2021 International Nuclear Atlantic Conference – INAC 2021
Virtual meeting, Brazil, November 29 – December 2, 2021

ISBN: 978-65-594-1256-3

Proposal for Thermal Study of a High Temperature Reactor Using a Computational Fluid Dynamic Tool

J. R. de Souza[1], A. L. Costa[1], A. A. C. dos Santos[1,2], M. C. Ramos[1],

junio8024@gmail.com, antonella@nuclear.ufmg.br, aacs@cdtn.br,
cerrogranderamosmario@gmail.com
[1]*Departamento de Engenharia Nuclear, Programam de Pós-graduação em Ciências e Técnicas Nucleares - Universidade Federal de Minas Gerais*
Belo Horizonte, Brazil
[2]*Centro de Desenvolvimento da Tecnologia Nuclear - Comissão Nacional de Energia Nuclear*
Belo Horizonte, Brazil

1. Introduction

The High Temperature gas cooled Reactor (HTR-10) is a small reactor, with thermal power of 10 MW, developed in China. This reactor belongs to type Pebble Bed High Temperature Gas cooled Reactor that are strong candidates for the next generation reactors [1]. The HTR-10 is a modular concept; the reactor reached criticality in the year 2000 and full power operation in 2003. The HTR-10 reactor core is cooled by helium gas, moderated by graphite and uses uranium spherical fuel elements composed by TRISO (TRi-structural ISOtropic) particles (see Fig. 1).

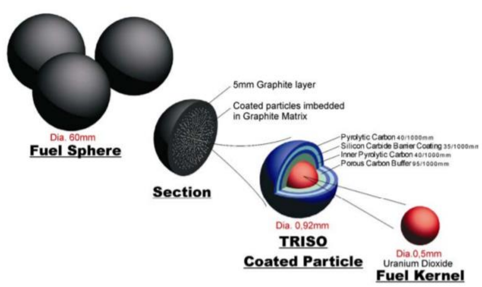

Figure 1: The fuel sphere used in the HTR-10. Adapted from [4].

In the initial core, fuel elements and graphite dummy balls (graphite balls without nuclear fuel) constitute the pebble bed. The lower part of the core has only dummy balls. There is a discharging tube below the coned core to unload the fuel elements. Only 87% of the helium effectively cools the fuel elements in the core. The total mass flow rate is 4,32 kg/s of helium. Table I presents some geometrical characteristics of the HTR-10 reactor core.

Table I: Geometrical characteristics of the HTR-10 reactor core [2].

Parameter	Value
Equivalent diameter, cm	180.0
Average height, cm	197.0
Volume, m³	5.0
Volumetric filling fraction of balls in the core	0.61
Height of the empty cavity above the pebble bed, cm	41.7
Diameter of fuel discharging tube, cm	50.0

The reactor equilibrium core contains about 27,000 fuel elements. The design parameters of the fuel elements and the dummy balls are given in Table II.

Table II: Design of fuel elements, dummy balls and loading ratio [2].

Parameter	Value
Fuel Element	
Diameter of ball, cm	6.0
Diameter of fuel zone, cm	5.0
Fuel	UO_2
Enrichment of U-238 (weight), %	17.0
Heavy metal (uranium) loading (weight) per ball, g	5.0
Dummy balls	
Diameter of ball, cm	6.0
Density of graphite, g/cm^3	1.73
Loading ratio of fuel balls to dummy balls	53:43

The behavior of the fluid through the core between the spherical elements has been the subject of study in recent years. These investigations are very important mainly about the safety of future nuclear reactors. Therefore, in this work, a Computational Fluid Dynamics (CFD) modeling approach has been developed to investigate the thermal-hydraulic characteristics within the core under steady-state conditions. Therefore, the HTR-10 was selected for the present simulations considering initially only a column of spheres long the core.

2. Methodology

The calculations were run on Ansys CFX 2019 R3. To the computational domain an arrangement of fuel spheres was considered as shown in Fig. 2. It was selected a column located at the central section of the core. Vertically, a column of 1200 mm with spheres of 60 mm perfectly stacked were considered, representing approximately one third of the active core high. Horizontally, there are nine spheres symmetrically distributed in such column. Considering that the modeled area is 1.27% of the total radial core area, the mass flow rate was taken as 4.32 x 0.87 x 0.0127 = 0.048 kg/s of helium. The inlet temperature was obtained by the validated RELAP5 modeling, described in [3]. As shown in Figure 3, in the level 7 of the RELAP5 modeling that corresponds to enter of the CFD model, the temperature is 594.5 K. This value was used as boundary condition to CFD model. In the level 12 of RELAP5 model, corresponding to the outlet of the CFD model, the temperature was 711.0 K. This value will be compared with the CFD simulations.

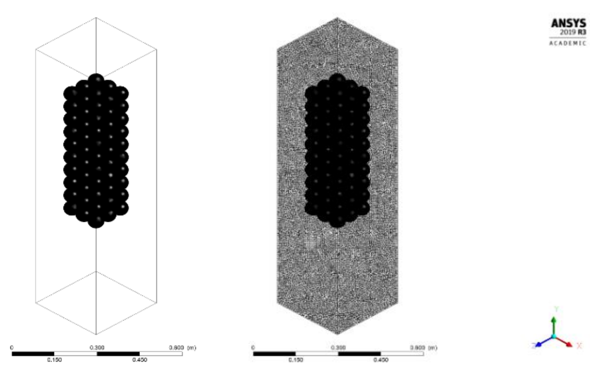

Figure 2: Arrangement of fuel spheres in CFD model.

3. Results and Discussion

Starting from the exposed boundary conditions, some results are shown from the simulations. In Figure 4 is shown the streamline representing the speed of the He from a front view. As it is possible to verify, there is a lot of turbulence at the outlet of the channel. It is probably because the way as the fuel balls are perfectly distributed in the model. In practice, the spheres will be randomly distributed. The same behavior can be observed in Figure 5 where there is a very high drop in velocity value between the spheres. Figure 6 represents the temperature distribution in the CFD model. As it is possible verify, the helium comes out from the model with an average temperature of about 1000 K, that is, about 40 % higher than predict by the verified model in RELAP5. As this is an initial research, the model will be adjusted to better represent the behavior of the helium circulation among the fuel balls.

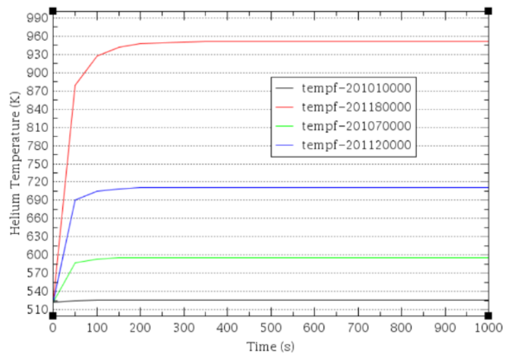

Figure 3: RELAP5 model – coolant temperature along the core. The levels 7 and 12 are the central parts.

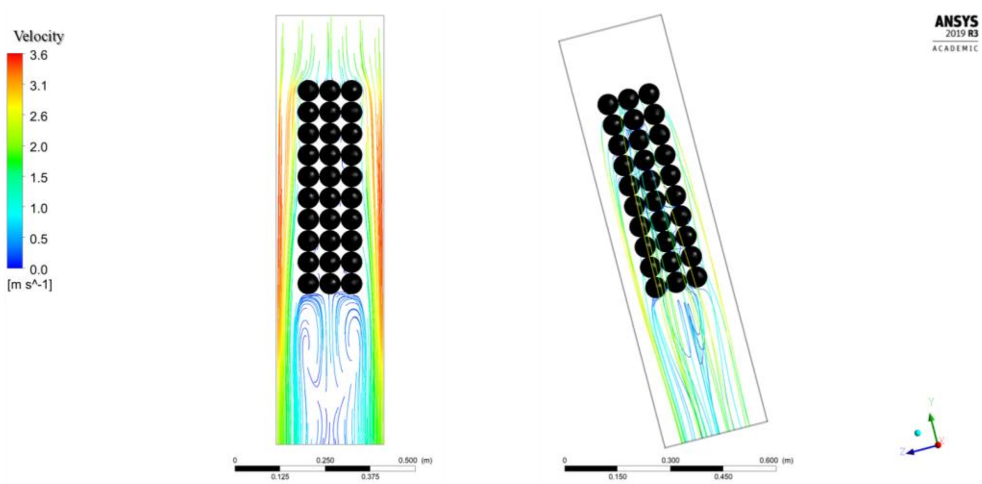

Figure 4: Streamline representing the speed of the He from a front view. CFD model.

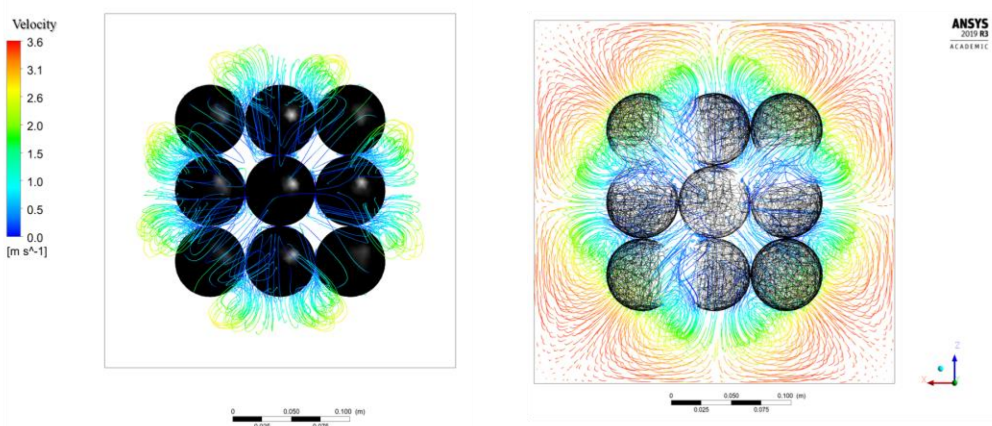

Figure 5: Streamline representing the speed of He around the combustible spheres. CFD model.

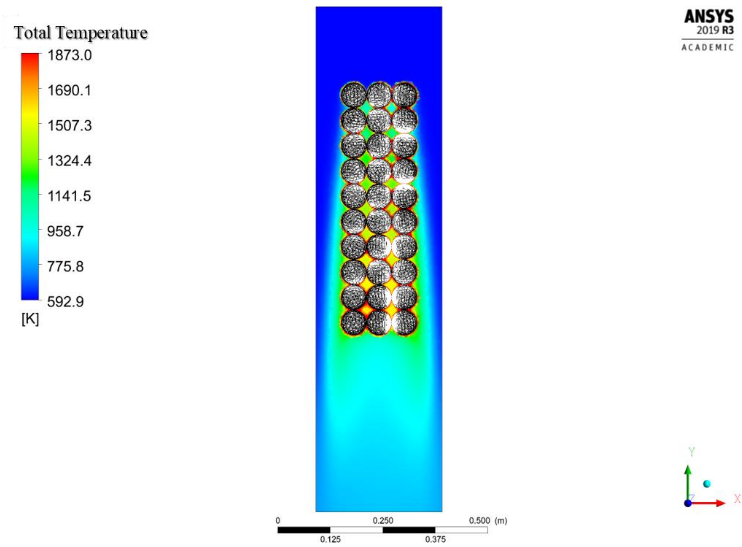

Figure 6: Color map representing the total temperature from a front view. CFD model.

4. Conclusions

This work presents the first results of a CFD modeling of part of the core of the HTR-10 advanced reactor. The model seems to simulate well the behavior of the coolant between the fuel spheres, but it is necessary to adjust it so that the helium exit temperature is lower. Modifications on geometry and mesh in the contact region will be investigated and presented in the future.

Acknowledgements

The authors are grateful to the *Comissão Nacional de Energia Nuclear* (CNEN), the *Coordenação de Aperfeiçoamento de Pessoal de Nível Superior* (CAPES), the *Fundação de Amparo à Pesquisa do Estado de Minas Gerais* (FAPEMIG) and the *Conselho Nacional de Desenvolvimento Científico e Tecnológico* (CNPq) for the support.

References

[1] International Atomic Energy Agency, "Current status and future development of modular high temperature gas cooled reactor technology", *IAEA-TECDOC-1198*, Vienna, Austria (2001).

[2] International Atomic Energy Agency, "Evaluation of high temperature gas cooled reactor performance: benchmark analysis related to the PBMR-400, PBMM, GT-MHR, HTR-10 and the Astra critical facility", *IAEA-TECDOC-1694,* Vienna, Austria (2013).

[3] M. E. Scari et al., "HTR Steady State and Transient Thermal Analyses", *International Journal of Hydrogen Energy*, v. 41, p. 7192-7196 (2016).

[4] Y.H. Fang et al., "Fuel pebble optimization for the thorium-fueled Pebble Bed Fluoride salt cooled high-temperature reactor (PB-TFHR)", *Progress in Nuclear Energy*, v. 108, p. 179-187 (2018).