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Thermal-hydraulics investigation of new generation TVS-2M fuel in Bushehr VVER-1000 reactor

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Abstract

The aim of this paper is to investigate the Thermal-hydraulics parameters of the VVER-1000 reactor core of Bushehr nuclear power plant by replacing the new generation of TVS-2M fuel assemblies (FAs) with current standard FAs (AFA) into the reactor core. TVS-2M fuel is the Russian newly proposed fuel assembly which contains gadolinium-oxide is mixed with UO2 by different gadolinium density and U-235 enrichments. In such manner, thermohydraulic modelling is done by a new method based on porous grids, porous media approach. This technique is created to make the conservation equations by means of porosity concept within the control volume method. Results show, according to the balanced axial temperature distribution into the core, the axial coolant temperature in the TVS-2M hottest fuel assembly is lower than in AFA fuel assembly. Also, the radial temperature distribution in the center of the hottest fuel rod in TVS-2M fuel assembly is lower than AFA fuel assembly.

Keywords: Thermal-hydraulics, VVER—1000, TVS-2M, AFA, Porous media approach.

Introduction

Bushehr VVER-1000 reactor is a Russian Pressurized Light Water Reactor (PWR) with a thermal power of 3000 (MWth) and an electric power of 1000 (MWe). Light water is used as the moderator and coolant into the core. The fuel is enriched Uranium Oxide [1]. The new generation of TVS fuels such as TVS-2M has several advantages compared with the current standard fuel (AFA) such as higher physical and chemical resistance, longer fuel life and longer active height of fuel rods and also fissile content.[2-3].

The porous media is a well-known approach for analyzing the Thermal-hydraulics parameters of FAs of the reactor core. This method is introduced to make the conservation equations by means of porosity concept within the control volume (According to our previus study [4]). In this regard, the momentum equations are solved with high accuracy and precision for single-phase fluid[4]. Although several reports on various technical aspects of TVS-2M fuels have been studied in the recent years[5]. The Thermal-hydraulics behaviors of this fuels have not been discussed in details.

Material and methods

Geometrically, the new TVS-2M FAs are almost identical to the AFA standard FAs except the structure at the beginning and end of the FAs. The most important factor is the active fuel height, which has increased from 353 (cm) in AFA fuels to 368 (cm) in TVS-2M. Another structural difference between TVS-2M and AFA fuels is the number and size of the grid spacers. With a 10.5 (cm) increase in active fuel height, the number of grid spacers has been reduced from 15 in AFA fuel assemblies to 13 in TVS-2M FAs. At the inlet of the flow to the fuel assemblies is a filter called Anti-Debris Filter (ADF) which prevents the entry of possible waste into the fuel area and damage the fuel rods [2-3]. In this study, thermal power of fuels are extracted in different axial intervals with MCNPX code (Neutronic model[6]) as an input for Thermal-hydraulics program. In this way, each rod was simulated and divided into a grid of lumped regions for subchannel analysis. The power peaking factor (PPF) of the FAs is listed in Table 1.

Figure 1. The power peaking factor [7].

FAs	**Power Peaking Factor (PPF)**	
	AFA	TVS-2M
Maximum	1.29	1.31
Minimum	0.74	0.71

Results and discussion

Figures 1 and 2 show the comparison of coolant temperature and density changes axially for both TVS-2M and AFA FAs, respectively.

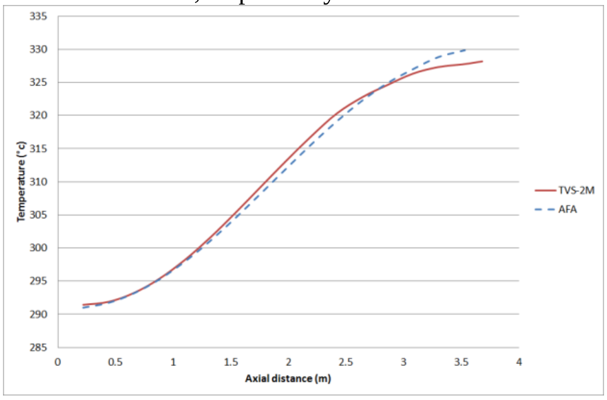

Figure 1. Axial coolant temperature in the hottest FA.

Due to the use of Gd2O3 as burnable poisons in TVS-2M fuels, the power peaking factor in the middle of the core is reduced. Hence, the power distribution almost tends to be flatten. As a result, a more balanced axial temperature distribution is created in the reactor core. Therfore, the axial coolant temperature in the TVS-2M hottest fuel assemby is lower than in AFA fuel assemby. Figure 3 illustrates the axial distribution of coolant pressure changes.

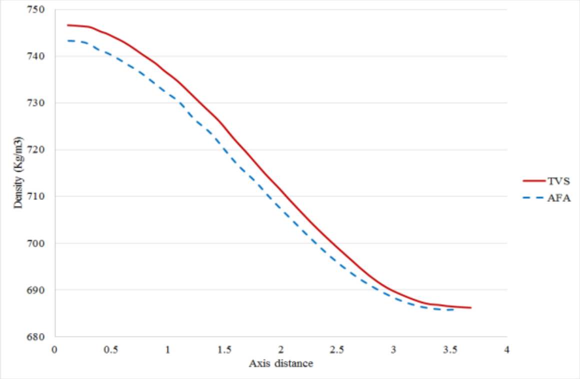

Figure 2. Axial coolant density in the hottest FA.

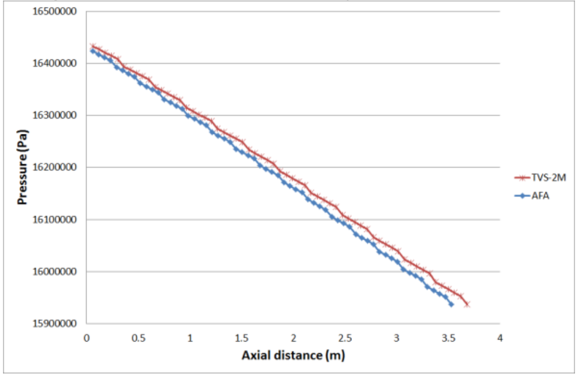

Figure 3. Axial distribution of coolant pressure changes.

Due to the presence of ADF inlet filters and the creation of resistance to the inlet current in TVS-2M FAs, a 15 (cm) increase in fuel length and also a change in the number and size of the spacer grids by increasing its height by 10 (cm) cause the coolant pressure drop along the TVS-2M FAs to be around 50 (kPa). However, this amount is about 48 (kPa) in AFA FAs.

On the other hand, due to the fact that a large part of the pressure drop in the reactor core is related to the closed fuel inlet area and the primary spacer grid, which due to its complex structure in two types of FAs, the maximum inlet pressure drop to confuse flow is created due to its effect on heat dissipation.

In this paper, the optimized Ross and Stout model is used to calculate the convection heat transfer coefficient of gap (h_g):

$$h_g = h_{gas} + h_s + h_r \qquad (1)$$

Because radiative heat transfer is important at very high temperatures, it has been omitted in this study. Heat transfer through the gases in the gap is calculated based on the following equations:

$$h_{gas} = \frac{K_{gas}}{D_g + A(\delta_{fuel} + \delta_{clad}) + g_f + g_c} \qquad (2)$$

$$A = 2.75 - (2.55\times10^{-8} P_{gas}) \qquad (3)$$

$$g_f + g_c = 0.718 \frac{k_{gas}\sqrt{T_{gas}}}{P_{gas}} \qquad (4)$$

$$K_{gas} = AT_{gas}{}^{S} \qquad (5)$$

Figure 4 demonstrates radial temperature distribution in the center of the fuel rod in the hottest fuel assembly.

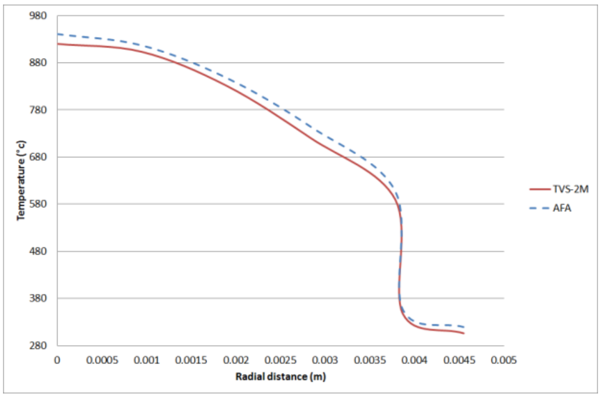

Figure 4. Radial temperature distribution in the center of the fuel rod in the hottest FA.

Obviously, according to the high thermal resistance of the gap, there is a sharp drop in temperature between the fuel pellet and the clad. On the other hand, in the clad, due to its very small thickness and its thermal properties, it heats up faster. Hence, the temperature inside and outside the clad has a very small difference.

Conclusions

The aim of this study is to investigate the Thermal-hydraulics model of a new generation of advanced TVS FAs in Bushehr VVER-1000 reactor core using porous media approach. VVER-1000 reactor core is modelled for both TVS-2M and AFA fuels. Results show, the axial coolant temperature in the TVS-2M hottest FA is lower than in AFA FA. Also, coolant pressure drop along the fuel assembly in TVS-2M FAs is more than AFA FAs due to the presence of ADF inlet filters and the creation of resistance in total height of the FA.

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