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PROCESS SIMULATION OF PLASMA-CHEMICAL SYNTHESIS OF OXIDE COMPOSITIONS FOR URANIUM-THORIUM TOLERANT ECONOMICAL FUEL HIGH-TEMPERATURE GAS-COOLED REACTORS

A.A. Kuznetsova
Scientific Supervisor: Assoc. Prof., Ph.D. A.G. Karengin
Tomsk Polytechnic University, Russia, Tomsk, Lenin str., 30, 634050
E-mail: aak264@tpu.ru

МОДЕЛИРОВАНИЕ ПРОЦЕССА ПЛАЗМОХИМИЧЕСКОГО СИНТЕЗА ОКСИДНЫХ КОМПОЗИЦИЙ ДЛЯ УРАН-ТОРИЕВОГО ТОЛЕРАНТНОГО ЯДЕРНОГО ТОПЛИВА ВЫСОКОТЕМПЕРАТУРНЫХ ГАЗООХЛАЖДАЕМЫХ РЕАКТОРОВ

А.А. Кузнецова
Научный руководитель: доцент, к.ф.-м.н. А.Г. Каренгин
Национальный исследовательский Томский политехнический университет,
Россия, г. Томск, пр. Ленина, 30, 634050
E-mail: aak264@tpu.ru

Аннотация. *Проведен поиск составов водно-органических нитратных растворов урана, тория магния и алюминия, отвечающих критериям адиабатической температуры и низкой теплотворной способности. Расчет синтеза проводился в лицензированной программе «ТЕРРА» при атмосферном давлении и температуре от 300 до 6000 К.*

Introduction. Accident tolerant and advanced technology fuel (ATF) also called "tolerant" fuel is the nuclear fuel that is resistant to abnormal situations at nuclear power plants (NPP). The development of ATF has become a key trend in the global nuclear industry in recent years, aimed at improving the safety of nuclear power plants, practically eliminating the possibility of accidents with negative environmental impact. Tolerant fuel, even in the event of loss of coolant and disruption of heat removal in the reactor core, must maintain its integrity for a sufficiently long time. In addition, separate ATF variants with alternative fuel compositions can make operation more cost-effective without increasing the level of uranium enrichment. Tolerant fuel has high thermal conductivity, low heat capacity, increased heat resistance and uranium content. Such properties are achieved by modifying the fuel rod cladding or the dispersive nuclear fuel (DNF) matrix.

The plasma-chemical method for obtaining highly dispersed powders of oxide compositions can compete with existing methods, as it has a number of advantages, such as single stage, compactness of process equipment, low energy consumption. The aim of the work was to model and study the process of plasma-chemical synthesis of oxide compositions using the TERRA licensed program and to determine the optimal composition of water-organic nitrate solutions (WONS), which ensures their energy-efficient plasma treatment. This study presents the results of theoretical studying the process of plasma-chemical synthesis of oxide compositions from BORR solutions, including an organic component (acetone), aqueous solutions of fissile (uranium, thorium) and matrix (magnesium, aluminum) metal nitrates.

Research methods. Magnesium and aluminum oxides were chosen as the matrix due to their high thermal conductivity, low thermal neutron capture cross section, lack of interaction with uranium, relative ease of production and alloy strength [1]. The net calorific value of a water-organic nitrate solution is determined by the following equation [2].

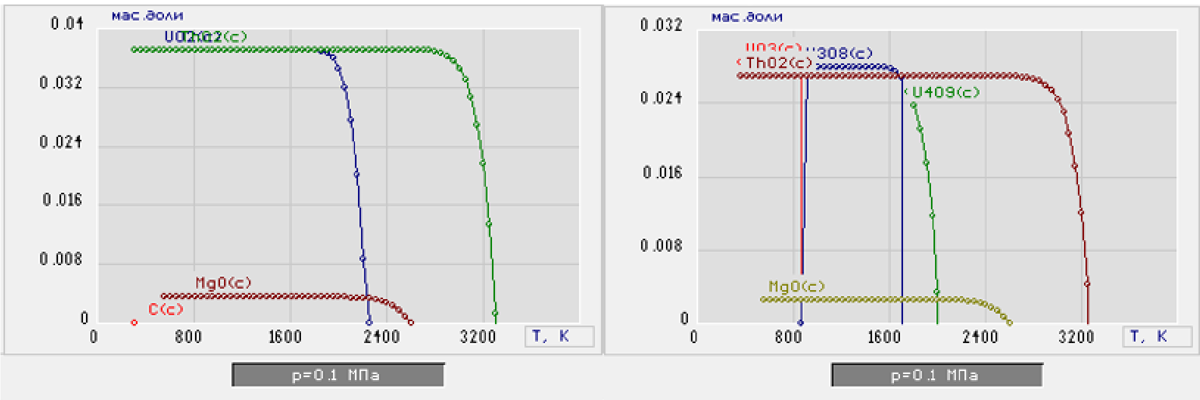
$$Q_l^s = \frac{(100 - W - A)Q_l^c}{100} - \frac{2{,}5W}{100},$$

where Q^c_l is the net calorific value of the combustible component, MJ/kg; W is water content, A is non-combustible mineral substances in the composition %; coefficient 2.5 takes into account the latent heat of evaporation of water at 0 °C, MJ/kg. A more objective indicator of the combustibility of a water-organic nitrate solution is the adiabatic combustion temperature, which was estimated using this formula:

$$T_{ad} = \frac{(100 - v_{ox})Q_l^s + v_{ox}C_{ox}t_{ox}}{100VC}.$$

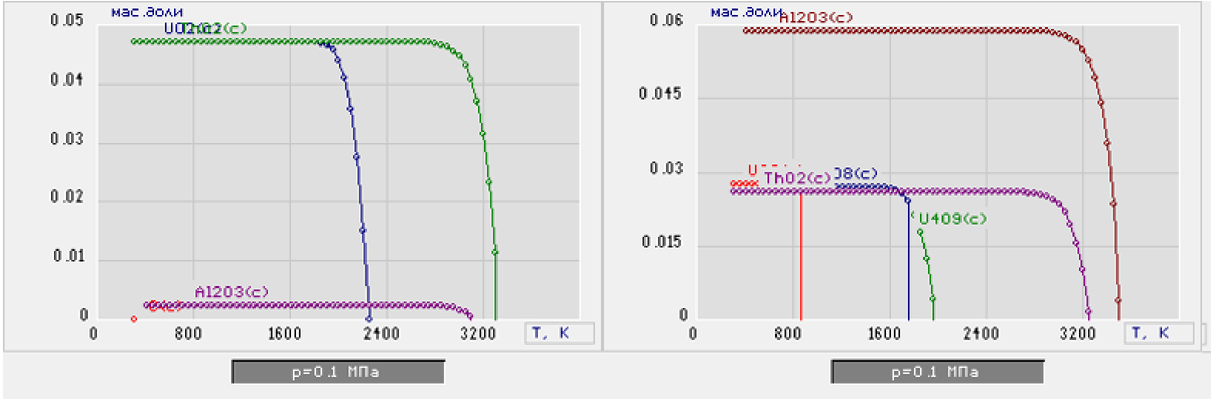
Water-organic nitrate solutions with T_{ad} = 1500-1600 K ensure their energy-efficient plasma processing in an air-plasma flow.

Results. The optimal values of the calorific value and adiabatic temperature at a coefficient α (the ratio of the fissile component to the non-fissile one) are to 0.5 and the matrices MgO and Al_2O_3 are shown in fig. (1, 2). Table 1 shows the results of calculating the WONS compositions with minimal energy consumption and the optimal value of the adiabatic temperature.



(a) (b)

Fig. 1. Correlation of the composition of the main products based on acetone on temperature after plasma treatment at α=0.5 and mass fraction of air 57% (a) and 59% (b). MgO 5%, WONS-1



(a) (b)

Fig. 2. Correlation of the composition of the main products based on acetone on temperature after plasma treatment at α=0.5 and mass fraction of air 55% (a) and 57% (b). Al_2O_3 5%, WONS-17

Table 1

WONS indicators

WONS, №	air, %	UO_2	U_3O_8	U_4O_9	UO_3	ThO_2	MgO	Al_2O_3	C	Q_{ls}, MJ/kg	T_{ad}, K	E_{un}, MJ/kg
1	57	+	-	-	-	+	+	-	-	5.44	1602	19.83
5	57	+	-	-	-	+	+	-	-	5.42	1591	19.98
9	57	+	-	-	-	+	+	-	-	5.40	1580	20.14
13	57	+	-	-	-	+	+	-	-	5.39	1569	20.30
17	55	+	-	-	-	+	-	+	-	5.14	1584	17.43
21	55	+	-	-	-	+	-	+	-	5.12	1553	17.69
25	55	+	-	-	-	+	-	+	-	5.10	1559	17.84
29	55	+	-	-	-	+	-	+	-	5.08	1547	17.90

Of the 74 WONS compositions obtained, only 8 complied with the requirements that ensure their energy-efficient plasma processing in an air-plasma flow. All 8 compositions of WONS were obtained on the basis of an organic component, acetone, at α = 0.5 – 0.8, with a mass fraction of the oxide matrix (MgO and Al_2O_3) 5% and an air content (55 and 57%).

Conclusion. The results obtained can be used to design a technology for the plasma-chemical synthesis of fuel oxide compositions of dispersed nuclear fuel for high-temperature gas-cooled reactors.

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