Energy Characteristics of a Combined Power Plant Based on a Hydronic Chemical Current Source

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ABSTRACT

This paper presents the results of energy characteristics calculations of a combined power plant (PP) based on a hydronic chemical current source (CCS) with an aluminum anode, as a hydrogen generator for an oxygen-hydrogen electrochemical generator (O₂/H₂ ECG). Calculations based on current-voltage characteristics (CVC) of sources. It has been shown that the hydronic CCS over the entire operating time of the O₂/H₂ ECG increases its CVC and power characteristic by 30% at the beginning of work and by 20% at the end of the 24-hour resource when using pure nickel cathodes in the hydronic CCS. Using cathodes with a MoS₂ catalytic coating in a hydronic CCS increases CVC of the ECG by 50% at the beginning of work and by 40% at the end of a 24-hour resource. At the same time, the hydronic CCS provides the O₂/H₂ ECG with hydrogen in full volume during the whole period of operation.

INTRODUCTION

The active consumption of oil and gas by mankind during the 20th century led to significant negative consequences for the environment, such as smog in large cities, the greenhouse effect, environmental disasters resulting from oil spills due to tanker accidents during transportation of fuel and much more. Therefore, the use of hydrogen as an energy carrier is considered as an alternative due to the practically unlimited reserves in the composition of the planet’s water resources, the highest specific energy (119.0 MJ/kg) among the known fuel and ecologically clean product (water) in reaction with oxygen.

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Among autonomous power plants (PP) that use hydrogen as fuel, the most energy efficient are oxygen-hydrogen fuel cells (O_2/H_2 FC), which are able to achieve the highest efficiency among all known power plants (up to 94%). In [1-5], it was shown that the combined use of hydronic CCS together with O_2/H_2 FC can form a combined PP consisting of two current sources – hydronic CCS and O_2/H_2 FC (O_2/H_2 electrochemical generator – ECG). Here the hydronic CCS is a source of hydrogen for O_2/H_2 ECG and an additional current source at the same time. Obviously, this should increase the energy characteristics of the PP compared to the PP, consisting only of the source of hydrogen and O_2/H_2 ECG.

EXPERIMENTS AND RESULTS

In this work, we calculated the energy characteristics of the combined power plant "Hydronic CCS + O_2/H_2 ECG" taking into account the functioning of the sources with a serial connection scheme (Figure 1).

An estimate calculation was made for O_2/H_2 ECG of power 3 kW (current 70A, voltage 43V, 72 cells in the battery) for 24 hours. Data on the characteristics of O_2/H_2 ECG are taken from its technical documentation. Its current-voltage characteristic and power characteristic are presented in Figure 2.

The CVC equation of the ECG is approximated by the equation:

\[ U = -56 \cdot 10^{-4} \cdot I_{ECG}^3 + 18,79 \cdot 10^{-2} \cdot I_{ECG}^2 + 56,39 \cdot I_{ECG} + 12,53, \]  

where \( I_{ECG} \) is the discharge current of ECG.

The CVC of the hydronic CCS was calculated for the source with the anode A995, electrolyte 4M KOH + 0.08M tartrate ion. Two electrodes were considered as cathodes: from nickel of mark N-0 and nickel cathode with experimental catalytic coating of molybdenum disulfide – Ni + MoS_2.

The interelectrode gap of the cell is assumed to be equal to \( \delta = 3 \) mm The calculations took into account the change in the interelectrode gap during the operation time and was defined as the algebraic sum of the CVC of the cathode, anode and voltage loss in the interelectrode gap by the equation:

\[ U = \phi_c - \phi_a - \frac{\delta}{\sigma} \cdot j, \]  

where, \( \phi_c, \phi_a \) – electrodes potentials, \( \sigma \) – electrolyte conductivity; \( \delta \) – interelectrode gap width.

CVC characteristics of electrodes are presented in Figure 3.

Taking into account the CVC of the working components of the hydronic CCS, the allowable current density of the hydronic CCS is assumed to be \( j_{hydr} = 1200 \) A/m^2 at the rated discharge current of the O_2/H_2 ECG (70 A). When choosing the current density of the hydronic CCS, the condition was taken into
account that it should operate in the mode of the current source, at the rated power of the \( \text{O}_2/\text{H}_2 \) ECG (3kW).

Figure 1. Schematic diagram of the combined power plant "hydronic CCS – \( \text{O}_2/\text{H}_2 \) ECG " with a series connection of sources.

Figure 2. The current-voltage and power characteristics \( \text{O}_2/\text{H}_2 \) ECG power 3kW.
The calculated assessment results of the energy characteristics for the combined power plant "Hydronic CCS + O2/H2 ECG" (and each of the sources separately) are shown in Figures 4 and 5.

From the obtained data it follows that the hydronic CCS throughout the entire operating time of the O2/H2 ECG increases its current-voltage and power characteristics by 30% at the start of work and by 20% at the end of the 24-hour resource when using pure nickel cathodes in the hydronic CCS.

Figure 3. Current-voltage characteristics of anodes A995, Al-In and Ni and Ni + MoS2 cathodes at 333 K.
Figure 4. Initial current-voltage and power characteristics of a hydronic chemical current source, O₂/H₂ electrochemical generator and a combined power plant.
Using cathodes with a MoS$_2$ catalytic coating in a hydronic CCS increases its current-voltage and power characteristics of the O$_2$/H$_2$ ECG by 50% at the beginning of work and 40% at the end of the 24-hour resource. The results of the energy characteristics calculations of the hydrogen generator based on the hydronic CCS as part of a combined power plant are given in Table I.
TABLE I. ENERGY CHARACTERISTICS OF A HYDROGEN GENERATOR BASED ON A HYDRONIC CCS AS PART OF A COMBINED POWER PLANT.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Combination of the working components</th>
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<tbody>
<tr>
<td></td>
<td>A995 – 4M KOH + 0,08M tartrate-ion – Ni</td>
</tr>
<tr>
<td></td>
<td>A995 – 4M KOH + 0,08M tartrate-ion – Ni+MoS₂</td>
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<tr>
<td>The voltage of the hydronic CCS at $I_{ECG}=70A$, V</td>
<td>0.208</td>
</tr>
<tr>
<td>The power of hydronic CCS at $I_{ECG}=70A$, W</td>
<td>896</td>
</tr>
<tr>
<td>at the beginning of work after 24 hours of operation</td>
<td>637</td>
</tr>
<tr>
<td>The average specific energy for 24 hours of discharge, kJ/kg (W·h/kg)</td>
<td>334 (93)</td>
</tr>
</tbody>
</table>

CONCLUSION

Thus, the results of calculations show that to increase the characteristics of a combined power plant, it is preferable to use a cathode with a MoS₂ catalytic coating in a hydronic CCS. This allows to increase the CVC and power characteristic up to 50%. At the same time, the hydronic CCS provides the O₂/H₂ ECG with hydrogen in full volume during the whole period of operation.

REFERENCES