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Mathematical Modeling of Heat and Mass Transfer in a Passive Autocatalytic Recombiner

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Abstract—A mathematical model of heat and mass transfer in a passive autocatalytic recombiner (PAR) is developed. Three-dimensional calculations of convection of a hydrogen-containing medium in a hydrogen recombiner of the RVK-315 model series are performed using the ANSYS Fluent commercial code. Due to the periodic structure of the catalytic block, calculations were performed for one rod arranged in its middle. The results of calculations are correlated with the experimental data acquired using the OAO VTI stand. The mismatch between the calculated and experimental data does not exceed 30% in the range of bulk hydrogen concentrations of 1.5–6.5%.

Keywords: computational fluid dynamics, hydrogen safety, catalyst, passive autocatalytic recombiner, PAR

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Results of computational analyses of beyond-design accidents at nuclear power plants performed up until now show that a great amount of hydrogen is formed during these accidents. Hydrogen at volume concentrations higher than 4% in combination with oxygen can form an explosive mixture, which is dangerous for the integrity of a protective shell.

The main current solution for provision of hydrogen safety in premises of nuclear power plants is oxidation of hydrogen at solid surfaces, which is performed using passive autocatalytic recombiners (PARs). The operational principle of the PAR is in the catalytic oxidation of hydrogen with oxygen on a catalyst with heat liberation, i.e.,

$$2H_2 + O_2 \rightarrow 2H_2O \text{ (vapor)} + 244.9 \text{ kJ/mol}.$$

No additional supply of power and controlling signals is required in this case. Thus, a passive action principle is implemented in the PAR; according to the safety rules at nuclear power plants, it is obligatory for the localizing safety systems.

Currently, recombiners of the Russian producer—CJSC INPK Russkie Energeticheskie Tekhnologii (CJSC INPK RET)—of the RVK model series and European recombiners of the FR-90/1 model series are currently used in Russia.

A passive autocatalytic recombiner consists of a metallic case, more often with a rectangular cross section, with a catalytic block arranged in its lower part. Open upper and lower ends of the recombiner are freely connected with the surrounding medium (Fig. 1a). A catalyst block consists of frames with rods (Fig. 1b), and the catalyst is incorporated into their pores by a certain method. As a catalyst, the platinum group metals (most often platinum itself) are used, while the carrier is fabricated from chemically and thermally stable materials, namely, oxides of aluminum, silicon, magnesium, titanium, zirconium; silicates; carbonates; alkali-earth metals and carbides of magnesium, silicon, and aluminum; and valve metals.

At sufficiently high hydrogen concentrations, the reacting gases, reaction products, and constructional elements can heat to temperatures sufficient to ignite the hydrogen–air mixture. In this case, the heat distribution in a recombiner plays an essential role; therefore, studying the regularities of processes of convective heat transfer in a gas medium, which are conjugated with the exothermic chemical reaction on a solid surface, is a topical problem.

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We consider a hydrogen-containing gas medium in which excess oxygen is contained (the hydrogen concentration is lower than 15%); therefore, the variation in its concentration almost does not affect the chemical reaction rate. Due to the exothermic reaction, the gas mixture near the walls is heated, which leads to the formation of a free-convective boundary layer. Since hydrogen oxidizes only on the catalyst surface, the