Study Thermohydraulic a Fixed Bed for Core of Nuclear Reactor

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Abstract: The fixed beds have the advantage of large heat transfer area, for they are used in some designs of innovative nuclear reactors as the reactor FBNR. Inside of study of fixed beds is important to define the following parameters: flow minimum and velocity profile of cooling fluid, temperature profile of cooling fluid and the fuel elements. In order to determine the parameters before described the Software COMSOL Multiphysics® was used, the geometry was established in 3D for core of nuclear reactor, and for termohydraulic study modules used were heat transfer, conjugated heat transfer and flow. In this study was considered to nuclear fuel spheres as heat sources, the cooling fluid used in the simulation was water and the type of study was stationary. The study of termohydraulic parameters is important to establish safe operating conditions to verify that the thermal limitations of the materials involved in the reactor core are not exceeded.

Keywords: Fixed Bed, Heat Transfer, FBNR, Nuclear Reactor.

1. Introduction

Faced with the growing demand of energy of world population, nuclear energy captures attention because is secure, competitive and does not produce greenhouse gases, there more covered the 15 % of demand the electricity worldwide in 2015[1][2].

Since 2000 until today so as to potentiate the inclusion of nuclear energy in the energy matrix, are being developed new concepts of nuclear reactors, known as nuclear reactors of fourth generation, through which seeks to improve the efficiency of heat transfer in comparison with reactors of previous generations, therefore the importance of thermohydraulics study of fixed beds has like advantage their larger surface area of heat transfer in the reactor core [3][4][5]. Under this concept are being developed the reactor FBNR (Fixed Bed Nuclear Reactor).

1.1 Description of Nuclear Reactor FBNR

The fixed bed nuclear reactor, FBNR bases its operation in pressurized water reactors (PWR). Has a small size (2m in diameter and 6 m high) compared to PWRs, generates an output of 70 MW, is modular in design, it does not require refueling site, since it can operate long periods with fuel loaded in the factory building and has an inherent safety system. All these features allow the reactor FBNR be part of the IAEA in the INPRO program, because it meets the requirements set for nuclear reactors of fourth generation, security and economic profitability [6][7][8].

The FBNR reactor is a research proposal of PhD. Farhang Sefidvash, fundamentals and technology of this reactor is public domain and is currently in the study phase.

The graphic representation of the FBNR can be seen in the Figure 1 [9].

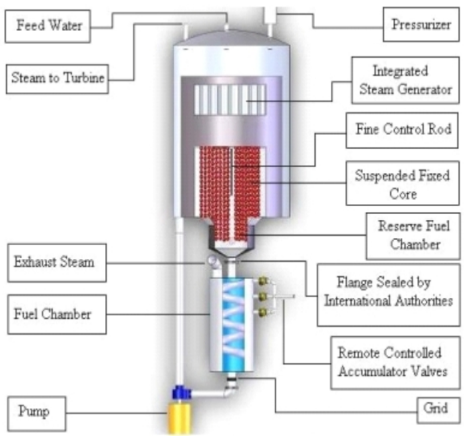

Figure 1. Schematic Design of FBNR

In the design of FBNR are identified 3 modules, with a specific and independent function which are: the core, the steam generator and the fuel chamber.

1.2 Core of Nuclear Reactor FBNR

According to the design proposed by Sefidvash F., the reactor core is constituted by a cylinder 1.71 m in diameter and 2 m high, the fuel spheres are inside forming a fixed bed, through which pressurized water circulates, the water acts as cooling fluid, which also ensures that heat removing the materials from which the fuel elements do not melt, the refrigerant ascends through the core and is recirculated to operate in a closed circuit [10].

The fuel elements are based on High Temperature Gas Cooled Reactor (HTGR) technology, in which the fuel elements are spherically shaped. Fuel spheres are made with CERMET, this material is characterized by the high temperature resistance.

The spherical CERMET fuel consists of coated UO2 kernels embedded in a zirconium, or zirconium hydride, matrix which is then overcoated with a protective outer fuel-free layer [11].

The Table 1. shows the values of the physical and thermal properties CERMET material used in the present study [12].

Table 1. CERMET properties

Properties	Temperature 300°C
Thermal Conductivity	28.2 W/m°K
Specific Heat	431 J/kg.°K
Density	6940 kg/m^3

2. Use of COMSOL Multiphysics® Software

In this section is described as COMSOL Software modules that were used, the required steps to create the model for core of the reactor FBNR, the initial conditions and established considerations for simulation

2.1 Modules of COMSOL Software used in the simulation

2.1.1 Entrance to simulation interface

- Select the wizard modeling
- Select 3D Model
- Select module conjugate heat transfer within this module select laminar flow section
- Select stationary study

2.1.2 Model Creation

Model creation is done in the geometry module by performing the following steps:

- Definition of material, choose the material (water) from the library of Software for the cooling fluid and create a new material for the spheres (CERMET) entering the thermophysical properties described in Table 1.
- In the CAD module, create the cylindrical container of the bed and create the spheres placing them in their respective coordinates according to the required structure BCC and FCC

2.1.3 Multiphysics study

- Select one of the circular faces of the cylinder and in the section laminar flow create a condition of entry that corresponds to the workflow and temperature input, output condition corresponding to the output
- Select the spheres and in the section of heat transfer in solid, creating a heat source, which should indicate the overall transfer rate which corresponds to the value of the total power

2.1.4 Meshing

- In the module meshing create a normal mesh
- In the study section place the value of 200 iterations and an error range of 20

2.1.5 Results

- In the results module select the data set
- Create lines and planes in the CAD model to later extract data
- Select show graphics
- Import data from lines and planes created in TXT format.

2.2 Considerations for the simulation

The considerations for the simulation were:

- Steady State Study
- Types of fixed bed structures: BCC and FCC

▪ Thermo physical properties of the materials involved remain constant
▪ There is no phase change
▪ There uniform heat generation in the particles that make up the fixed bed

2.2 Initial Conditions

The initial conditions established by Sefidvash F. are shown in Table 2 [13].

Table 2. Initial conditions for simulation of core of FBNR

Initial conditions	Value
Inlet temperature	290 °C
Heat generation	134.4 W per sphere
Inlet Pressure	16 MPa

3. Experimental Results

3.1 BCC Configuration

The nuclear fuel in the form of spheres can support a maximum temperature of 3113 ° K. This fundamental parameter in the simulation because the critical temperature points are located in the central part of the fixed bed, as shown in Figure 2.

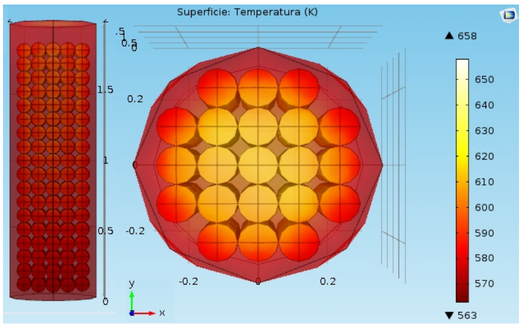

Figure 2. BCC configuration

3.1.1 Temperature of spheres

The critical area analysis is in the middle of the bed is therefore important to know what happens to each area along the bed length, the Figure 3 shows the status of the spheres at different flow.

3.1.2 Temperature of fluid

Spheres transferred heat energy to the fluid, this enters with a temperature of 563 ° K, the outlet temperature of the fluid is important because this is then studied for the design of the heat exchanger. The energy that wins the cooling fluid of the spheres is represented in the below Figure 4.

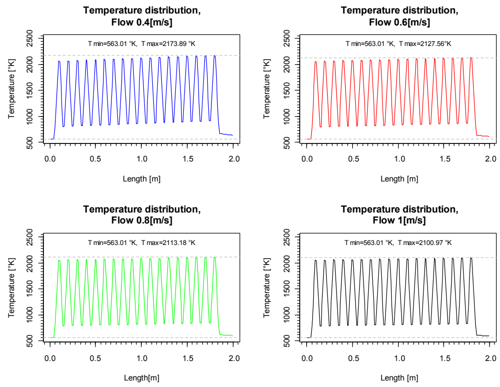

Figure 3. Temperature of spheres in BCC configuration

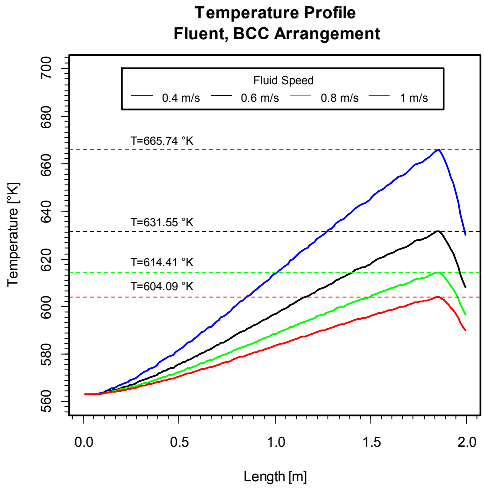

Figure 4. Temperature of fluid in BCC configuration

3.1.3 Pressure

BCC arrangement has greater porosity because in this type of bed more open spaces, this parameter helps determine the pressure drop that the reactor core may have, the pressure curves are shown in the following Figure 5.

3.2 FCC Configuration

FCC conditions mentioned in accordance BCC are valid in the FCC arrangement. The following

Figures 6, 7, 8, 9 helps visualize is happening in the reactor core.

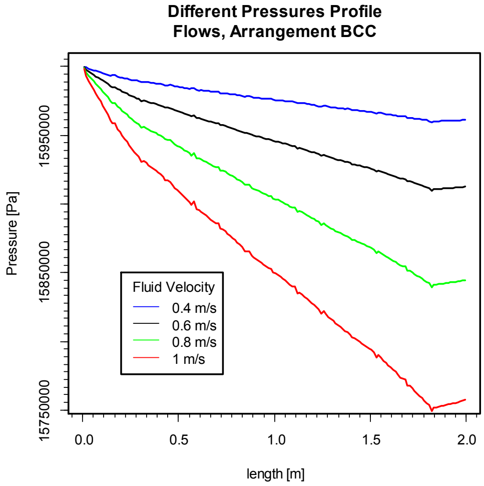

Figure 5. Pressure in BCC configuration

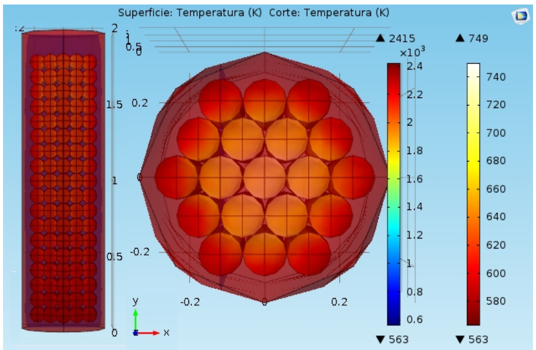

Figure 6. FCC configuration

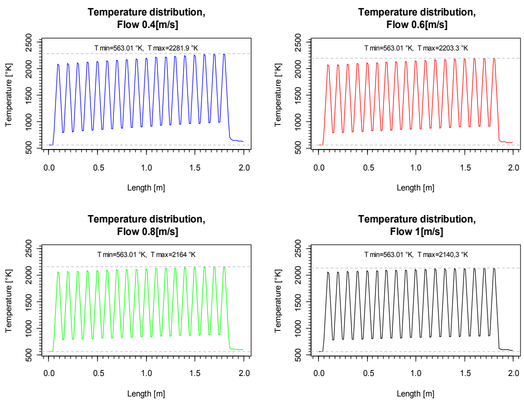

Figure 7. Temperature of spheres in FCC configuration

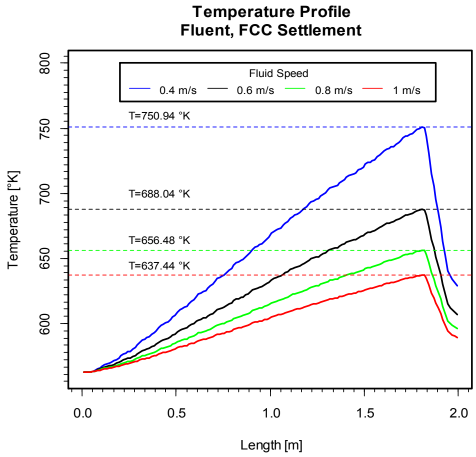

Figure 8. Temperature of fluid in FCC configuration

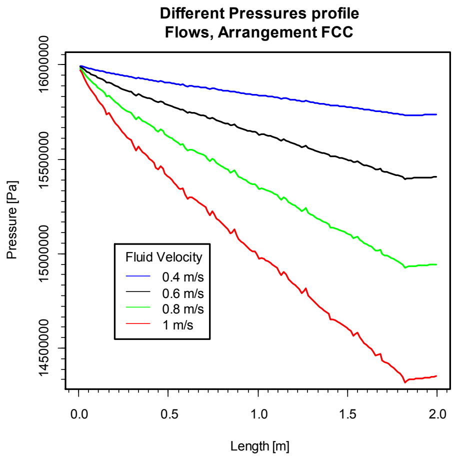

Figure 9. Pressure in FCC configuration

4. Discussion

Figure 10 shows that there are points where the fluid stagnates and as a result those points higher concentration generate heat this happens for both FCC and BCC arrangement. Comparing Figure 10 with Figure 2 and 3 must points having lower speed higher temperature acquired, this is because the convection coefficient at these points is small. This phenomenon helps determine until temperature can reach areas in all flows presented the interior temperature of the area does not exceed the maximum working.

As shown in Figures 5 and 9 the pressure drop is very small and increases with the fluid velocity. The ideal design parameter is 0.6 m / s because pre hydraulic designs consent to be used a pump with features of 16000000 Pa and 0.6 m / s. With these parameters fluid temperatures and areas under safe working parameters, shown in Figures 3 , 4, 7, 8 decreased fluid velocity will cause the spheres acquire larger temperatures implying increased monitoring reactor core.

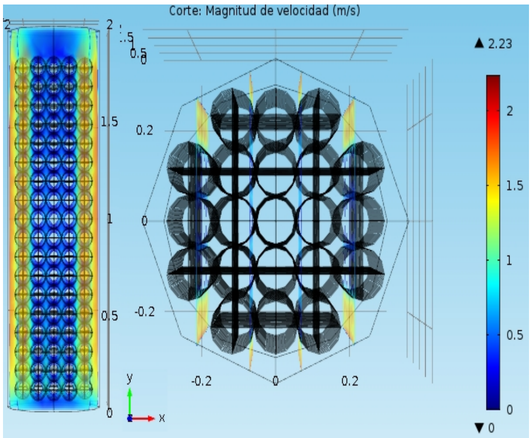

Figure 10. Graphic of velocity

As seen in Figure 11 the arrangement BCC has lower pressure drop and higher heat concentration which is beneficial for the cooling fluid. Figures 3, 4, 7, 8 shows that the arrangement BCC is more stable and easier to create a traceability control each of the areas along the bed, it benefits the periodic maintenance and analysis and material control nuclear which is operational. Create a BCC arrangement is less costly than an FCC arrangement.

5. Conclusions

- BCC arrangement is more stable than the FCC arrangement has greater benefits to the cooling fluid, Traceability control of each of the areas of nuclear material increases compared the FCC.
- BCC configuration having higher porosity has a lower pressure drop compared to the FCC structure, this causes reduction of energy loss in the operation of recirculation pumps predesigned.

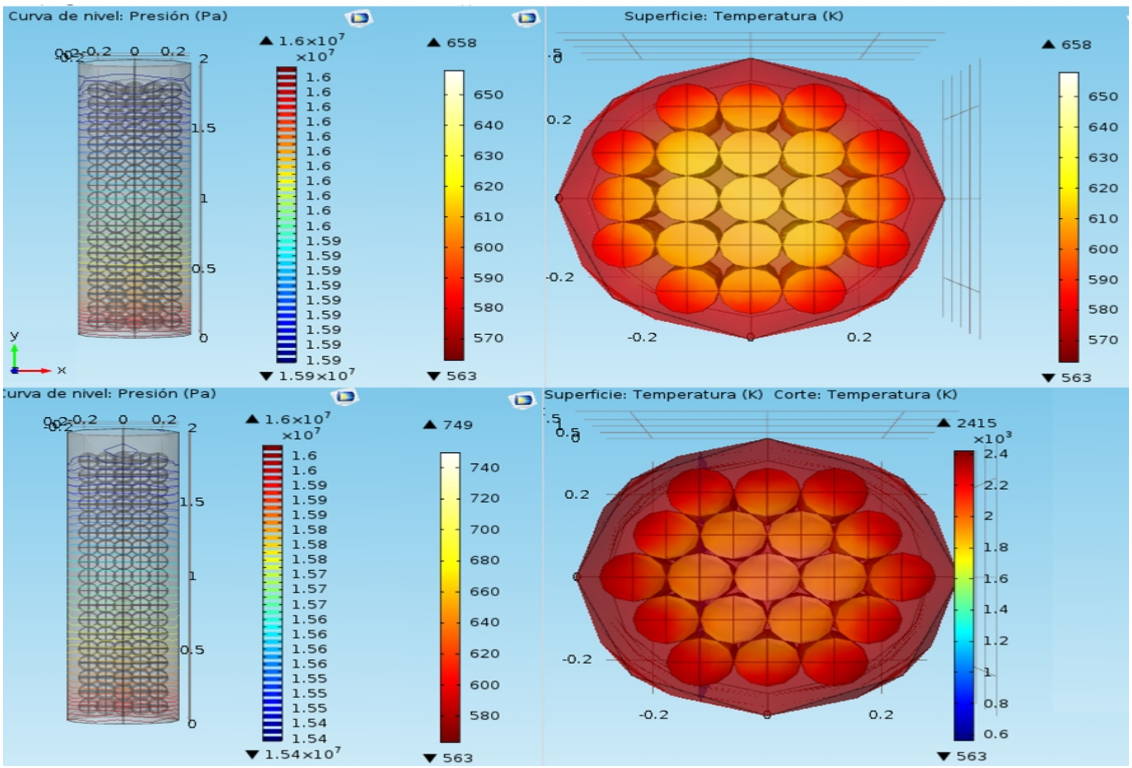

Figure 11. Pressure drop and Temperature for BCC and FCC configuration

Pressure parameters are initial conditions of the simulation for determining the temperature profile both fluid and spheres.

- In all cases both under FCC and BCC nuclear material does not exceed the limit operating temperature as long as the fluid velocity is between 0.4 and 1 m / s, if the fluid velocity decreases can raise the temperature of the spheres and creating an unstable and dangerous system.

- This type of analysis by simulation with COMSOL allows evaluate, correct and improve designs without creating highly costly prototypes, simulation time in each of the cases had an average of 5 hours, the interactive interface that COMSOL presents excellent since you can see the convergence of the results in real time and make the necessary corrections to improve results

- The data obtained in this paper will used to set the required parameters in the study of neutronic in nuclear material present in the Fixed Bed Nuclear Reactor. Such studies can be performed with other modules of COMSOL multiphysic offers, remaining well as future work to study this type of physical phenomenon.

- The stability of treatment and data acquisition COMSOL is robust, it allows linking several physical phenomena in the same time interval thus reducing costs and post processing simulation data. Whether the graphic presentation and interactive design makes this software unique when simulate geometries with different metaphysical robust interactions.

6. References

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