ESTIMATION OF EFFICIENCY OF USING HYDROGEN AND ALUMINUM AS ENVIRONMENTALLY-FRIENDLY ENERGY CARRIERS

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Introduction

Over several decades researchers in the energy field have been studying hydrogen energy – the global energy system, in which hydrogen is the basic energy carrier. Currently these studies are gaining in importance due to aggravated problems on greenhouse gas emissions and expected shortage of hydrocarbon fuel.

Alongside with undoubted advantages, the environmental purity of combustion products being one of them, hydrogen has essential disadvantages as an energy carrier because of its expensive transportation and storage. Therefore, the search for other potential energy carriers with advantages of hydrogen and without its disadvantages is of great scientific concern. Aluminum can be considered as one of such energy carriers. Product of its oxidation is the solid, nontoxic matter Al_2O_3. Aluminum has high calorific value, is easily stored and transported with low costs. Besides, its storage and transportation do not cause such hazards as fires, explosions, as is the case with hydrogen.

In general, the technology of using aluminum as an energy carrier includes the following stages: a) aluminum production on the basis of “primary” electricity; b) aluminum transportation to the area of final consumption; c) aluminum storage (to cover an uneven annual electric load curve at uniform aluminum production and transportation); d) generation of “secondary” electricity from hydrogen produced from aluminum fuel; e) reverse transportation of Al_2O_3.

Studies on installations

The paper describes technical and economic studies on the energy system based on aluminum energy carrier. Much attention is paid to installations for electricity production from aluminum fuel as the least studied element of the indicated system.

A combined energy installation including high-temperature fuel cells using aluminum as a fuel provides the highest energy efficiency. A considerable portion of the calorific value (chemical energy) of aluminum in them is converted to electric energy. However, currently the high-temperature fuel cells, in which aluminum is used as a fuel, are not well-tested electricity sources. This work deals, therefore, with two other schemes of electricity generation from aluminum. Both include an intermediate stage of hydrogen production from aluminum on the basis of the reaction of aluminum with steam. In the combined cycle power installations with high-temperature fuel cells a stoichiometrically needed (for oxidation of aluminum supplied to the reactor) steam volume is injected into the reactor. As a result virtually pure hydrogen (owing to formation of Al_2O_3 at the condensed phase) that is admitted to the high-temperature air-hydrogen fuel elements is produced in the reactor (Fig.1). The efficiency of this scheme is high enough, but it requires pipe-type heating surfaces placed in the reactor with molten aluminum to transfer heat to a working medium of the steam turbine cycle. The gas turbine installation with hydrogen combustion in the combustion chamber of a gas turbine and steam generation that is required for hydrogen production and heat usage in the waste heat boiler has lower efficiency, but does not require pipe-type heating surfaces to be placed in the reactor and does not use fuel cells.

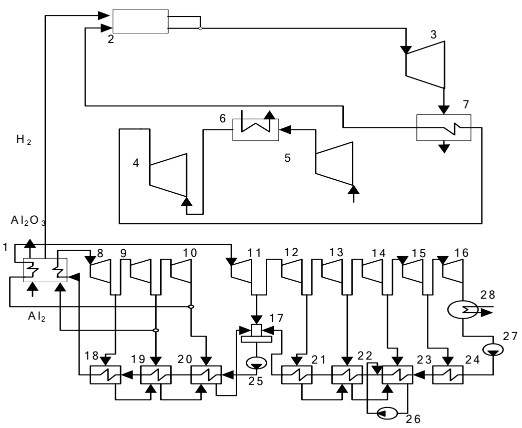

Fig.1. A process flowsheet of combined cycle power installation with fuel cell using hydrogen as a fuel: 1 – reactor for hydrogen production, 2 – fuel cell, 3 – gas turbine, 4 – 5 – air compressors, 6 – air-water cooler, 7 – air-gas heat exchanger, 8 – 16 – steam turbine sections, 17 – deaerator, 18 – 20 – high pressure heater, 21 – 24 – low pressure heater, 25 – 27 – pumps, 28 – steam turbine condenser.

The energy efficiency, design characteristics of basic elements, investments in the installation depending on its thermodynamic parameters and flow rates of working media were determined by the mathematical model constructed for each studied installation. The models were applied to solve optimization problems of the installation parameters.

The next stage of work was to compare economic efficiency of the energy system based on aluminum fuel with that of alternative energy systems that include hydrogen energy on the base of nuclear power plants, coal-fired power plants with electricity transportation by DC transmission lines, etc.

Conclusions

Energy installations with intermediate hydrogen production from aluminum fuel and use of heat released in the reactor for hydrogen production in the steam turbine cycle have high efficiency, which motivates interest to further more detailed studies on engineering decisions for the indicated technologies.