

# MOLECULAR HYDROGEN PRODUCTION AT THERMOCATALYTIC AND THERMOCATALYTIC AND RADIATION TRANSFORMATION OF WATER IN THE BeO+H<sub>2</sub>O SYSTEM

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The dependence of an yield of the molecular hydrogen received at thermal and radiation thermocatalytic transformation of water under influence of  $\gamma$ -quanta ( $^{60}\text{Co}$ ,  $P = 20.1$  rad/s) on the BeO+H<sub>2</sub>O system, with sizes of particles  $d_{\text{Be}} < 4$   $\mu\text{m}$  has been studied: 1) from the general temperature ( $T = 300; 373; 473; 573; 623$ , and  $673$  K) of system at constant value of water vapor density which is equal  $\rho = 10$   $\text{mg}/\text{cm}^3$  and 2) from water vapor density ( $\rho = 0.5; 1; 2.5; 5$ , and  $10$   $\text{mg}/\text{cm}^3$ ) at constant value of temperature  $T = 673$  K. In this system in the reactionary environment with a density of water of  $\rho = 10$   $\text{mg}/\text{cm}^3$  in the range of temperatures  $300 \leq T \leq 473$  K, molecular hydrogen turns out only by radiation and thermocatalytic (activation energy of process is  $E_a = 1.1$  kJ/mol), and in the range of temperatures  $573 \leq T \leq 673$  K – by thermocatalytic ( $E_a = 97.5$  kJ/mol) and radiation and thermocatalytic ( $E_a = 56$  kJ/mol) ways. In the BeO+H<sub>2</sub>O system at a constant temperature of  $T = 673$  K, and at values of density of water  $\rho = 0.5; 1; 2.5; 5$ , and  $10$   $\text{mg}/\text{cm}^3$  the rate of accumulation of molecular hydrogen, received by the thermocatalytic and thermocatalytic and radiation transformation of water, grows in direct ratio to its density, and at values of  $\rho \geq 2.5$   $\text{mg}/\text{cm}^3$  this proportionality is violated and deceleration is observed. The possible mechanism of processes which is rather well explaining the obtained experimental data is specified.

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## INTRODUCTION

Since beryllium has such physical properties as high melting point, good thermal conductivity, small atomic mass, small hydrogen uptake at high temperatures, low thermal neutron absorption and high reflection efficiency, high elastic modulus, chemical and corrosion resistance at high temperatures, it and its various compounds (beryllium oxide, beryllium fluoride, fluoride beryllium) are used as constructional materials in nuclear and thermonuclear reactors (MTR, ETR, ATR, EBR-II, ITER) [1–3]. Since these materials inside the reactor, under different conditions (in contact with air, water, steam, etc.), operate under the influence of temperature and ionizing rays (neutrons, protons,  $\gamma$ -quanta, electrons,  $\alpha$  particles, high-energy ions etc.), then the changes that can occur within them, on their surface and in the environment, are of great importance for workers engaged in this field.

Researchers have recently begun to study the process of radiation-heterogeneous transformation of gases, liquids (especially water,) in nanosystems and micro-heterogeneous systems. This plays an important role in obtaining of environmentally friendly fuel – hydrogen, as well as for the safe operation of reactors. From the results of the research, it appears that at the contact of some metals and metal oxides (in particular beryllium oxide) with water and water vapor under the action of  $\gamma$ -quanta, the radiation-chemical yield of molecular hydrogen is the highest [4–13]. The researchers conducted these processes under two conditions. It was investigated at first, the suspension of these materials in water, and secondly, the dependence of the amount, rate of formation, and radiation-chemical yield of molecular hydrogen obtained during the radiation-heterogeneous transformation of water adsorbed on the surface of these materials from:

- the width of the forbidden band of a solid;
- particle size of a solid;
- the degree of water filling the surface of a solid;
- total system temperature;
- density of water in the reaction medium;
- the mass of a solid suspended in water.

From the data obtained by various experimenters, it was found that in the radiation-heterogeneous transformation of water under the action of  $\gamma$ -quanta on a system with nano- and microdimensional materials [14], the amount, accumulation rate and radiation-chemical yield of the obtained products is several times higher than in pure water [4–14].

In the present work, the dependence of the amount, rate of formation and radiation-chemical yield of molecular hydrogen on the temperature of the system ( $T = 300; 373; 473; 573$ , and  $673$  K) and on the density of water vapor ( $r = 0.5; 1; 2.5; 5$ , and  $10$   $\text{mg}/\text{cm}^3$ ) in the reaction medium during the radiation-heterogeneous transformation of water on the BeO surface (with particle sizes  $d < 4$   $\mu\text{m}$ ) under the influence of  $\gamma$ -quanta ( $^{60}\text{Co}$ ,  $P = 20.1$  rad/s).

## EXPERIMENTAL PART

As the object of investigation, beryllium oxide was taken with a purity of 99.9%. Initially, beryllium oxide was passed through a sieve, and particles with dimensions  $d < 4, 32...53, 75...106$   $\mu\text{m}$  were obtained, which were then thermally treated ( $T = 673$  K) in air for  $t = 72$  hours. Then it was taken the desired mass weighed on the balance and added to the quartz ampoule ( $V = 19$  ml), purified under special conditions and thermally treated ( $T = 773$  K). After the thermal treatment of BeO ( $T = 673$  K) under vacuum conditions ( $P = 10^{-3}$  mm Hg) in an ampoule for 4 hours, it was cooled, and then the required amount of doubly-distilled

- the kind of solid;

water, purified from air, was adsorbed on its surface [12, 13, 15].

Next, the ampoules were sealed and irradiated by a  $^{60}\text{Co}$  source with a dose rate  $P=20.1$  rad/s. The absorption dose rate was determined by ferrosulfate and methane methods. In a particular investigated object, the absorption dose rate was calculated using the method of comparing of electron densities [15, 16].

Molecular products –  $\text{H}_2$ ,  $\text{O}_2$ , and  $\text{H}_2\text{O}_2$ , obtained during the radiation-heterogeneous process, were determined by chromatographic method. Since part of  $\text{O}_2$ , which is one of these products, is trapped on the surface, and  $\text{H}_2\text{O}_2$  remains in solution, the errors are large in determining of these products. Therefore, more precise information about the kinetic regularity of the process of radiation-heterogeneous water transformation was given on the basis of the amount of molecular hydrogen.

The reaction products were analyzed on an “Agilent-7890” chromatograph. To confirm the results, a modernized chromatograph Tsvet-102 (accuracy 8...10%) was used in parallel. In the Tsvet-102 chromatograph, a 1 m long column with an inner diameter of 3 mm was used. Inside the column, activated charcoal was used with a particle size  $d = 0.25 \dots 0.6$  mm and argon of high purity was used as a carrier gas in each of the two chromatographs.

## RESULTS AND ITS DISCUSSION

As the temperature in the  $\text{BeO}+\text{H}_2\text{O}$  system increases, the process of desorption of water adsorbed on the particle surface begins. Therefore, the dependence of the yield of molecular hydrogen, obtained both by thermocatalytic and thermocatalytic and radiationconversion of water in the reaction medium, on the density of water, was considered.

In Fig. 1 the kinetic curves of molecular hydrogen obtained under the influence of  $\gamma$ -quanta during the radiation-thermal transformation of water vapor of different densities upon contact with  $\text{BeO}$  at a temperature  $T = 673$  K are given, and in Fig. 2 under the same conditions kinetic curves are given for the dependence of the yield of molecular hydrogen obtained during the thermal transformation of water on the time.

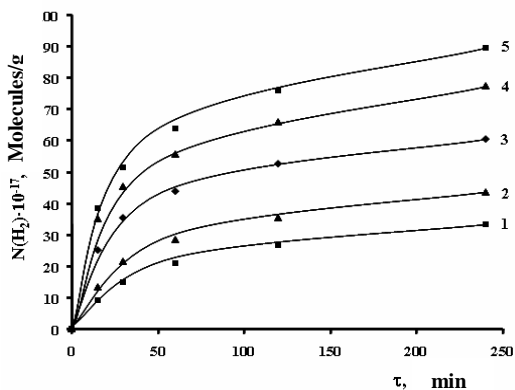


Fig. 1. Kinetics of the production of molecular hydrogen at the radiation-thermal transformation of water in contact with  $\text{BeO}$  at a temperature of  $T = 673$  K and the density of water vapor  $\rho = 0.5$  (1); 1 (2); 2.5 (3); 5 (4), and 10 (5)  $\text{mg}/\text{cm}^3$

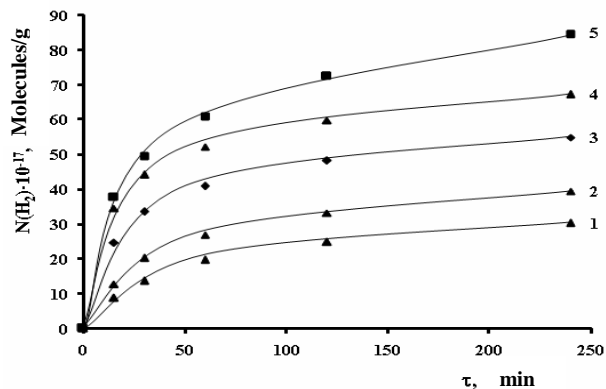


Fig. 2. Kinetics of molecular hydrogen production at the thermal transformation of water in contact with  $\text{BeO}$  at a temperature of  $T = 673$  K and the density of water vapor  $\rho = 0.5$  (1); 1 (2); 2.5 (3); 5 (4), and 10 (5)  $\text{mg}/\text{cm}^3$

Based on the initial sections of the kinetic curves ( $\tau = 0 \dots 30$  min), it were determined the rates of formation of molecular hydrogen obtained under the thermocatalytic ( $W_T(\text{H}_2)$ ) and radiation-thermocatalytic ( $W_{RT}(\text{H}_2)$ ) water conversion and on the basis of expression (1) based on the difference in rates, the fraction of radiation was determined:

$$W_R(\text{H}_2) = W_{RT}(\text{H}_2) - W_T(\text{H}_2). \quad (1)$$

The radiation-chemical yield of molecular hydrogen was calculated on the basis of  $W_R(\text{H}_2)$  and the results obtained are given in Tabl. 1.

Table 1

The formation rate and the radiation-chemical yield ( $G(\text{H}_2)$ ) of molecular hydrogen obtained by the thermocatalytic ( $W_T(\text{H}_2)$ ) and radiation-thermocatalytic ( $W_{RT}(\text{H}_2)$ ) conversion of water vapor of different densities in contact with  $\text{BeO}$  at a temperature of  $T = 673$  K

The formation rates ( $W(\text{H}_2)$ ) and the radiation-chemical yield ( $G_R(\text{H}_2)$ )	Water density, $\text{mg}/\text{cm}^3$				
	0.5	1	2.5	5	10
$W_T(\text{H}_2) \cdot 10^{-14}$ , molec./g·s	0.97	1.41	2.73	3.825	41.8
$W_{RT}(\text{H}_2) \cdot 10^{-14}$ , molec./g·s	0.99	1.45	2.81	3.91	42.75
$W_R(\text{H}_2) \cdot 10^{-14}$ , molec./g·s	0.2	0.4	0.8	0.85	0.95
$G_R(\text{H}_2)$ , molec./100 eV	1.6	3.2	6.38	6.7	6.97

In the reaction medium, the rate of formation and the radiation-chemical yield (Tabl. 2) of molecular hydrogen obtained in the thermocatalytic and radiation-thermocatalytic transformation of water in contact with  $\text{BeO}$  at a temperature of  $T = 673$  K and a water vapor density of  $\rho = 0.5; 1; 2.5; 5$ , and  $10 \text{ mg}/\text{cm}^3$  was observed as a function of the water density. When  $\rho < 2.5 \text{ mg}/\text{cm}^3$  the radiation-chemical yield of molecular hydrogen grows directly in proportion to the water density, and at  $\geq 2.5 \text{ mg}/\text{cm}^3$  this proportionality is violated and deceleration is observed. In this system, the dependence of the rate of formation of molecular

hydrogen on the density of water can be represented by the Langmuir expression (2):

$$w_{T(RT)}(\text{H}_2) = \frac{k_{T(RT)}b\rho_{\text{H}_2\text{O}}}{1 + b\rho_{\text{H}_2\text{O}}}, \quad (2)$$

where  $k_{T(RT)}$  is the rate of thermocatalytic and radiation-thermocatalytic processes;  $b$  is the equilibrium rate in adsorption processes, and the  $\rho_{\text{H}_2\text{O}}$  is the density of water vapor. In the Langmuir equation, if we take into account that  $b\rho_{\text{H}_2\text{O}} \ll 1$  for small values of the water vapor density, the rate of formation of molecular hydrogen  $w_{T(RT)}(\text{H}_2) = k_{T(RT)}b\rho_{\text{H}_2\text{O}}$  obtained by the thermocatalytic (radiation-thermocatalytic) transformation of water is directly proportional to the density of water vapor, and for values of  $b\rho_{\text{H}_2\text{O}} \gg 1$  it assumes a constant value, equal to

$$w_{T(RT)}(\text{H}_2) = k_{T(RT)}.$$

In Fig. 3 kinetic curves of the effect of temperature ( $T = 300$  (1), 373 (2), 473 (3), 573 K (4)) on the yield of molecular hydrogen obtained by radiation-thermal

conversion of water vapor density of  $\rho = 10 \text{ mg/cm}^3$  in contact with BeO under the action of  $\gamma$ -quanta.

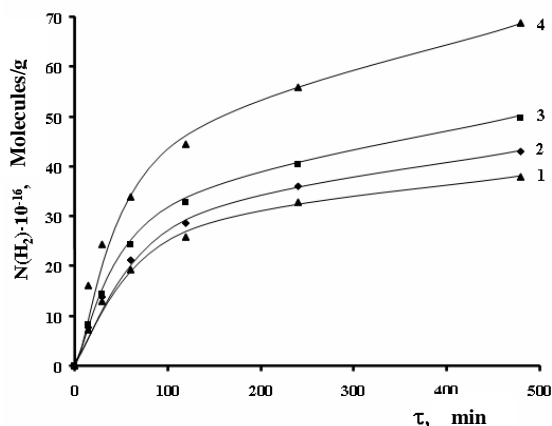


Fig. 3. Effect of temperature ( $T = 300$  (1); 373 (2); 473 (3); 573 K (4)) on the yield of molecular hydrogen obtained by radiation-thermal conversion of water vapor of density  $\rho = 10 \text{ mg/cm}^3$  in contact with BeO

Table 2  
Effect of temperature on the formation rate and the radiation-chemical yield of molecular hydrogen obtained by the thermocatalytic ( $W_T(\text{H}_2)$ ) and radiation-thermocatalytic ( $W_{RT}(\text{H}_2)$ ) conversion of water with a density of  $\rho = 10 \text{ mg/cm}^3$  in contact with BeO

$T, \text{ K}$	$W_T(\text{H}_2), \text{ molec.}/(\text{g}\cdot\text{s})$	$W_{RT}(\text{H}_2), \text{ molec.}/(\text{g}\cdot\text{s})$	$W_R(\text{H}_2), \text{ molec.}/(\text{g}\cdot\text{s})$	$G_R(\text{H}_2), \text{ molec.}/100 \text{ eV}$
300	–	$0.81 \cdot 10^{14}$	$0.81 \cdot 10^{14}$	6.40
373	–	$0.83 \cdot 10^{14}$	$0.83 \cdot 10^{14}$	6.54
473	–	$0.85 \cdot 10^{14}$	$0.85 \cdot 10^{14}$	6.80
573	$0.88 \cdot 10^{14}$	$1.78 \cdot 10^{14}$	$0.90 \cdot 10^{14}$	6.93
623	$10.3 \cdot 10^{14}$	$11.23 \cdot 10^{14}$	$0.93 \cdot 10^{14}$	6.95
673	$41.8 \cdot 10^{14}$	$42.75 \cdot 10^{14}$	$0.95 \cdot 10^{14}$	6.97

At the second stage, the process was carried out under the same conditions only under the influence of temperature. And then from the linear parts of the kinetic curves of both thermocatalytic and thermocatalytic and radiation (see Fig. 3) processes, the rates of formation of molecular hydrogen (1) and then the radiation-chemical yield were determined. The results are summarized in Tabl. 2

From the dependence of the rate of formation of molecular hydrogen on temperature, the activation energies of the processes in Arrhenius coordinates ( $\lg W(\text{H}_2), 1/T$ ) were determined. In the temperature range  $300 \leq T \leq 573 \text{ K}$ , during the thermocatalytic transformation of water the process of molecular hydrogen yield is not observed, but is observed only in the radiation-catalytic transformation, the activation energy of which is equal to  $E_R = 1.1 \text{ kJ/mol}$  (Fig. 4 (1a)). And in the temperature range  $573 \leq T \leq 673 \text{ K}$ , the production of molecular hydrogen occurs both at the thermocatalytic (see Fig. 4 (2)) and thermocatalytic and radiation (see Fig. 4 (1b)) transformation of water, and the activation energy of these processes is defined as  $E_{RT} = 56 \text{ kJ/mol}$  and  $E_T = 97.5 \text{ kJ/mol}$  respectively.

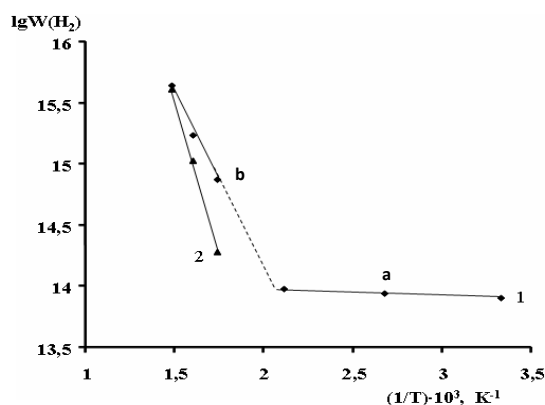
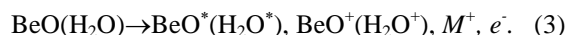


Fig. 4. Dependence of the rate of formation of molecular hydrogen obtained during the thermocatalytic (2) and radiation and thermocatalytic (1) conversion of water of density  $\rho = 10 \text{ mg/cm}^3$  in contact with BeO, on the temperature

Adsorption on the surface of the oxide is possible with the participation of oxygen atoms playing a non-bridge role, and due to the unsaturated coordination atoms of the metal. Strong adsorption of electron-donor water molecules on the surface is possible with the participation of acceptor centers. On the BeO surface, these acceptor centers are the coordinative unsaturated

Be atoms [17, 18]. Practically and theoretically [19] it was proved that the bond energy in the complex formed by the  $\text{Be}^{2+}$  ion with water molecules (400...500 kJ/mol) is higher in comparison with the ions of other metals.

In the physical stage of the process, such types of energy carriers as electron-ion pairs ( $\text{BeO}^+ - e^-$ ,  $\text{H}_2\text{O}^+ - e^-$ ), formed by the ionization of molecules, and electron-excited states ( $\text{BeO}^*$ ,  $\text{H}_2\text{O}^*$ ) (excitons) [20–24] are formed in BeO,  $\text{H}_2\text{O}$ , BeO+ $\text{H}_2\text{O}$  systems under the influence of ionizing rays ( $\gamma$ -quanta, electrons, etc.):



A certain part of the electrons formed by (3) in accordance with the Onsager effect, recombining with their ion, can form an electron-excited state (exciton). The remaining part of the energy carriers, depending on the temperature and the intensity of the external surface, migrating to different distances, is localized in structural defects, while the other part, migrating to the surface, can localize at the centers of the surface. Some of the electrons migrating to the surface are emitted from the surface and pass into water adsorbed on the surface or water vapor.

The intermediate products [25] formed under the influence of temperature and  $\gamma$ -quanta and directly involved in the formation of molecular hydrogen as a result of the thermocatalytic and radiation-thermocatalytic transformation of water can be symbolically represented in the form (4) below:



Active intermediates, by adsorbing water molecules in a vaporous form, form intermediately active complexes (5):



Intermediate active complexes formed between water molecules and catalytically active  $\text{Be}^{2+}$  centers on the surface of beryllium oxide play an important role in the formation of molecular hydrogen by thermocatalytic and radiation-thermocatalytic water splitting. Active intermediate products, transferring their excitation energy to water molecules, result in the formation of highly reactive intermediate products H and OH (6) as a result of water transformation:



Finally, as a result of thermocatalytic and radiation-thermal-catalytic water splitting, molecular hydrogen (7) is formed:



The following conclusions were obtained from the researches:

- In the BeO+ $\text{H}_2\text{O}$  system at a constant temperature  $T = 673$  K, and for water density  $\rho = 0.5$ ; 1; 2.5; 5, and 10  $\text{mg}/\text{cm}^3$ , the rate of formation of molecular hydrogen obtained during the thermocatalytic and radiation-thermocatalytic transformation of water increases in direct proportion to its density, and at  $\rho \geq 2.5$   $\text{mg}/\text{cm}^3$  this proportionality is violated and a deceleration is observed.

- In the BeO+ $\text{H}_2\text{O}$  system with a constant water density of  $\rho = 10$   $\text{mg}/\text{cm}^3$ , molecular hydrogen is obtained: 1) in the temperature range  $300 \leq T \leq 473$  K only as a result of radiation-thermocatalytic processes, and the activation energy of these processes is  $E_R = 1.1$  kJ/mol and 2) in the temperature range  $573 \leq T \leq 673$  K as a result of thermocatalytic and radiation-thermocatalytic processes, and the activation energy of these processes is 56 and 97.5 kJ/mol respectively.

- In the BeO+ $\text{H}_2\text{O}$  system in the temperature range  $300 \leq T \leq 673$  K, the radiation-chemical yield of molecular hydrogen obtained by the thermocatalytic and radiation-thermocatalytic water conversion calculated for the radiation fraction is  $G(\text{H}_2) = 6.4 \dots 7.0$  molec./100 eV.

## REFERENCES

1. Technical Basis for the ITER Final Design Report. G A0 FDR 1 01-03-05 W0.2. – ITER Garching Joint WorkSite, 2001.
2. Safety Analysis Data List (SADL-3) / Ed. by H.-W. Bartels, L. Topilski, and T. Honda. G 81 RI 5 00-02-29. – ITER Garching Joint WorkSite, 2000.
3. В.Е. Матясова, М.Л. Коцарь, С.Л. Кочубеева, В.И. Никонов. Получение бериллиевых материалов для ядерной и термоядерной энергетики из бериллийсодержащих отходов // *ВАНТ. Серия «Физика радиационных повреждений и радиационное материаловедение»*. 2013, № 2(84).
4. G. Merga, В.Н. Milosavijevic, D. Meisel // *J. Phys. Chem. B*. 2006, v. 110, p. 5403-5408.
5. N.G. Petrik, A.B. Alexandrov, A.I. Vall // *J. Phys. Chem. B*. 2001, v. 105, p. 5935-5944.
6. T. Schatz, A.R. Cook, D. Meisel // *J. Phys. Chem. B*. 1999, v. 103, p. 10209-10213.
7. J.A. LaVerne // *J. Phys. Chem. B*. 2005, v. 109, p. 5395-5397.
8. J.A. LaVerne, L. Tandon // *J. Phys. Chem. B*. 2003, v. 107, p. 13623-13628.
9. J.A. LaVerne, S.E. Tunnies // *J. Phys. Chem. B*. 2003, v. 107, p. 7277-7280.
10. J.A. LaVerne, L. Tandon // *J. Phys. Chem. B*. 2002, v. 106, p. 380-386.
11. T. Schatz, A.R. Cook, D. Meisel // *J. Phys. Chem. B*. 1998, v. 102, p. 7225-7230.
12. А.А. Гарибов, Т.Н. Агаев, Г.Т. Иманова, К.Т. Эюбов // *ВАНТ. Серия «Физика радиационных повреждений и радиационное материаловедение»*. 2015, №5(99), с. 48-51.
13. А.А. Гарибов, Т.Н. Агаев, Г.Т. Иманова, С.З. Меликова, Н.Н. Гаджиева // *ХВЭ*. 2014, с. 48-51.
14. T.A. Yamamoto, S. Seino, M. Katsura, et al. *Nanostructured Materials*. 1999, v. 12, N 5, p. 1045-1048.
15. А.К. Пикаев. *Дозиметрия в радиационной химии*. М.: «Наука», 1975.
16. Я.Д. Джафаров, А.А. Гарибов, С.А. Алиев и др. Расчет поглощенной дозы гамма-облучения в оксидных диэлектриках // *Атомная энергия*. 1987, т. 63, в. 4, с. 269-270.
17. Ю.И. Орлов. Электронные строения, энергетика образования и свойства

адсорбированных комплексов полярных молекул на поверхности кремнезема // *ЖФХ*. 1985, т. 9, в. 5, №5, с. 1213-1218.

18. В.Б. Казанский. Современное представление о структуре активных центров на поверхности окисных катализаторов и некоторые проблемы квантово-химического описания реакций с их участием // *ЖФХ*. 1985, т. 9, в. 5, №5, с. 1057.

19. А.И. Невзоров, Ю.А. Зарафьянц. *Электронные процессы на поверхности полупроводников на границе раздела ДП*. Новосибирск: «Наука», 1974, с. 129.

20. V. Santos, M. Zeni, C.P. Bergman // *Rev. Adv. Mater. Sci.* 2008, N 17, p. 62.

21. S. Uehara, H. Nikjoo // *J. Radiat. Res.* 2006, v. 47, p. 69-81.

22. Y.D. Jafarov. Mathematical modelling of radiolysis process of water under the impact of low-energy electrons // *PAST. Series "Nuclear Physics Investigations"* (56). 2011, N 5, p. 42-47.

23. N.G. Petrik, A.B. Alexandrov, T.M. Orlando, A.I. Vall // *Trans. ANS*. 1999, v. 81, p. 101-102.

24. J. Kontsky, J. Kosik. Radiation damage of structural materials // *Materials Science Monograph*. Elsevier, 1994, v.79.

25. A.A. Garibov. Radiation-heterogenic processes of hydrogen accumulation in water-cooled nuclear reactors // *Nukleonika*. 2011, v. 56(4), p. 333-342.

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## ПОЛУЧЕНИЕ МОЛЕКУЛЯРНОГО ВОДОРОДА ПРИ ТЕРМОКАТАЛИТИЧЕСКОМ И РАДИАЦИОННО-ТЕРМОКАТАЛИТИЧЕСКОМ ПРЕВРАЩЕНИЯХ ВОДЫ В СИСТЕМЕ $\text{BeO}+\text{H}_2\text{O}$

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Изучена зависимость выхода молекулярного водорода, полученного при термокаталитическом и радиационно-термокаталитическом превращениях воды под воздействием  $\gamma$ -квантов ( $^{60}\text{Co}$ ,  $P = 20,1$  рад/с) на систему  $\text{BeO}+\text{H}_2\text{O}$  с размерами частиц  $d_{\text{Be}} < 4$  мкм: 1) от общей температуры ( $T = 300, 373, 473, 573, 623$  и  $673$  К) системы и при постоянном значении плотности паров воды ( $\rho = 10$  мг/см<sup>3</sup>); 2) от плотности паров воды ( $\rho = 0,5; 1; 2,5; 5$  и  $10$  мг/см<sup>3</sup>) и при постоянном значении температуры ( $T = 673$  К). В этой системе в реакционной среде с плотностью паров воды  $\rho = 10$  мг/см<sup>3</sup> и в интервале температур  $300 \leq T \leq 473$  К молекулярный водород получается только радиационно-термокаталитическим способом (энергия активации процесса  $E_a = 1,1$  кДж/моль), а в интервале температур  $573 \leq T \leq 673$  К – термокаталитическим ( $E_a = 97,5$  кДж/моль) и радиационно-термокаталитическим ( $E_a = 56$  кДж/моль) способами. В системе  $\text{BeO}+\text{H}_2\text{O}$  при постоянной температуре  $T = 673$  К и при значениях плотности паров воды  $\rho = 0,5; 1; 2,5; 5$  и  $10$  мг/см<sup>3</sup> скорость образования молекулярного водорода, полученного при термокаталитическом и радиационно-термокаталитическом превращениях воды, растет прямо пропорционально ее плотности, а при значениях  $\rho \geq 2,5$  мг/см<sup>3</sup> данная пропорциональность нарушается и наблюдается замедление. Указан возможный механизм процессов, достаточно хорошо объясняющий полученные экспериментальные данные.

## ОТРИМАННЯ МОЛЕКУЛЯРНОГО ВОДНЮ ПРИ ТЕРМОКАТАЛІТИЧНОМУ І РАДІАЦІЙНО-ТЕРМОКАТАЛІТИЧНОМУ ПЕРЕТВОРЕННІ ВОДИ В СИСТЕМІ $\text{BeO}+\text{H}_2\text{O}$

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Вивчено залежність виходу молекулярного водню, отриманого при термокаталітичному і радіаційно-термокаталітичному перетвореннях води під впливом  $\gamma$ -квантів ( $^{60}\text{Co}$ ,  $P = 20,1$  рад/с) на систему  $\text{BeO}+\text{H}_2\text{O}$  з розмірами частинок  $d_{\text{Be}} < 4$  мкм: 1) від загальної температури ( $T = 300, 373, 473, 573, 623$  і  $673$  К) системи і при постійному значенні щільності парів води ( $\rho = 10$  мг/см<sup>3</sup>); 2) від щільності парів води ( $\rho = 0,5; 1; 2,5; 5$  і  $10$  мг/см<sup>3</sup>) і при постійному значенні температури ( $T = 673$  К). У цій системі в реакційному середовищі зі щільністю парів води  $\rho = 10$  мг/см<sup>3</sup> і в інтервалі температур  $300 \leq T \leq 473$  К молекулярний водень виходить тільки радіаційно-термокаталітичним способом (енергія активації процесу  $E_a = 1,1$  кДж/моль), а в інтервалі температур  $573 \leq T \leq 673$  К – термокаталітичним ( $E_a = 97,5$  кДж/моль) і радіаційно-термокаталітичним ( $E_a = 56$  кДж/моль) способами. В системі  $\text{BeO}+\text{H}_2\text{O}$  при постійній температурі  $T = 673$  К і при значеннях щільності парів води  $\rho = 0,5; 1; 2,5; 5$  і  $10$  мг/см<sup>3</sup> швидкість утворення молекулярного водню, отриманого при термокаталітичному і радіаційно-термокаталітичному перетвореннях води, зростає прямо пропорційно щільності, а при значеннях  $\rho \geq 2,5$  мг/см<sup>3</sup> ця пропорційність порушується і спостерігається уповільнення. Вказано можливий механізм процесів, що досить добре пояснює отримані експериментальні дані.