Conference Paper

Parameters Influencing Thermal Stability of U-Gd Nuclear Fuel

A. Karpeeva[1], I. Timoshin[1], and E. Mikheev[2]

[1]PJSC Mashinostroitelny Zavod, Elektrostal, Russia
[2]JSC VNIINM, Moscow, Russia

Abstract

One of the main parameters influencing substantiation of reactor's safe operation is stability of fuel pellet geometry (diameter) under irradiation, which in a certain manner correlates to thermal stability ("resintering") of fuel pellet geometry and density. "Resintering" tests are carried out following the certified procedure that implies soaking sintered U-Gd pellets at temperature (1725±25)°C for 24 hours. The currently obtained "resintering" results for fuels with burnable poisons fully meet existing requirements. However, when using U-Gd fuel pellets with high burnable poison content (8%mass and higher), it becomes difficult to understand the factors that influence thermal stability values. This article investigates several parameters influencing "resingering" of U-Gd fuel pellets with 8.00%mass Gadolinia content.

Keywords: Thermal stability, resintering, U-Gd fuel, fuel pellets, pore-former, sintering temperature.

Corresponding Author:
Anastasiya Karpeeva
karpeevaanastasiya@gmail.com

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1. INTRODUCTION

Currently "resintering" requirements for VVER nuclear fuel are within 0 to 0.4% range (monitoring of thermal stability pertaining to pellet geometry). Compliance with the specified requirements is the most challenging task for nuclear U-Gd fuel with high Gadolinia contents (exceeding 8.00% mass).

Fuel "resintering" is thermal stability of fuel pellet geometry (diameter) and density. In its turn, both fuel pellet dimensions as well as density depend on many process parameters. This work investigates the following parameters influencing thermal stability values of sintered U-Gd fuel pellet geometry, namely: sintering temperature, quantity and method of adding pore-former to source powder.

[1-4] reference materials present studies of U-Gd fuel sintering process, however, at present the influence or process parameters on U-Gd fuel "resintering" has not been fully investigated.

2. MATERIALS AND METHODS

The process of accumulating statistical data on variations (diameter) of thermal stability values in U-Gd fuel with 8.00%mass Gadolinia content in order to analyse regular patterns of "resintering" process started in 2016 (see Fig. 1).

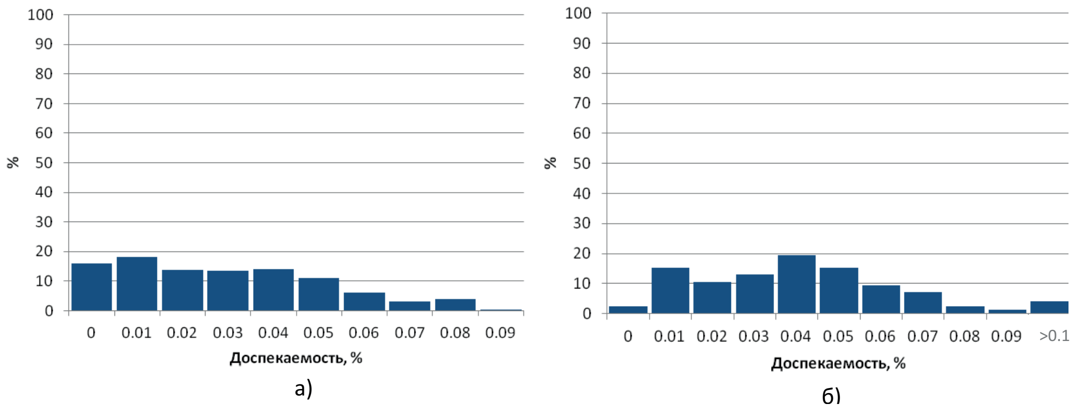

Figure 1: Results of U-Gd fuel thermal stability (values) statistical evaluation (Gd_2O_3 8.00%мас.) a – 2016 г., б – 2017 г.

Statistical analysis (see Fig. 1) was conducted using fuel pellet lots manufactured at different mixing, pressing, sintering, etc. parameters. However, thermal stability values differ. Therefore three test steps were carried out to investigate influence of process parameters on "resintering"; each step included several experiments with different options.

The first step investigated influence of sintering temperature on thermal stability of pellet geometry. Two experiments were conducted: the first experiment included three options to manufacture U-Gd fuel with sintering temperatures of 1680°C, 1700°C and 1730°C, fuel pellets stayed in the high-heat zone for 7 hours. The second experiment comprised manufacture of the three options with sintering temperatures of 1680°C, 1690°C, 1700°C, fuel pellets stayed in the high-heat zone for 6 hours. Oxygen potential of the sintering atmosphere during high-heat sintering in both experiments was the same. The obtained sintered pellets for all six options were ground and sampled for "resintering" test and hydrostatic measurement of density and porosity, as well as it was determined what percentage of pores with effective diameter of 1 to 10 μm they had.

The second step in studying influence of process parameters on "resintering" was to investigate influence of the input fore-former quantity. Two options of U-Gd fuel were manufactured with different pore-former quantities (0.6% and 1.0%). Pellets were sintered in a high-temperature furnace at 1730°C for 7 hours. Pellets obtained from the two options underwent "resintering" test and hydrostatic measurement of density and porosity, as well as it was determined what percentage of pores with effective diameter of 1 to 10 μm they had.

The third step comprised the experiment to study influence of pore-former adding method on thermal stability values of U-Gd fuel geometry. Two options of U-Gd fuel pellets were manufactured similar to the two previous steps; the only difference was the method of adding pore-former. Pellets under option one were manufactured by adding pore-former in the mixer to the pre-mixed powders (UO_2, Gd_2O_3, $(UGd)_3O_8$). The difference with pellets manufactured under option two from option one was that a portion (0.6%) of pore-former was added during processing of powder mixture (UO_2, Gd_2O_3, $(UGd)_3O_8$) inside a vibratory mill. The obtained fuel pellets underwent "resintering" test and hydrostatic measurement of density and porosity, as well as it was determined what percentage of pores with effective diameter of 1 to 10 μm they had.

Thermal stability values of pellet geometry were measured according to the certified procedure [5], density was determined by hydrostatic method; porosity and percentage of pores with effective diameter up to 10 μm was determined by OLYMPUS SZ-STU2 microscope (SIAMS-600 software).

3. RESULTS AND DISCUSSION

The results of investigations on influence of sintering temperature on thermal stability values related to U-Gd fuel geometry are given in Table 1.

TABLE 1

	Time in high-heat zone – 7 h			Time in high-heat zone – 6 h		
Sintering temperature, °C	1680	1700	1730	1680	1690	1700
Resintering, %	0.04	0.03	0.01	0.05	0.04	0.04
Density, g/cm^3	10.34	10.37	10.33	10.53	10.52	10.50
Percent of pores with effective diameter 1-10 μm	93.9	84.8	81.0	91.0	91.5	87.1

It can be noted, when analysing obtained results, that if sintering temperature decreases, thermal stability values increase. However, there is a manifested dependence: percentage of pores with effective diameter up to 10 μm grows when sintering temperature decreases. The obtained density results do not agree with classical concepts regarding how the prepared powder behaves during sintering; therefore the obtained data require further study testing.

The results of investigations on influence of pore-former quantity on thermal stability values of pellet geometry are given in Table 2.

Table 2

Pore-former q-ty, %	0.6	1.0
Resintering, %	0.00	0.02
Density, g/cm^3	10.35	10.26
Percent of pores with effective diameter 1-10 μm	80.3	77.4

Pore-former contributes to generation of large-size pores (see Fig. 2), which act as gas collectors and influence "resintering". Increase of pore-former quantity allows increasing "resintering" values. However when pore-former quantity is increased, density decreases.

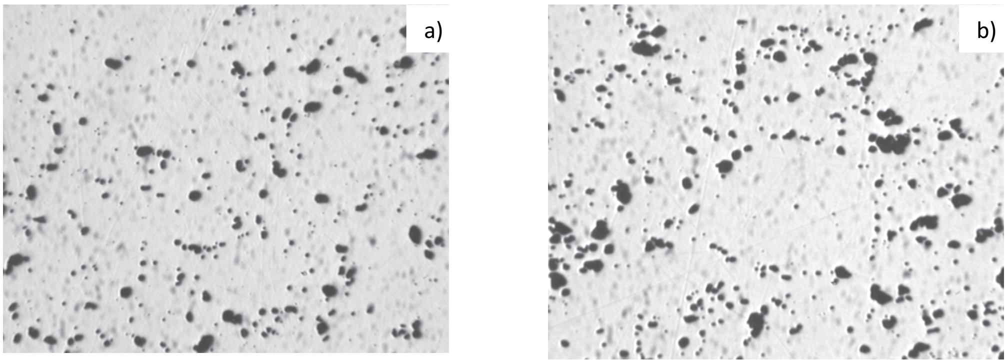

Figure 2: Characteristic pellet porosity (x100) a) with 0.6% pore-former; b) with 1,0% pore-former.

The third investigation step was conducted to increase "resintering" and simultaneously maintain density values – the step-wise method of adding pore-former. Experiment results are given in Table 3.

Table 3

Adding Method Pore-former	direct	step-wise
Resintering, %	0.03	0.02
Density, g/cm^3	10.21	10.37
Percent of pores with effective diameter 1-10 μm	77.8	84.8

Fig. 3 shows characteristic pellet porosity of the option with direct adding of pore-former (a) and step-by-step adding of pore-former to source powder (b).

As mentioned earlier, pore-former generates large pores (see Fig. 2) that act as gas collectors; at the same time, because of mechanical compaction of pore-former (at

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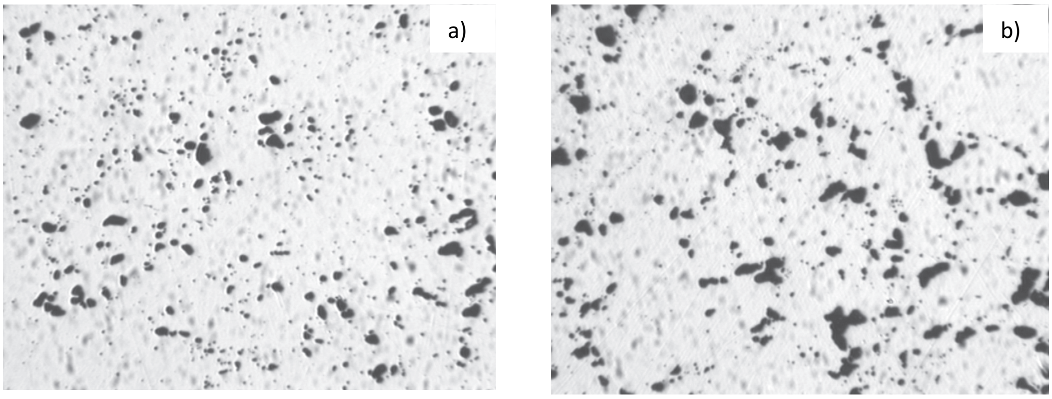

Figure 3: Characteristic pellet porosity (x100) a) direct adding of pore-former; step-by-step adding of pore-former to source powder (b).

the stage when it is added into vibration sieve), it becomes possible to obtain micron pores to stabilize the “resintering”.

Through the increase in particle dispersion ability by means of the investigated scheme of step-wise addition of pore-former, the amount of pores of 1 to 10 μm within the pellet volume grows. This effect allows maintaining fuel “resintering” values without decrease in density.

4. CONCLUSIONS

1. Influence of sintering temperature on thermal stability of sintered U-Gd pellet geometry (with 8.00%mass Gadolinia content) has been investigated. When sintering temperature decreases, thermal stability of U-Gd fuel geometry (with 8.00%mass Gadolinia content) increases.

2. It has been investigated how to increase thermal stability of sintered pellet geometry by increasing quantity of added pore-former. However this is accompanied by decrease in density.

3. Step-wise method of adding pore-former has been investigated in order to simultaneously maintain density as well as increase thermal stability of pellet geometry.

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[5] 323.000.302-2015 Measurement procedure titled "Uranium dioxide fuel pellets with Gadolinia mass concentration from 3.0 to 10.5%. Determining thermal stability of pellet geometry and density (resintering)". JSC VNIINM, 2015.