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An experimental aluminum-fueled power plant

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ABSTRACT

An experimental co-generation power plant (CGPP-10) using aluminum micron powder (with average particle size up to 70 μm) as primary fuel and water as primary oxidant was developed and tested. Power plant can work in autonomous (unconnected from industrial network) nonstop regime producing hydrogen, electrical energy and heat. One of the key components of experimental plant is aluminum–water high-pressure reactor projected for hydrogen production rate of ~10 nm^3 h^{-1}. Hydrogen from the reactor goes through condenser and dehumidifier and with −25 °C dew-point temperature enters into the air-hydrogen fuel cell 16 kW-battery. From 1 kg of aluminum the experimental plant produces 1 kWh of electrical energy and 5–7 kWh of heat. Power consumer gets about 10 kW of electrical power. Plant electrical and total efficiencies are 12% and 72%, respectively.

1. Introduction

Aluminum has been proposed for the role of perspective non-organic energy storage mater by a number of researchers [1–9]. Potentially high level of aluminum integration in future energy economy is mainly bound with high content of aluminum in the earth's crust [10], safety and moderate cost of aluminum storage and transportation [11], as well as possible regeneration of such energy carrier.

Exothermic process of aluminum oxidation in aqueous solutions with the production of hydrogen as intermediate fuel proved to be one of the effective technologies that convert aluminum chemical energy into useful energy (electrical or thermal) [2,7,12–17]. Recently developed method of aluminum micron powder oxidation in high-temperature water steam [12,13] allowed applying pure (without alkali and any other chemical activators) water as oxidant. Kinetics of aluminum micron powders oxidation in high-temperature boiling water was studied in [18]. It was established that aluminum powders with average particle size from 4 to 70 μm, which are produced in industrial scale, were intensively oxidized within special reactor under about 300 °C and 10 MPa water steam; the reaction time was several tens of seconds.

Further development of power plant based on "aluminum–water" reactor as high-pressure steam-hydrogen generator was based on the results of kinetic experiments and a number of designing investigations. One of such calculations was presented in [19]. It was devoted for thermodynamics of nonstop reactor operation. Reactor thermo- and gas-dynamic parameters estimation and optimization was carried out in that work, an optimum parameter field (composed of reactor temperature, pressure, volume and others) in the view of thermodynamic effectiveness was determined.

Based on the results of [18,19] and other designing investigations an experimental co-generation power plant CGPP-10 was developed. It consumes aluminum micron powder as primary fuel and pure water as primary oxidant. Hydrogen, which is produced within aluminum–water reactor, is used as secondary fuel for electrical energy generation. "10″ in power plant label means nominal hydrogen generation rate in "nm^3 h^{-1}". CGPP-10 outputs useful electrical energy and heat. If it is necessary, CGPP-10 can produce hydrogen as end product.

In present work CGPP-10 structure, operation principle and operation features are considered. One of the primary purposes of experimental activities was CGPP-10 nonstop run organization. It was attained and so the results of nonstop test are presented in this work. Both each CGPP-10 component separately and experimental plant wholly are studied. Following the results of experiment main CGPP-10 technical specifications and energy indexes are examined. Thermodynamic and economic analyses for CGPP-10 are also estimated.

Abbreviations: RB, reactor block; ECG, electrochemical generator; AHFC, air-hydrogen fuel cell; EETDS, energy transformation and distribution system; FH, fan heater; HT, hydrogen tank; ACMS, automated control and management system; DHPP, dosage high-pressure pump; T_i, temperature sensor; P_i, pressure sensor; L_i, liquidometer; CV, cutoff valve; OWV, one-way valve; VI, voltage inverter; LABB, lead-acid batteries block; BC, battery charger; FS, feeder switchboard; BL, ballast load.

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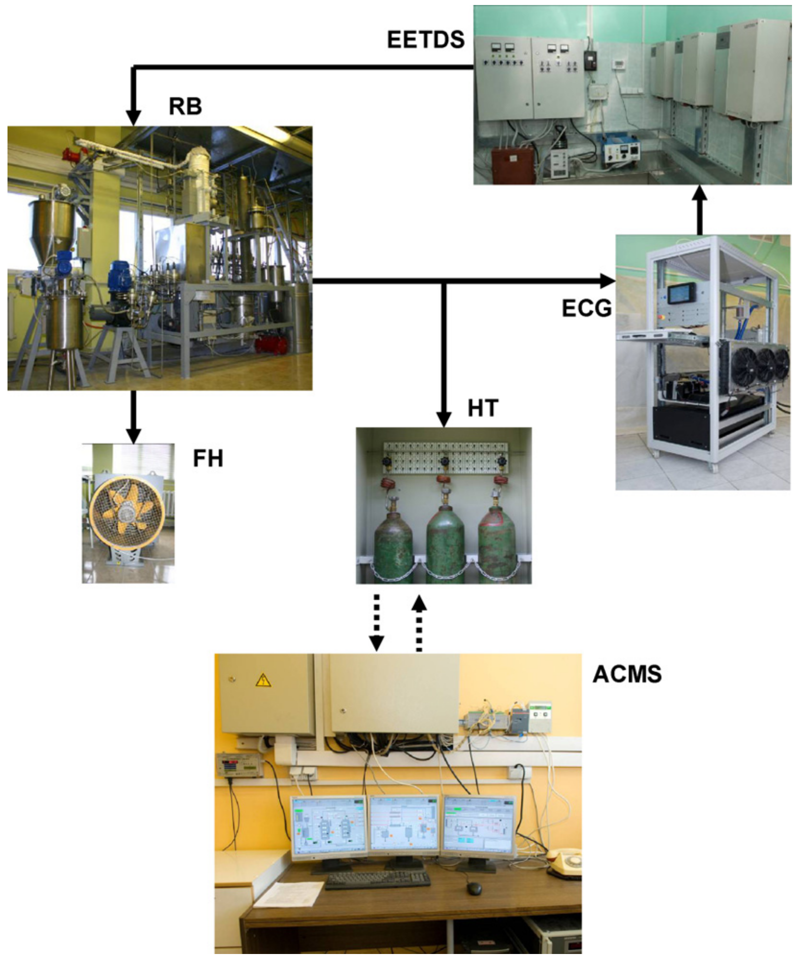

Fig. 1. CGPP-10 main components. RB – reactor block, HT – hydrogen tank, ECG – electrochemical generator, FH – fan heater, EETDS – electrical energy transformation and distribution system, and ACMS – automated control and management system.

2. Experimental plant

Experimental plant general components are shown in Fig. 1. The crucial unit of CGPP-10 is the reactor block (RB) where in accordance with the developed method of aluminum micron powder oxidation the nonstop process of hydrogen and heat generation was realized. For hydrogen utilization an electrochemical generator (ECG) based on the air-hydrogen fuel cells (AHFCs) was chosen. Electrical energy produced by AHFC battery is directed to the electrical energy transformation and distribution system (EETDS). EETDS realizes CGPP-10 power supply switch from industrial network to ECG (and back) providing autonomous, non-networked, operation of whole experimental complex. Thermal energy produced by RB is transformed into the useful heat warming up the room by means of fan heater (FH). For ECG trouble-free performance the CGPP-10 involves hydrogen tank (HT), which smoothes the electrical energy consumption irregularity and in case of zero load stores the secondary fuel. Experimental plant is remotely managed by operator from operating room through the automated control and management system (ACMS).

2.1. Reactor block

RB in-life view and its schematic diagram are shown in Fig. 2a and b, respectively. Nonstop hydrogen and heat generation in RB is based on nonstop initial reagents (water and aluminum powder) supply to reactor and simultaneous nonstop oxidation products removing from reactor. Aluminum powder is entered into the reactor in the form of aluminum–water mixture with fixed value of water to aluminum mass ratio. Mixture is prepared within mixing tank. Aluminum into the mixing tank goes from aluminum powder storage bunker by means of dosage screw; water goes from distilled water tank by means of dosage pump. During the experiment the mixture level in mixing tank is kept within fixed interval and it is controlled by liquidometer. Necessary water to aluminum mass ratio in the mixture is achieved due to the preliminary motor frequency adjustment of dosage devices.

From mixing tank to reactor the mixture is entered with the help of dosage high-pressure pump (DHPP). The products of aluminum–water reaction are removed from the reactor both from the top and from the bottom. From the top of the reactor mainly gaseous phase of oxidation products (hydrogen and water steam mixture) is removed, from the bottom—aluminum hydroxide and water in condensed state. Aluminum powder is fully oxidized within the reactor, because condensed phase necessary volume is always maintained in the bottom of reactor. Condensed phase volume is controlled by contactless level sensor, which governs the removing of oxidation products from the bottom of reactor. From the top of the reactor the products are removed through the controllable valve with variable cross-section.

Hydrogen and water steam mixture goes from the reactor into the heat exchanger, where it is cooled by circuit water. Thermal energy, which is transferred to the heat exchanger, is spent on circuit water heating and room warming. Hydrogen and condensed