be noted that the deterioration of FCS characteristics during storage (even for a whole year) is reversible. As an example, consider two FCS test starts on the 645th and the 650th days. The first of them was performed a year after the previous test; the FCS power was the lowest recorded in the present study, while the ramp time reached its maximum. However, at the next start 5 days after, the FCS power reached its maximum (Figs. 2, *b, c*).

The FCS VACs have a shape typical of such devices [4] (Fig. 2, *d*). At voltages less than 36 V (~ 0.65 V per IFC), diffusion limitations associated with oxygen transport and

electrolyte wetting are observed. In general, no significant changes in VACs and power characteristics of the studied FCS are noted. Slight differences may be attributed to the length of intervals between starts and changes in environmental conditions (temperature and humidity), which affect the ramp rate of the FCS, its cooling, and cathode wetting.

The contribution of each IFC to the FCS operation was investigated after the 11th start ($t_{FSC} = 1067$ days). The thermal image obtained in operation under nominal electrical load reveals no regions with excess temperature (Fig. 3, *a*), which is indicative of normal and steady operation of all IFCs in the FCS. Measuring contacts were mounted on each of the 55 IFCs in order to measure the dependence of voltage on the applied electrical load. No noticeable difference between the IFCs was observed within the studied range of polarizing currents, which is again indicative of their normal functioning as part of the FCS. The voltage spread between the IFCs is 42–95 mV depending

on the applied load current (Fig. 3, *b*). The presence of such a spread may be attributed to the non-uniformity of the supply of air to the FCS inlet channels. This affects the difference in IFC temperatures and is fairly typical of FCSs with an open cathode [15,16]. It should be noted that the non-uniformity of the IFC voltage distribution becomes more pronounced with increasing load current (Fig. 3, *c*), which is consistent with the results reported in [17].

Thus, testing of the FCS with a rated power of 1.1 kW in three-year operation with irregular starts revealed that the observed deterioration of performance characteristics during storage is reversible. The research data suggest that the guidelines for storage of FCSs of this kind should stress the need to start them at least once every six months. The obtained results provide an opportunity to optimize the operation and storage procedures for FCSs, contributing to an increase in their reliability and efficiency in various energy applications.

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Conflict of interest

The authors declare that they have no conflict of interest.

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