BJRS

BRAZILIAN JOURNAL
OF
RADIATION SCIENCES
08-03B (2021) 01-19

SBPR
Sociedade Brasileira de Proteção Radiológica

CFD Analysis of the VHTR Prismatic Core with Variation of Geometry Parameters

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ABSTRACT

The Very High Temperature Reactor is a thermal, graphite moderated and helium cooled nuclear reactor. The purpose of this work is to study the behavior of the VHTR by means of parametric analysis, altering the energy generation profile in the fuel blocks and the influence of modifications in the geometry itself. The coolant flow through the coolant channels and by-pass channels were analyzed in a 1/12th section of a fuel block column. Geometry was used with by-pass channels of different dimensions, besides one that had only the cooling channels, without by-pass channel. It has been found that the existence of a by-pass flow induces an increase in the temperature gradient in the fuel block. Comparative studies were performed between the results obtained in simulations carried out with different profiles of thermal energy generation (uniform and sinusoidal) in the fuel channels. It was verified that when there is the same total thermal energy generation in the fuel block, the maximum temperature observed in each of the materials is smaller for the generation with sinusoidal profile. Computer simulations were performed using a geometry with a central channel with the same diameter as the others to verify the hypothesis that the existence of a temperature gradient in the fuel block, with the highest temperature at the center and the lowest temperature being at the periphery of this block, is due to the smaller dimension of the coolant channel located in the center of this block. The results obtained confirm the hypothesis

Keywords: CFD, VHTR, parametric analysis.

ISSN: 2319-0612
Accepted: 2020-11-06

1. INTRODUCTION

The Very High Temperature Gas-cooled Reactor (VHTR) is a thermal reactor, cooled by helium gas and graphite moderated. The technology involved in the development of this type of reactor is based on the experience of High Temperature Gas-cooled Reactors (HTGR).

One of the most challenging points in developing VHTR is keeping the fuel temperature at a safe level. With the coolant outlet temperature at 1000 °C, the maximum temperature difference between the fuel and the helium should be less than 250 °C, so that the fuel temperature limit usually accepted for the reactor in normal operation, approximately 1250 °C (1523 K), is not reached (TAK et al, 2008).

In the case of accidents, the temperature in the fuel channels can be significantly higher than the maximum temperature accepted for normal operation of the reactor. A basic safety parameter of this reactor is the upper limit of the temperature of the fuel, generally accepted as 1600 °C (1873 K), since, above this temperature, the coatings of the TRISO (TRIStructural ISOtropic) particles begin to suffer damages that imply the significant release of fission products (CLIFFORD, 2013).

By-pass flow is the flow of helium gas through the interstitial spaces between the fuel blocks, and between these blocks and the adjacent reflecting elements. These interstitial spaces are initially present due to the tolerance in the manufacture of the fuel blocks and reflectors, and also to the inaccuracy of the installation of these blocks. The thickness of these spaces changes with the time of operation of the reactor due to the thermal expansion and the shrinkage of the graphite due to the irradiation of neutrons (SATO et al, 2010; TRAVIS; EL-GENK, 2013b).

By-pass flow in the reactor raises concerns regarding the distribution of helium flow in the core and the potential to develop hotspots in the fuel blocks. Helium flow through the by-pass channel decreases the flow in the cooling channels, leading to an increase in the temperature gradients inside the fuel blocks.

The purpose of the present work is to evaluate the characteristics of the flow and temperature distribution in a sector of 1/12th of a column of fuel blocks when different profiles of thermal energy generation are adopted in the fuel channels; when the width of the interstitial space between the fuel blocks, in which the by-pass flow occurs, is modified; and when the geometry of the fuel block is changed, using a central channel of larger diameter. It is also investigated the influence of the heat flux to the upper and lower reflectors on the heat transfer coefficient in the coolant channels.

2. MATERIALS AND METHODS

2.1. Constitutive Aspects of the VHTR Core

A widely known HTGR model is the gas turbine modular helium reactor GT-MHR. This model generates 600 MWth and it operates at a pressure of 7.07 MPa. The coolant temperatures at the inlet and the outlet of the core are approximately 490 °C and 850 °C, respectively.

The prismatic core of the GT-MHR (Figure 1) is composed of 10 concentric rings of hexagonal prismatic fuel blocks and reflectors (graphite).

The active core is composed of 10 layers of fuel blocks, with 102 of these blocks in each layer, making a height of approximately 7.93 m.

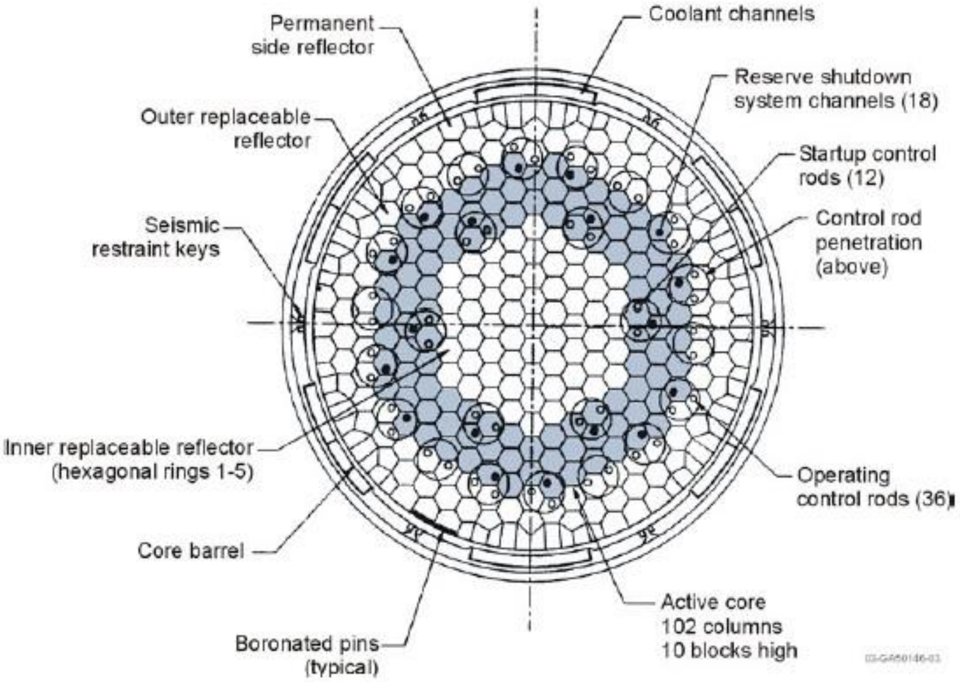
The fuel blocks and radial reflectors are 0.793 m high and 0.36 m flat-to-flat. There are also reflector blocks installed above and below the active core, with heights of 1.189 m and 1.585 m, respectively, for a total core height of 10.704 m.

The fuel material consists of TRISO particles dispersed in a graphite matrix, forming cylindrical fuel pellets.

The standard fuel blocks (Figure 2) have 108 coolant channels, 102 of which are 1.5875 cm in diameter and 6 are 1.27 cm in diameter (the latter are located around the center of the block).

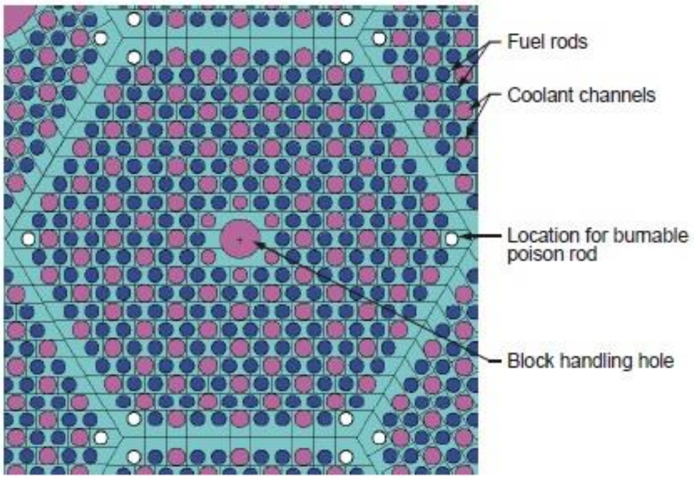
The helium coolant enters the reactor pressure vessel via an annular inlet, flows upward between the pressure vessel and the core barrel, enters the upper plenum and flows downstream through the active core of the reactor. The temperature of the coolant increases as it flows down through the cooling channels (and through by-pass and control rod channels), reaches the lower plenum and exits the vessel via the outlet tube. In the present work, the cross flow between the upper and lower faces of the stacked blocks was ignored and the widths of the interstitial spaces between the blocks were assumed to be constant from top to bottom.

Figure 1: *Cross sectional view of the GT-MHR core*



Source: MACDONALD et al., 2003

Figure 2: *Standard hexagonal fuel block cross section*



Source: MACDONALD et al., 2003

2.2. 1/12th Section of a Stack of Prismatic Fuel Elements

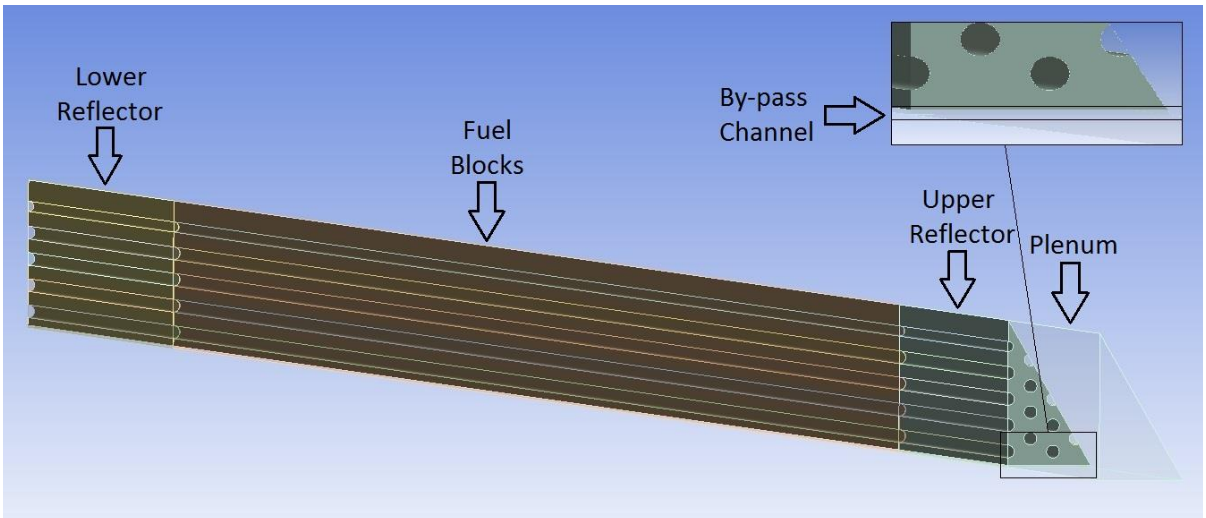
The approach used to evaluate the 1/12th sector of the standard fuel block column (Figure 3), 10.704 m high (including active core and upper and lower reflectors), is due to the fact that this configuration has symmetry on all sides (including by-pass) in order to greatly simplify numerical analysis. For the numerical simulations, the Ansys CFX CFD software was used.

1/12th sector of the fuel block column comprises 8.5 coolant channels of 15.88 mm in diameter; 0.5 coolant channel 12.7 mm in diameter; 17.5 fuel channels; and 0.5 channel for burnable poison rod. The total mass flow rate for the sector was 0.2 kg/s, imposed at the entrance of the upper plenum, with the fluid temperature at the inlet at 490 °C.

In the present simulation, an upper plenum of 1 meter in height, located on the upper graphite reflector, was considered. The consideration of the existence of this upper plenum in the simulation allowed us to impose a total mass flow as an inlet condition.

As the power of the reactor under analysis is 600 MWth, it is estimated that the volumetric rate of thermal energy generation should be 27.88 MWth/m³. In the simulations, it was considered that burnable poison rods had thermal properties equal to H-451 graphite, and that there was no thermal energy generation at these rods, as stated by Tak et al. (2008).

Figure 3: *View of the 1/12th sector of a block column.*



The origin of the coordinate system was defined on the plane of the upper face of the active core of the reactor, i.e. at the interface between the upper reflector and the adjacent fuel block. The z axis has direction parallel to the height of the fuel blocks and it is oriented downwards.

2.3. Numerical analysis and meshing

The standard $k-\varepsilon$ turbulence model with the scalable wall function was applied to the coolant flow. The scalable wall function prevents the first grid point from sliding into the linear profile area. High resolution advection scheme was used to calculate the advection terms in the discrete finite volume equations. The values of y+ are approximately 10.

A mesh refinement study was carried out to evaluate if the values obtained in the simulations would vary significantly if the mesh was more and more refined. The flow was simulated in the geometry containing a mesh with 15.5 million nodes and 17.2 million elements. After that, an even more refined mesh was constructed, and a new simulation was performed, using the same parameters of the previous computational experiment. This new, more refined mesh had 19.2 million nodes and 20.8 million elements.

Comparing the values obtained for the temperature distribution and the mass flow through the coolant channels in the geometries with the two different meshes, the difference between the maximum temperature values in the fuel was of 0.26%, in graphite 0.28%, and in helium 0.29%. The difference between the average outlet temperatures of the coolant channels was around 0.36% and the difference between the total mass flows was about 0.3%. These results indicate that the less refined mesh is sufficient for the simulation of the coolant flow and to obtain the temperature distribution throughout the domain.

The residual is the measure of the local imbalance of each conservative equation in the control volume. It is the most important measure of convergence, since it is directly related to the precision of the resolution of the equations (ANSYS, 2013). The residual RMS value of 10^{-6} was chosen, that is, when the imbalance of the conservative equations in the control volume reached below this value, the convergence would be reached.

2.4. Thermal Energy Generation Profile in the Fuel Channels

In the majority of the simulations carried out in the present study, a uniform heat generation profile along the fuel channels was used; however, in order to assess the importance of considering the heat generation profile in the fuel channels, a simulation was performed considering the variable profile for the heat generation along these fuel channels. In this case, the geometry considered had a 5 mm wide by-pass flow channel.

Due to the core structure of the reactor and to the disposition of the fuel channels inside the reactor, the rate of heat generation is not uniform in a realistic VHTR. The sinusoidal profile for the heat generation was based on the work of Johnson et al (2009). In the present case, the expression used was:

$$q''' = A_r q_{con}\left\{1 + \left(A_p - 1\right) sin\left(\frac{\pi z}{L}\right)\right\} \qquad [MW/m^3] \tag{1}$$

q''' is the volumetric rate of heat generation; q_{con} is a calibration constant, established to obtain the same total thermal energy generation in the core, and in the present case q_{con} is $27{,}88/(1+(0{,}6/\pi))$ $[MW/m^3]$; A_r is the radial generation factor, which assumed values of 1 (average) and 1.25 (peak); e A_p is the axial peak factor, which was considered to be 1.3.

These factors were based on neutronic analysis, according to Johnson et al (2009), based on the study by MacDonald et al (2003), and all of them will be used in the present simulation.

2.5. Materials

The properties of the materials used were obtained from the work of Johnson et al. (2009), who, in turn, obtained the helium properties from the *National Institute of Standards and Technology*; the graphite properties, reference H-451, from General Atomics safety analysis report, 1977; and the properties of UO_2 pellets from the work of MacDonald et al (2003).

3. RESULTS AND DISCUSSION

3.1. Temperature Distribution in the 1/12th Sector - Altering the By-pass Width

Simulations were performed on geometries of different dimensions of by-pass channels, besides that without this channel, using the $k-\varepsilon$ turbulence model. In this case, the behavior of the coolant and the distribution of temperature throughout the system were studied using 3 mm and 5 mm wide by-pass channels.

The region with the highest temperature in the graphite and fuel domains is approximately 6 cm above the exit face of the active core of the reactor. In Figures 4, 5 and 6 it is shown the temperature distribution in the plane located at z = 7.87 m, for the three cases. It should be noted that, in order to facilitate the comparison of the results, the same temperature scale was used in these three figures; this scale is shown in Figure 4.

As can be seen, as the width of the by-pass channel is increased, the higher the temperature gradient in all domains, whether in the coolant, the graphite, or the fuel channels.

Table 1 shows the values of the minimum and maximum temperatures, in the above-mentioned plane, in each of the component domains of the system.

Figure 4: *Temperature distribution in a geometry without by-pass channel.*

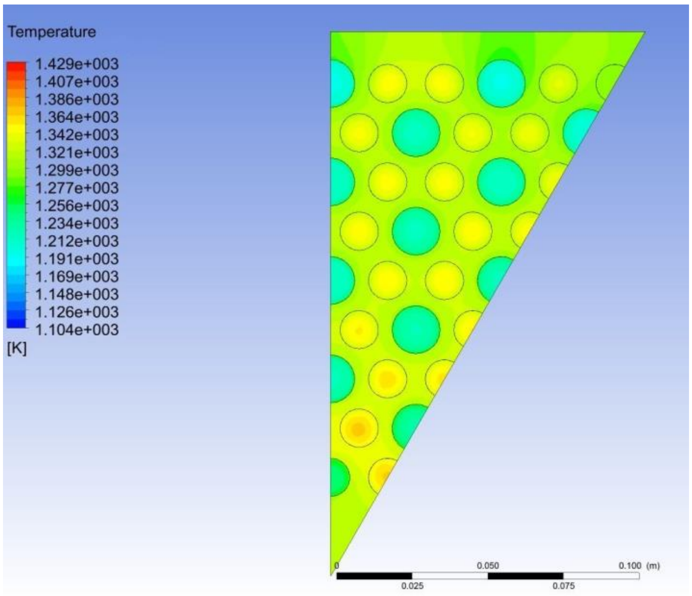


Table 1: Maximum and minimum temperatures in the hottest plane of the active core, for each of the geometries and in each of the domains.

	No *by-pass*		***By-pass* 3 mm**		***By-pass* 5 mm**	
Domain/Temperature	**T min [K]**	**T max [K]**	**T min [K]**	**T max [K]**	**T min [K]**	**T max [K]**
Graphite	1268,17	1342,84	1220,17	1367,94	1149,71	1404,4
Fuel	1295,09	1368,26	1250,05	1392,93	1200,01	1429,01
Helium	1198,55	1325,22	1164,01	1350,76	1104,22	1387,83

The by-pass flow through the 5 mm wide channel corresponds to 10.489% of the total mass flow that enters the upper plenum of the reactor section under study. The flow through the 3 mm wide by-pass channel is equivalent to 4.713% of the total mass flow.

The increase in the temperature gradient observed in Figures 4, 5 and 6 is due to the fact that the bypass flow "steals" the fluid that would pass through the coolant channels, cooling the structure around it.

Figure 5: *Temperature distribution - 3 mm by-pass channel.*

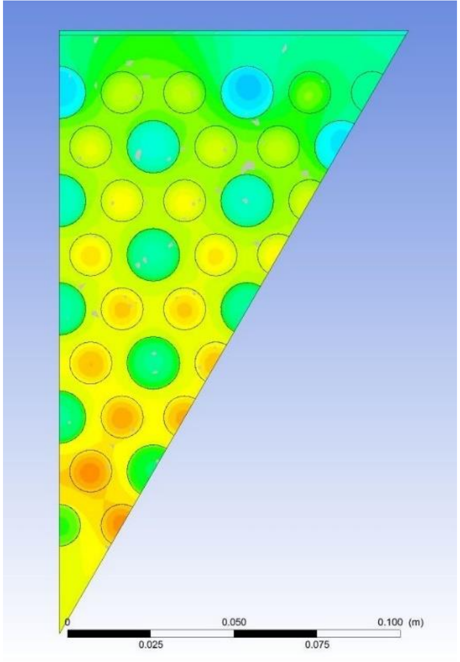
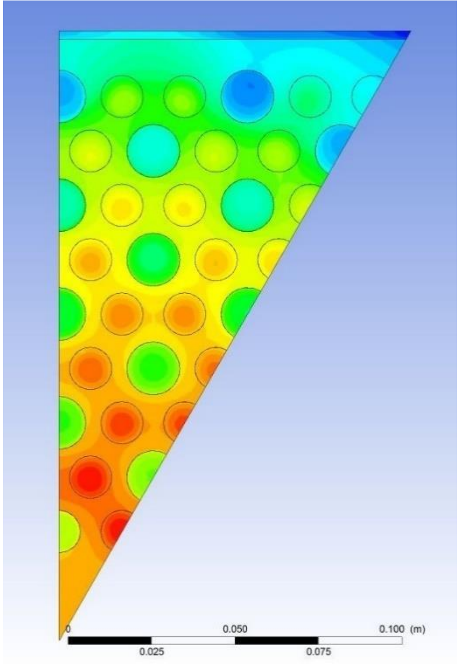


Figure 6: *Temperature distribution - 5 mm by-pass channel.*



3.2. Variation in Power Generation Profile

For both the uniform profile and the sinusoidal profile, with a radial factor equal to 1, the total thermal energy removed by the fluid was equal, and, therefore, the value of the bulk temperature at the end of each channel was strictly the same for the adopted profiles.

The graph in Figure 7 shows the values of the wall temperatures in the channel and the bulk temperatures of the helium gas, for both profiles of power generation considered (uniform and sinusoidal with radial factor equal to 1), along the channel.

It is verified that the temperature in the channel wall was higher, for the case of the uniform profile of heat generation, up to $z/D \cong 150$. From this point on, the temperature in the wall becomes higher for the sinusoidal profile, which lasts up to $z/D \cong 440$. Thereafter the temperature in the wall is again higher for the case of uniform profile.

It can be seen that the uniform profile of heat generation provides the highest temperatures in the first half of the channel to the bulk temperature of the fluid, up to $z/D \cong 250$. From this point on, the temperature in the fluid is higher for the case of sinusoidal profile, until at the end of the channel temperatures are equal.

From the analysis of Figure 8, it can be seen that the heat transfer coefficient is very similar for the simulations carried out with uniform and sinusoidal profile (with radial unitary factor) of energy generation. The maximum difference is approximately 10 W/m²K, which corresponds to a deviation of approximately 0.5%, which occurs in the section near the entrance of the channel. From then on, the values converge very well, with a maximum difference of 0.2%.

Figure 7: *Wall channel temperature and helium bulk temperature, for the uniform and variable profiles of thermal energy generation.*

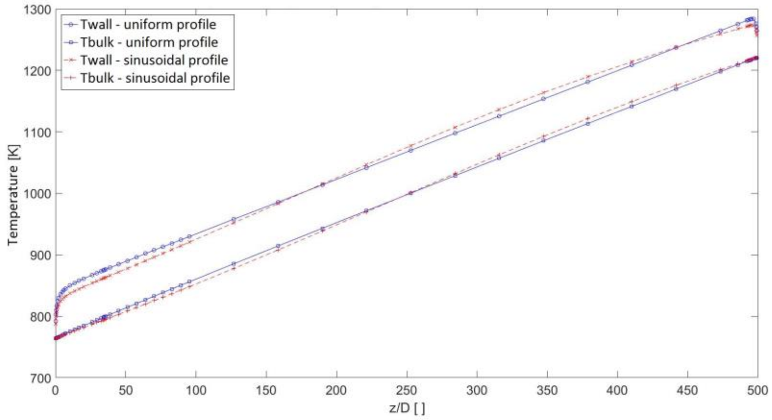
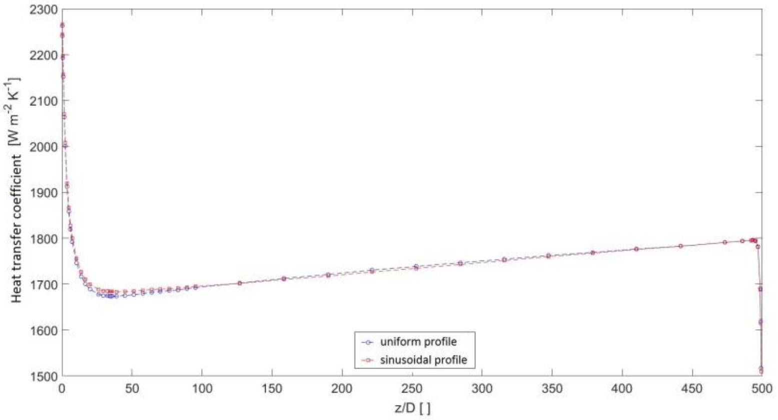


Figure 8: *Heat transfer coefficient along the channel, for uniform and variable profiles.*



The planes in which the highest fuel temperatures are found, for the uniform profile of energy generation (Figure 9) and for the sinusoidal profile (Figure 10), with a radial factor of 1, are located in the same region, in both cases, at approximately z = 7.87 m. For the simulation in which the sinusoidal thermal energy profile, with a radial peak factor of 1.25, was considered, the hottest plane was located in the same region.

When comparing the results obtained between the simulation with uniform heat generation profile and the sinusoidal generation profile with a unitary radial factor, that is, between the two situations where there is the same total thermal energy generation, it is observed that the maximum temperature in each of the domains is lower for the variable profile, which is positive from the safety perspective.

Figure 9: *Temperature profile [K] in the hottest plane, with uniform power generation profile.*

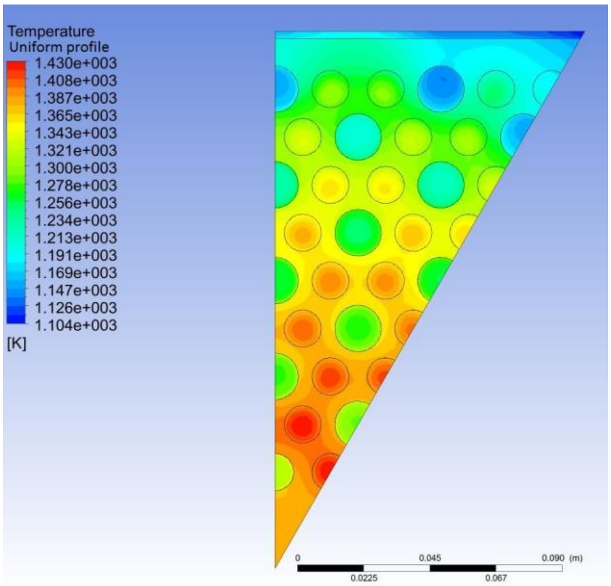
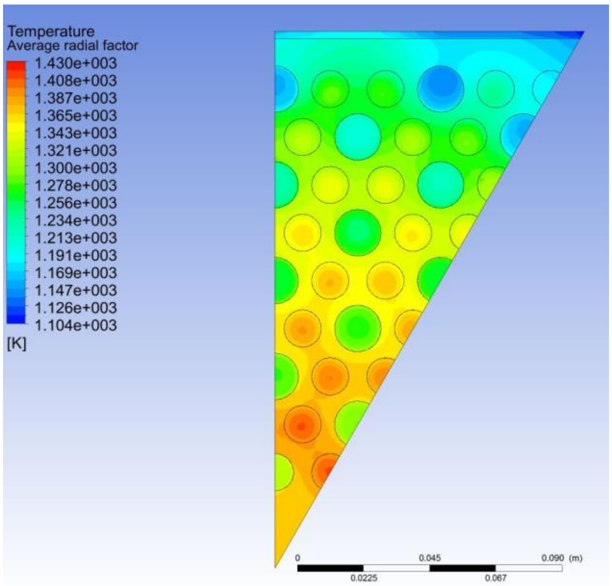


Figure 10: *Temperature profile [K], with sinusoidal power profile (radial factor = 1).*



In Figures 11 and 12 there is a comparison between the temperatures in the hottest planes obtained in the simulations performed with variable thermal energy generation profile, with different radial factors (1 and 1.25). For the case where the radial factor 1.25 was used, the temperatures in the fuel channels are quite high, exceeding in some points the safety limit of the usually accepted fuel temperature (approximately 1250 ºC, or 1523 K) for the normal operation of the reactor, which, in case of accidents, such as loss of coolant, leads to the occurrence of temperatures so high that they can extrapolate values considered critical for the rupture of the containment structures of the TRISO particle (1600 °C, or 1873 K).

Figure 11: *Temperature profile[K], with sinusoidal power profile (radial factor = 1).*

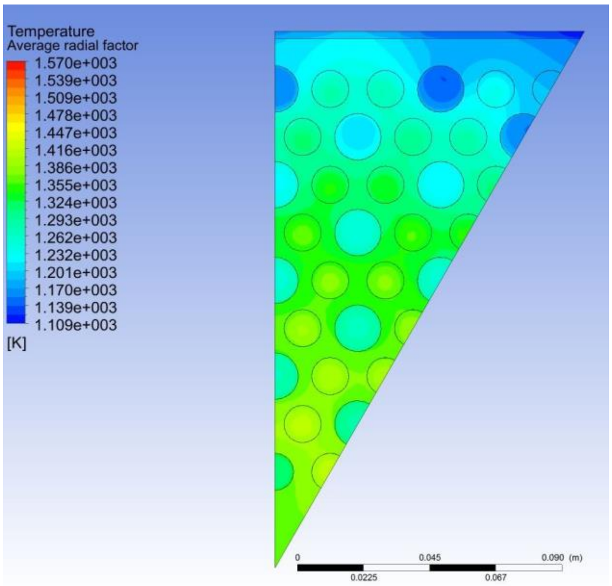


Figure 12: *Temperature profile[K], with sinusoidal power profile (radial factor = 1.25).*

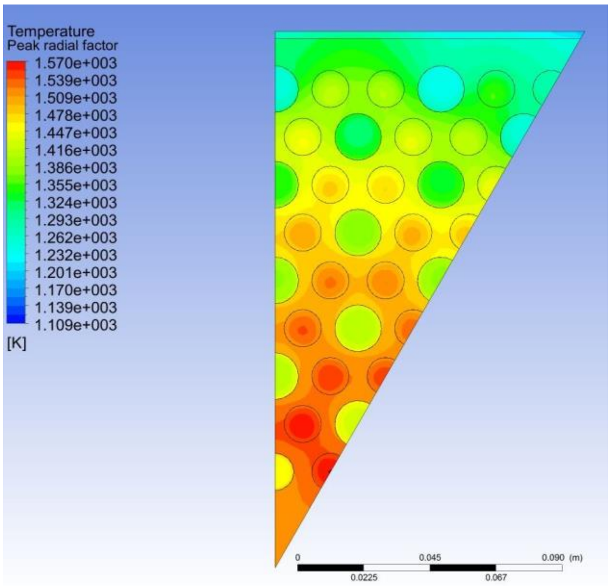


Table 2 compares the maximum value found in each of the domains for each of the simulations.

Table 2: Maximum temperature in each of the materials, according to thermal energy generation profile.

Domain/Profile	Uniform profile	Variable profile – average radial factor	Variable profile – peak radial factor
Fuel	1429,02 K	1410,89 K	1570,28 K
Graphite	1404,27 K	1389,15 K	1544,67 K
Helium	1347,93 K	1343,22 K	1488,55 K

3.3. Influence of the Central Channel Diameter on the Temperature Gradient

Wang et al. (2016) have indicated that a major reason for the temperature gradient in the fuel block from the center (hotter) to the peripheral region is the fact that the coolant channels located in the center of that block have a smaller diameter than those standard coolant channels.

In order to investigate this hypothesis, we performed simulation using a geometry designed so that the central channels had the same diameter of the other cooling channels, that is, 15.88 mm. Two types of comparison were performed.

In the first one, the results obtained with the simulation of the flow in this altered geometry were compared to those already obtained in the simulation with the same mass flow, but with normal geometry; that is, the input condition for the simulations was mass flow rate at the upper plenum inlet of 0.2 kg/s. In both geometries, by-pass channel had 5 mm in width.

The percentage of mass flow through the by-pass channel decreased from 10.487% in the standard geometry to 10.206% in the altered geometry. The value of the mass flow was lower in the standard channels, this difference varying from 1% to 2.8%. The mass flow in the central channel, whose size was changed, increased by 83.2%, while the flow in the by-pass channel had a decrease of 2.68%. As a consequence of the change in mass flow, there was also a change in the temperature distribution throughout the structure, i.e. in graphite, in fuel and in coolant.

There was an increase in the outlet temperature in the coolant channels farthest from the center of the fuel element, from 0.3% to 0.8%, while in the channels closest to the center the fluid left the structure with a temperature lower than those verified in the geometry unchanged, being this difference from 0.1% to 2.75%. In the central channel, the temperature fell by 5.7%, and in the by-pass channel there was an increase of 0.9%.

For this first case, there was a general decrease of the maximum temperature per domain (graphite, fuel and fluid), for the geometry with the central channel changed. The maximum temperature fell 2.16% in the graphite, 1.93% in the fuel channels and 2.46% in the fluid.

Figures 13 and 14 show the temperature profiles in a cross section at z = 7.87m, the maximum temperature location. There has been a displacement of the hotter region on the plane which transversely cuts the active core. This warmer region passed from the center of the block to the intermediate zone, between the center and the periphery of the fuel block. The peripheral region remains the lowest temperature because it continues to be cooled by the by-pass flow. In order to isolate the effect of the change of the dimension of the central channel, we proceed to the simulation of the geometry without by-pass channel.

In this second comparison, it was found that, in fact, the temperature gradient in the fuel block, with the highest temperatures being in the center of the block and the smaller ones in its periphery, is due to the fact that the central channel has smaller diameter; however the gradient would be even larger, but in the opposite direction, i.e. the periphery of the block would be warmer than the center, if the central channel had the same diameter of the other cooling channels, for the condition of non-existent by-pass flow. This is shown in Figures 15 and 16.

Figure 13*: Temperature profile for the block without changing the central channel.*

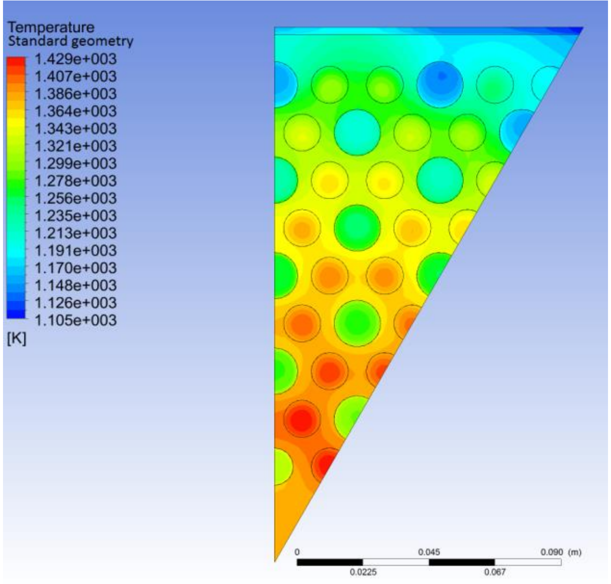


Figure 14: *Temperature profile for the block with the change of the central channel.*

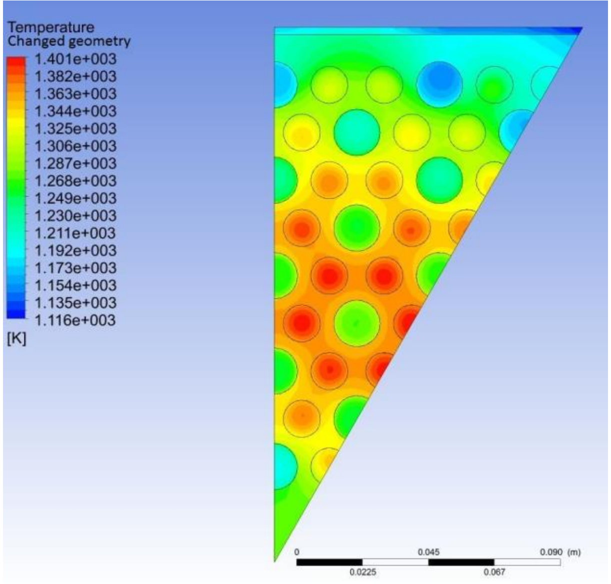


Figure 15: *Temperature in the fuel channels, unchanged geometry***.**

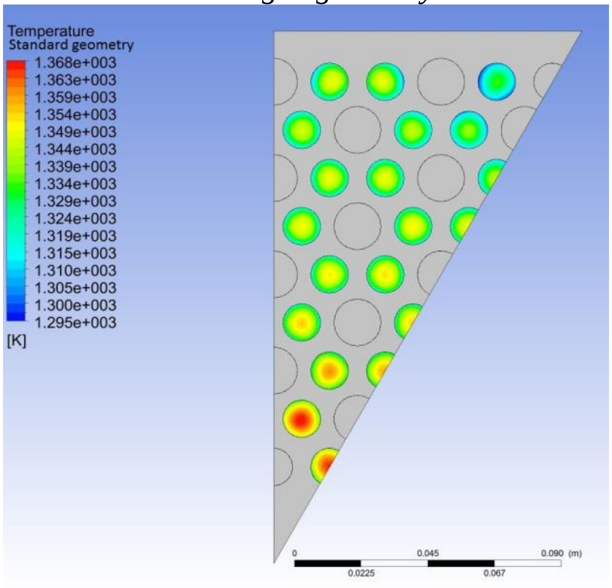


Figure 16: *Temperature in the fuel channels, changed geometry.*

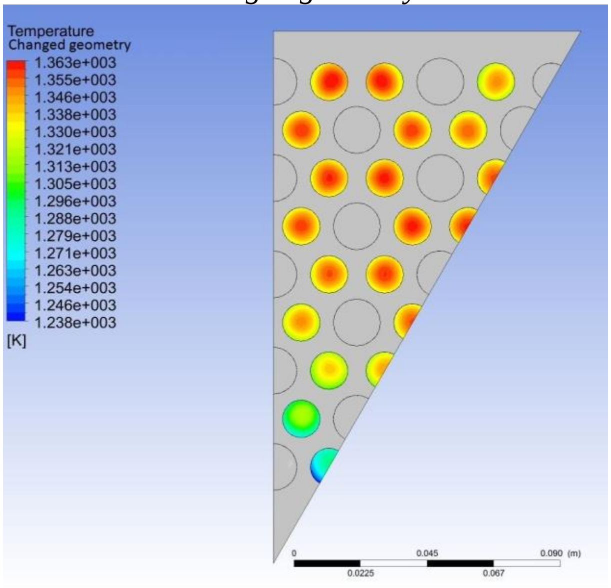


Figure 15 shows the temperature distribution in the fuel channels in the hottest section for the case of the center channel unchanged. It can be seen that, although the maximum temperature is somewhat higher than in the case shown in Figure 16, the difference between the maximum and the minimum temperature in that section in the fuel is approximately 73 K.

Figure 16 depicts the temperature distribution in the hottest section for the case where the diameter of the central channel was increased and the same total mass flow rate of 0.2 kg/s was maintained. Although the maximum temperature in the fuel is about 5 K lower than the previous case, it is observed that the difference between the highest and the lowest temperature in that same section in the fuel is about 125 K.

3.4. Influence of the Heat Flow to the Reflectors on the Heat Transfer Coefficient

The Nusselt number calculated along the coolant channels decreases in the direction of fluid flow. The gas mixture occurring at the inlet of the heated section increases the local turbulent heat transfer coefficient. The helium flow, when it enters the active core of the reactor, is not fully developed. When the Nusselt number ceases to be a function of the location, there we have the fully developed flow. The Nusselt number drop is linear along the channel, not varying with position, except in the inlet and outlet regions.

In the entrance region, there is the natural effect of the gas mixture, which greatly increases the heat transfer coefficient; however, in addition, there is another factor that contributes to change the Nusselt number in this region, which is the heat flux to the upper graphite reflector. In the case of channel inlet, the heat flux to the upper reflector decreases the effect of gas mixing on the heat transfer coefficient.

Similar effect occurs in the region of exit of the active core of the reactor. Although there is no mixing as there is at the entrance, heat flows to the lower graphite reflector. As thermal energy flows to the lower reflector, less energy is supplied to the coolant channels in the vicinity of the active core outlet, and hence, as the average temperature of the fluid and the temperature of the internal face of the graphite do not suddenly drop, the heat transfer coefficient decreases, which directly reflects the Nusselt number.

In order to ascertain the importance of the effect of heat transfer to the reflectors, and to analyze the hypothesis that the Nusselt number was altered for this reason, we performed computational simulation with a geometry practically identical to the standard used in the other numerical experiments, with a 5 mm wide by-pass channel, the only difference being the imposition of boundary conditions on the upper and lower faces of the fuel element (at the edges of the active core with the upper and lower reflectors) as adiabatic surfaces.

With this consideration, it was possible to ascertain the behavior of the helium gas flow through the coolant and by-pass channels and the temperature distribution in the system in the case where there was no thermal energy flow to the upper and lower reflectors.

It was verified that in the entrance and in the exit of the channel the effect of the heat flux to the reflectors does not influence significantly the global parameters of the system, since the change of the heat transfer coefficient in the channels occurs for this effect only in channel length equivalent to its diameter, i.e. less than two centimeters at the entrance and at the exit.

Figures 17, 18 and 19 show that the value of the heat transfer coefficient, and consequently of the Nusselt number, is influenced by the heat flux to the reflectors. The heat flux to the upper and lower reflectors corresponds to about 0.5% of the thermal energy generated in the fuel.

Figure 17: *Nusselt number along the coolant channel for the standard case and for the case where the upper and lower faces of the active core are adiabatic.*

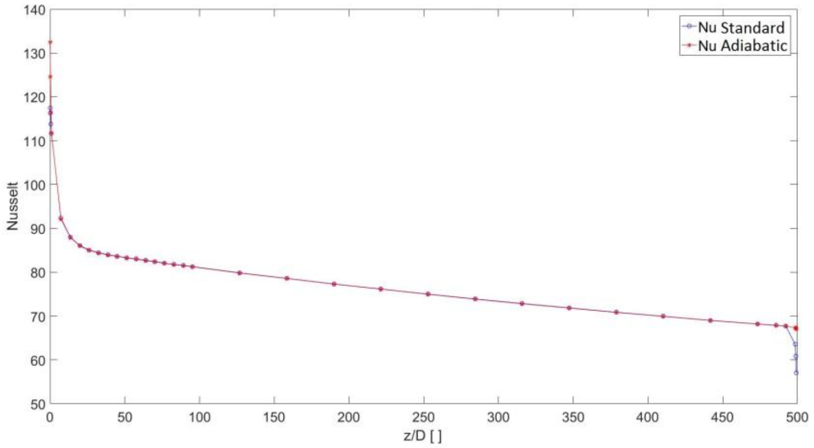


Figure 18: *Nusselt number along the coolant channel entrance, in which it is observed the influence of the heat flux to the upper reflector.*

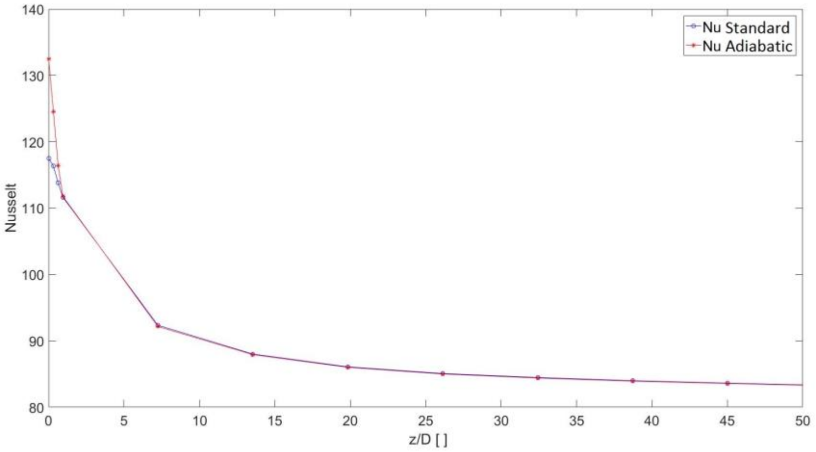
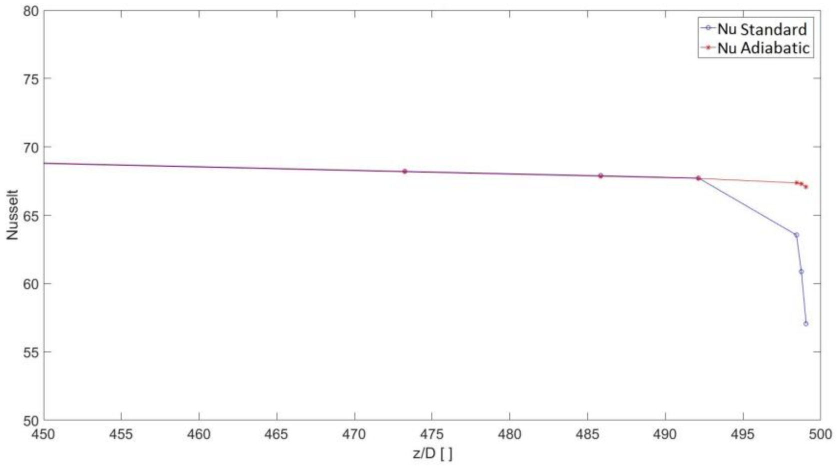


Figure 19: *Nusselt number along the coolant channel exit, in which it is observed the influence of the heat flux to the lower reflector.*



4. CONCLUSIONS

Based on the computational experiments that were performed in the present study, some conclusions were reached. Among these, we highlight:

1. The by-pass flow produces a significant change in the temperature distribution in the VHTR core. The higher the flow through this channel, the higher the temperature gradient in the materials that compose the active core of the reactor, with the higher temperature being closer to the center of the element and the cooler at the periphery of the fuel block, in the region adjacent to the by-pass channel. This fact raises questions concerning the safety of the reactor, since a significant increase of the flow through these interstitial spaces can lead to the occurrence of hotspots, eventually exceeding the temperature limits usually accepted for normal operation of the reactor.

Furthermore, the high temperature gradient transverse to the channels' direction induces a large difference in the outlet temperature of the fluid in the coolant channels, causing the temperature of certain channels to be so high that it can cause structural damage to the lower plenum of the reactor. It is also desired that this coolant fluid is well mixed as it exits the lower plenum so as not to cause malfunctions in downstream equipment such as turbines and heat exchangers.

2. The thermal energy generation with sinusoidal profile, when the unitary radial factor is applied, provides temperature distribution throughout the structure similar to the temperature distribution that occurs for the case of the uniform energy generation profile, with only a slight drop in the maximum temperature reached in the former case.

When the peak radial factor is applied to the sinusoidal profile, however, the temperature in the structure rises sharply and at certain points exceeds the temperature limit for normal operation of the reactor.

The heat transfer coefficient in the channels does not show significant change when the power generation profile changes. In fact, when comparing the values of this coefficient for the cases of uniform generation and sinusoidal generation profile, with a unitary radial factor, the maximum difference observed is 0.5% in the entrance region, while along the channel, after the entrance region, this difference drops to 0.2%.

3. It was tested the hypothesis that the temperature gradient observed in a cross-section of the fuel block is decisively due to the smaller diameter of the cooling channels located in the center of these blocks. This temperature gradient is characterized by higher temperatures in the center of the block and colder temperatures in its periphery. A simulation was carried out in a structure with a central channel with the same diameter as the other cooling channels and it was confirmed that in this case there was inversion in the direction of the temperature gradient, causing the higher temperatures to be located in the periphery of the fuel blocks and lower temperatures in the center of these blocks. Also, the difference between the highest and the lowest temperature in the section increased for the case of the modified structure.

4. Heat conduction to the upper and lower reflectors, although it promotes a change in the Nusselt number curve at the entrance and exit of the channels, does not significantly affect the heat transfer parameters of the system, since the influence of this heat conduction is in a very small region of the channels, being limited to about 2 cm in the entrance and exit of the channel.

The conclusion should bring the main points of the article, reflecting the problem statements and the objectives. The conclusion can also summarize the implications of your findings and suggest further researches.

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