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Computational study of the effect of fuel element geometry on pellets' maximum temperature

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Abstract. One of the factors that determine reliable operation of fuel elements in a nuclear reactor is maximum temperature of fuel pellets. This paper presents the computational study results of the effect of the pellet's central hole on its maximum temperature when using different types of fuel.

1 Introduction

Fuel elements are the most important and strained nodes in the core of a modern nuclear power plant reactor. The design of a fuel element must ensure its long-term operational reliability under extremely severe operating conditions.

At present most nuclear reactors are fueled with a compound known as uranium dioxide (UO_2), since this fuel does not interact with water and steam even at high temperatures, is compatible with fuel rod's cladding material, and is characterized by a a high melting point. Among its downsides are low thermal conductivity and brittleness.

Uranium carbides (UC and UC_2) are seen as potential nuclear fuels. They are characterized by higher density as compared to UO_2 and have a high thermal conductivity. The disadvantage of uranium carbides is a relatively high activity with many reactor materials. In the future the use of uranium nitrides (UN) and silicides is also possible. They are similarly characterized by high density and thermal conductivity but at the same time they are more compatible with reactor materials [1].

One of the most significant factors that determine operational reliability of a fuel element is maximum temperature of the fuel pellets. This temperature can be decreased by using fuel with higher thermal conductivity as well as by enhancing heat-transfer properties of a pallet-clad gas gap. Another method for lowering the peak temperature of the pellet involves application of fuel pellets with a central hole.

The objective of this work is to study the effect of a central hole and its dimensions on the pellets' maximum temperature when using different types of fuels.

2 Calculations and methodology of the study

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The model of the object of the computational study is given in Fig.1. The assumed geometry and mode characteristics of a conventional fuel element are presented in Table 1.

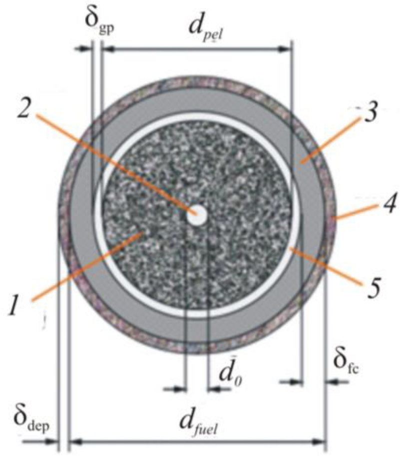

Fig 1. Cross-section of a conventional fuel rod: 1 – pellets; 2 – hole; 3 – cladding; 4 - deposits; 5 – gap.

Table 1. Main characteristics of a conventional fuel element.

Parameter	Description
Coolant	non-boiling water
Gas in pellet-clad gap	helium
Cladding material	Zr alloy
Coolant pressure p_c	16 MPa
Coolant temperature t_c	305 °C
Coolant velocity w_c	6 m/s
Spacer arrangement	triangular
Fuel rod pitch S_{pitch}	1.4
Pellet diameter d_{pel}, mm	7.53 mm
Cladding thickness δ_{cl}	0.685 mm
Gap thickness δ_{gap}	0.1 mm

The algorithm for determining pellet's maximum temperature includes well-known expressions [2]. This algorithm suggests the use of different nuclear fuels; their thermal conductivity is calculated by means of approximating expressions [1, 4].

Temperature distribution in fuel pellets including peak temperature can be calculated in the process of solving one-dimensional heat conduction problem by Seidel iteration method [3].

To implement the algorithm mentioned above and perform calculations of the temperature characteristics of the fuel composition the *FUEL* computer program has been developed in the Department of Nuclear and Thermal Power Plants of the Tomsk Polytechnic University. The program is made in the Borland Turbo Delphi 2006 intergated development environment and is actually a Windows Service application. The program's executable module allows graphic interpretation of the calculation results and their import to MS Excel.

Screenshot of the *FUEL* program's main window is presented in Fig. 2.

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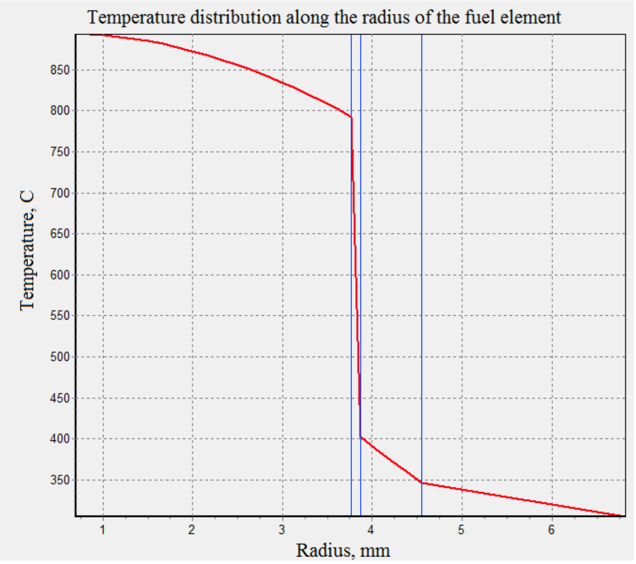

Fig. 2. Screenshot of the *FUEL* main window.

Two cycles of the variational calculations of the fuel rod's temperature characteristics were performed using the *FUEL* program (Fig.1). In each calculation cycle we varied the values for central hole diameter (d_0=0…2 mm) and fuel type (UO_2, UC, UN, and U_3Si_2).

The conditions for the first calculation cycle were: q_s = const and q_l = var (i.e. output of a fuel rod N_{fuel}=var); for the second cycle: q_s = var and q_l = const (N_{fuel}=const).

The main calculation results for uranium dioxide are given in Fig. 3.

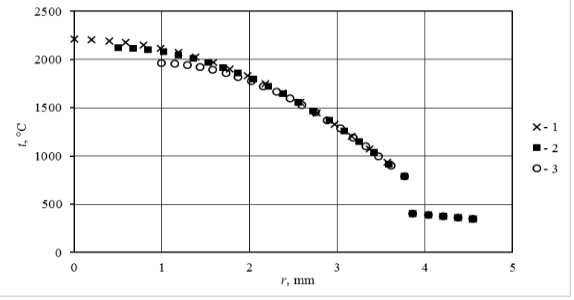

Fig. 3. Temperature distribution in a fuel rod (pellet material is UO_2) at different diameters of the central hole. q_l = 440 Wt/cm: 1 – d_0 = 0; 2 – d_0 = 1 mm; 3 - d_0 = 2 mm.

The main calculation results for other fuels are presented in Fig. 4.

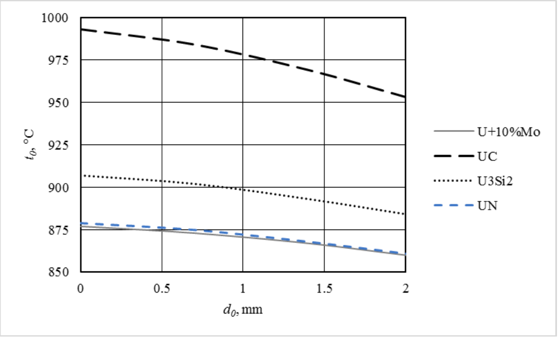

Fig. 4. Dependence of the pellets' maximum temperature on the diameter of a central hole for different fuels. q_l = 440 Wt/cm.

3 Conclusion

1. The presence of a central hole in the fuel pellets decreases their maximum temperature t_0 for any of the common fuel types. Yet, the amount of the decrease in temperature is largely dependent on the type of fuel.
2. When changing the central hole diameter from 0 to 2 mm the most considerable decrease in t_0 is observed for the pellets made of uranium dioxide (~250 °C). For other fuels changes in temperature t_0 are in the range of 17...40 °C, i.e. the decrease in temperature is much smaller.
3. Meanwhile, drop in the maximum temperature of the pellets due to the presence of a central hole is observed in both cases: when q_s = const and when q_l = const.

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