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Thermohydraulic analysis of the coolant entrance into the core of pebble bed gas-cooled reactor.

Abel G. Rodríguez[1,2], Daniel M. Pérez[1], Carlos A. Brayner de Oliveira Lira[2]

[1] abel.rodriguez@ufpe.br, daniel.milian@ufpe.br, Departamento de Energia Nuclear - Universidade Federal de Pernambuco, Ave. Prof. Luiz Freire, No. 1000, Cid. Universitária, CEP 50740-540, Brazil

[2] brayner@cnen.gov.br, Centro Regional de Ciências Nucleares – CRCN – NE/CNEN, Ave. Prof. Luiz Freire, No. 200, Cid. Universitária, CEP 50730-120, Brazil

1. Introduction

The Very High Temperature gas-cooled Reactor (VHTR) is one of the candidates for the next generation of nuclear reactors according to the IAEA [1]. Evaluation of thermohydraulic performance and experimental comparison were proposed to the international research community. The HTR-10 was selected as a reference reactor of high temperature pebble bed gas-cooled reactor by OIEA to study the performance of some technology components under different conditions [2]. The HTR-10 is the only one SMR of this technology currently in operation [3]. Predicting the thermohydraulic behavior of High Temperature Reactors (HTR) is an important contribution to the development of the technology of the pebble bed gas-cooled SMRs. The computational prediction of the thermohydraulic behavior of this rector involve different physic-neutronic approach and detailed structural information. In these sense, three-dimensional thermohydraulic analysis of a whole nuclear reactor is a great challenge due to the large geometric volume and complex structures [4]. Multiscale approach and Multiphysics coupled techniques are others of the challenges in the simulation of reals situations [5]. The main dimension of some of principal components of this reactor is known [6]. One of the internal structures present in the high temperature pebble bed SMR is the top reflector [2]. The top reflector structure provides several essential functions among which stand out: neutron reflection, helium inlet control, and distribution into the core, neutron shielding, thermal shielding, etc [7], [8]. In this sense, the three-dimensional CFD thermohydraulic analysis of the entrance pattern to the core of a High Temperature SMR using ANSYS CFX has been done.

2. Methodology

This research presents a comparison between three patterns of the entrance of coolant into the HTR-10 core: a prototype model of 460x∅2.5cm distributed vertical channels, a model of 20x∅12cm of equivalent area vertical channels, and a simplified vertical porous media model. From these three patterns was be done a analyse of the thermohydraulic behavior of the coolant before and after troughing the top reflector. In this work was used the methodology discussed in [5], [9]. The computational model was limited to simulate the helium flow starting from the coolant channels within structural components at the bottom region as showed in Figure 1. A mass flow rate of 1.8792 kg/s was imposed at the inlet. As outlet was defined the region limited by the beginning of the conical region of the reactor core. An average static pressure over whole outlet was imposed. The adiabatic condition was forced at all wall condition and the thermal energy model was used to consider the heat exchange at the fuel elements temperature in the core. To estimate the impact of the patterns of the entrance of coolant in the bulk properties of the pebble bed core was used a simple homogeneous pebble model proposed by [5].

The realized study was carried on using the CFD code ANSYS CFX. The independence mesh analyse was done from meshes between 0.6 and 14.3 million of unstructured mesh. All meshes were created with inflated prisms layers of way that the scalable turbulent wall functions were possible to use with the κ-epsilon model. To predict the pressure drop thought the simplified vertical porous media model was used a thick perforated plate analytical approach model according to [10].

3. Results and Discussion

The Figure 1 shows the coolant velocity distribution of the three cases of study. As a result, in all of the cases was observed that the coolant raises from the inlet till the cold helium chamber reaching 16.3m/s, approximately. Then the coolant flows through the cold helium chamber with similar patterns in the three cases. In the cases, using the prototype with 460x∅2.5cm vertical channels and the simplified porous media model, the coolant reaches the top core cavity with a spread distribution as shown in Figure 1 a) and c). In this case, using the 20x∅12cm of equivalent area model, the coolant is injected into the top core cavity as showed in Figure 1 b).

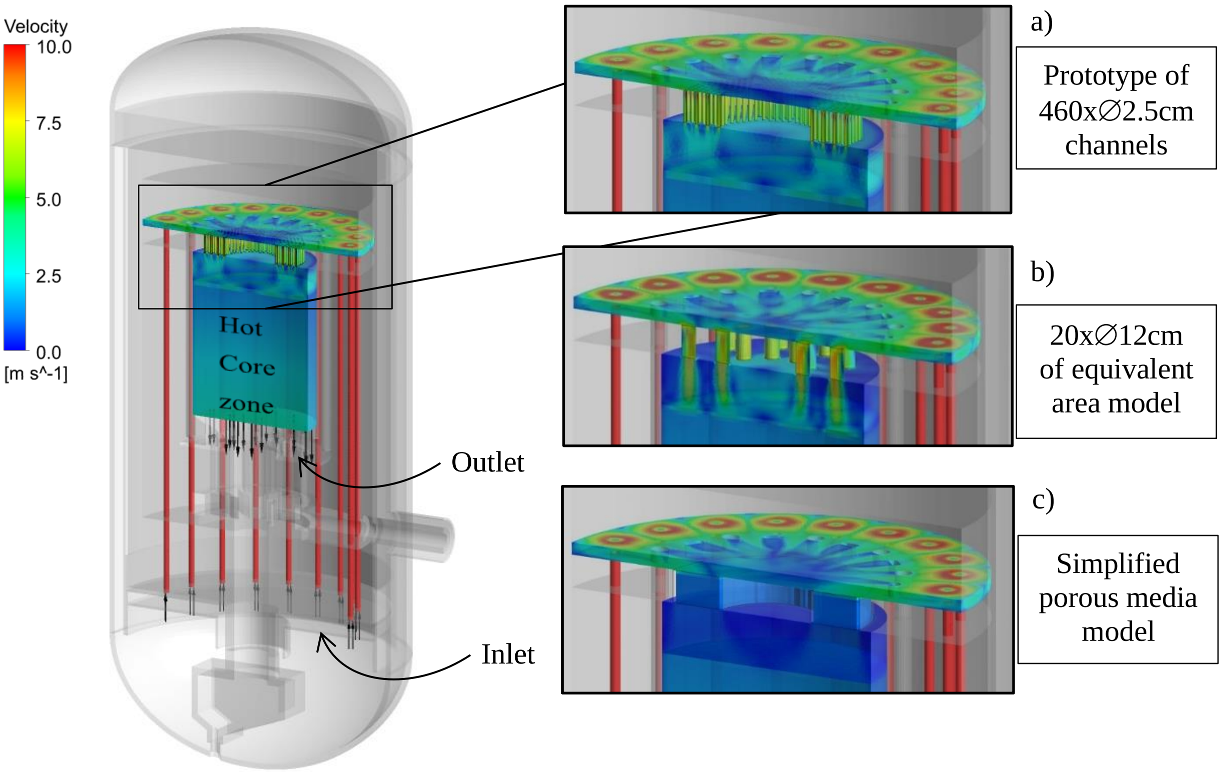

Figure 1: Coolant modelled region inside the HTR-10 and velocity distribution profiles from 3D volume representation.

The Table I have shown the average thermohydraulic parameters. A simple comparative analysis confers a similar behavior of the coolant in the three models. By the way, the average velocities of coolant through the hot core zone were around 2.30m/s with a relative difference less of than 0.5%. The maximum relative difference of the average temperature of the coolant in the core zone was 1%. For the temperature in the surface of the fuel elements, the maximum relative difference was, as well, inferior to this value.

The three cases showed in the Figure 1 and the equivalent results of prediction of the average parameters of the hot core zone, reflect the poor impact that has to assume a detailed model as the prototype with 460x∅2.5cm vertical channels, or the model with 20x∅12cm of the equivalent area, or the simplified porous media model. Despite this, the model 20x∅12cm of the equivalent area requires less than 5 times of computational resource than the prototype with 460 little channels and the simplified porous media model requires less than 10 times. Such a performance confirmed the applicability of the proposed models with 20xÆ12cm of the equivalent area or the simplified porous media model in the design studies of similar reactors.

Table I: Main thermohydraulic parameters obtained with the three models.

Model	Temperature [C]			Global pressure drops [Pa]	Ave Velocity at hot core zone [m/s]
	Coolant in the core zone		Fuel elements Surface		
	Ave	Max	Ave		
Prototype of 460x∅2.5cm	618.05	1104.80	724.24	1091.8	2.30219
20x∅12cm model	619.61	1083.19	725.53	1070.5	2.30683
porous media model	617.93	1098.46	724.04	983.0	2.28866

4. Conclusions

The comparison shows good agreement in the estimative of the averages surface fuel temperature, coolant temperature, and helium velocity between the porous media model and prototypic models. The prediction of the pressure drop from the thick perforated plate analytical approach is an acceptable prediction as well. In conclusion, was demonstrated the potential applicability of the porous media models for an integral full-scale reactor simulation in the future. As a benefit, the porous media model reduces the mesh quantity from a prototypic model. Correspondingly, the computation time was reduced.

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