CFD ANALYSIS OF CALANDRIA BASED NUCLEAR REACTOR: PART-II. PARAMETRIC ANALYSIS OF MODERATOR

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Abstract

Nuclear power is an economical technology for extenuating environmental alteration and can make a considerable influence to environment safety. A nuclear power plant is a thermal power station having the primary heat source as a nuclear reactor. In the previous work, the study of modelling and analysis of temperature distribution of Moderator in Calandria of Nuclear Reactor was carried out. The study included the complete understanding of the design of Calandria and how moderator carried out the heat from calandria. . The Temperature distribution was validated with actual working conditions. Various factors play a vigorous role in the designing of Calandria and their effect on the Moderator needs to be studied effectively. In the present work, the parametric analysis of moderator is carried out to observe the temperature distribution within the Calandria of Nuclear Reactor.

Keywords: *Calandria, CANDU Reactor, Moderator, CFD Analysis, Parametric Analysis, Temperature Distribution*

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1. INTRODUCTION

A nuclear power plant is a thermal power station in which the heat source is a nuclear reactor. As it is typical in all conventional thermal power stations the heat is used to generate steam which drives a steam turbine connected to a generator which produces electricity. A nuclear reactor is a device to initiate and control a sustained nuclear chain reaction in a nuclear power plant.

All nuclear reactors operate on the same basic principle, although there are different kinds of nuclear reactors in use throughout the world. A nuclear power station design in Canada, known as the CANDU reactor, uses a calandria reactor core which is based on the use of heavy water, or deuterium, and natural uranium fuel. The core of a CANDU reactor is contained in a large, horizontal, cylindrical tank called a "calandria" which contains the heavy water moderator. Several hundred fuel channels run from one end of the calandria to the other. Each channel has two concentric tubes [1].

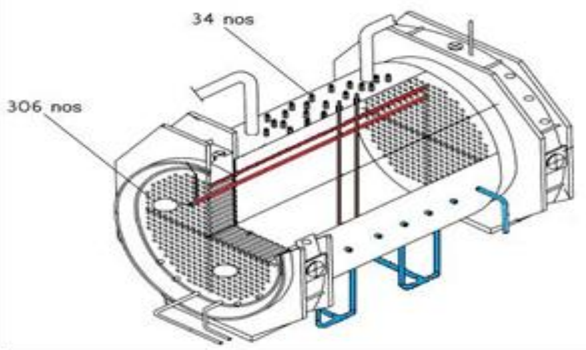

Fig 1: Sectional View of Calandria

As shown in Fig 1, the tubes in red color show calandria tubes, in which fuel bundles are kept. The rods in brown color show control rod using for absorption of neutrons as per requirement. Horizontal blue pipes are inlet of moderator and vertical blue pipes are outlet. Calandria is isolated at both ends using end shield due to radioactivity. The whole assembly of coolant tubes and control rods is submerged in moderator.

Moderator is a medium that reduce the speed of first neutrons, thereby turning them into thermal neutrons capable of sustaining a nuclear chain reaction. The fuel, in the form of bundles of rods containing uranium pellets, is inserted into the pressure tubes by remotely operated fuelling machines, which can function while the reactor is operating [2].

2. MODERATOR

Moderation is the process of reduction of the initial kinetic energy of free neutron. As energy is conserved, this reduction of the neutron kinetic energy takes place by transfer of energy to a material known as a moderator. It is also known as neutron slowing down along with the reduction of energy, comes a reduction in speed.

Moderator is a medium that reduces the speed of fast neutrons, thereby turning them into thermal neutrons capable of sustaining a nuclear chain reaction involving uranium-235. Moderators consist of nuclei which are light and don't absorb neutrons. The neutrons hit the moderator and bounce off but in the process they lose a little energy. After enough such bounces, the neutrons are no faster than expected from their temperature [3].

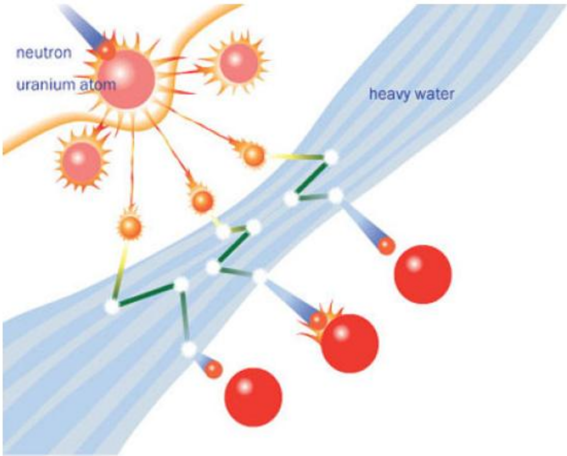

Fig 2: Principle of Moderator

When the temperature of Moderator increases above 90 ^{0}C, the rolled joint at both the ends of calandria tube expands. Due to higher pressure of circulating De-Mineralized (DM) Water, it leaks out through expanded rolled joint and mixes with Heavy water. Increase in temperature and pressure of moderator is dangerous hence, it is important to maintain temperature up to 90 ^{0}C [4].

Commonly used moderators are regular water, solid graphite & heavy water.

3. RESEARCH METHODOLOGY

Three combinations of control rods positions with different flow-rate of moderator are considered for parametric analysis.

a. Control-rods position at 60 %, 70 % and 80 % of total depth of calandria
b. Flow rate of moderator 20 kg/s, 50 kg/s and 100 kg/s.

The universal technique for resolving each case for 3-D simulation problem in ANSYS WORKBENCH is mainly divided into 4 steps.

Fig 3: Steps for simulation

3.1 Geometrical Modelling for Different Positions of Control Rods in Calandria

The model of Calandria discussed in the paper is utilized for a 220 MW capacity Nuclear Power Plant. The geometries at various positions of control rods in calandria are created by using Creo-Parametric Software.

The measurements of geometry for each case are given in table 1.

Table 1: Geometrical features

Sr. No	Parameter	Dimensions (in mm)
1.	Calandria diameter	6046
2.	Calandria length	4159
3.	Coolant channel diameter	107.7
4.	Center-center distance	228.6
5.	Moderator inlet/outlet pipe diameter	200
6.	Control rod diameter	70

The geometries for different positions of control rods in calandria are shown in Fig 4.

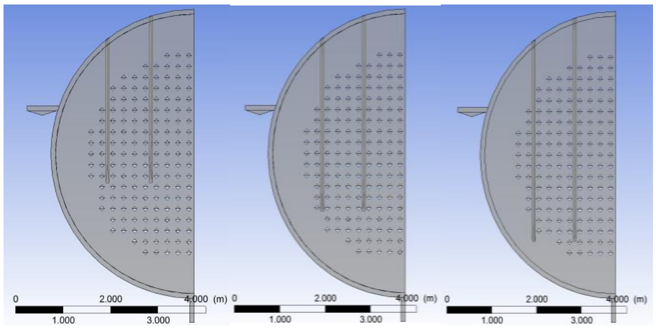

Fig 4: Different positions of control rods in calandria

3.2 Meshing of Volumes

After geometrical modeling, meshing of the inner volume for each combination is carried out with meshing specifications shown in the table 2 given below:

Table 2: Mesh Specifications

Sr. No	Particulars	Significance
1.	Meshing Method	Unmapped
2.	Type of elements	Tetrahedrons
3.	No: of Nodes (as per geometry)	150000 - 200000
4.	No: of Elements (as per geometry)	800000 - 100000

The figure 5 given below shows one of the meshed volumes of the Calandria out of the three cases as per the meshing specifications.

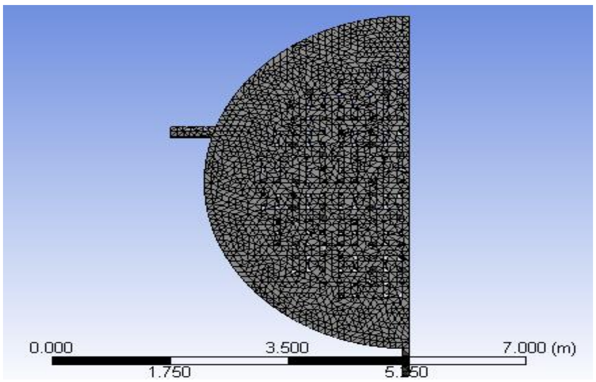

Fig 5: Meshing of moderator volume in calandria

3.3 Setup

3.3.1 Assumptions for Parametric Analysis

In order to perform parametric analysis of the moderator various assumptions need to be established as follows [1]:

1. Heat produced by 306 tubes is assumed to be uniform throughout the length.
2. Heat produced by all the tubes is assumed to be the same throughout the calandria.
3. Neutron flux density is assumed to be uniform throughout the calandria.

3.3.2 Properties of Fluid and Solid

The properties of fluid as well as solid used for simulation are as per the tables given below [1].

Table 3: Fluid Properties

Sr. No	Property	Value
1.	Fluid	Heavy Water
2.	Density	1104.36 Kg/m^3
3.	Specific Heat	1.6907 J/Kg K
4.	Thermal Conductivity	0.595 W/m K
5.	Viscosity	1095 Kg/m s

Table 4: Solid Properties

Sr. No	Property	Value
1.	Material	Zircolay 2
2.	Density	6560 Kg/m^3
3.	Specific Heat	0.285 J/Kg K
4.	Thermal Conductivity	21.5 W/m K

3.3.3 Boundary Conditions

In order to accomplish parametric analysis, several boundary conditions need to be applied to each of the geometry. Hence, boundary conditions as shown in Fig 6 are applied to the design [5].

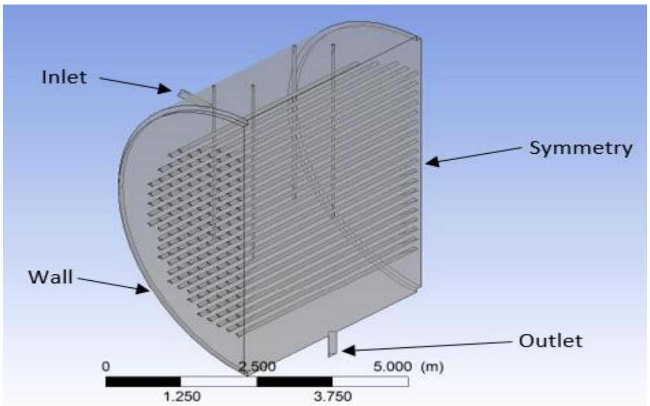

Fig 6: Boundary Conditions

The values of each of the boundary conditions considered for the given design is depicted in table 5.

Table 5: Boundary Conditions

Boundary Conditions	Particulars
Inlet	Temperature = 328 K
Outlet	Backflow total Temperature = 300 K
Coolant Tubes	Temperature = 341 K Heat Transfer Co-efficient = 7.879 W/m^2 K Free Steam Temperature = 300 K

3.4 Solution

For a moderator mass flow rate of 20 Kg/sec, the temperature distribution in Calandria is obtained as shown in the following figures.

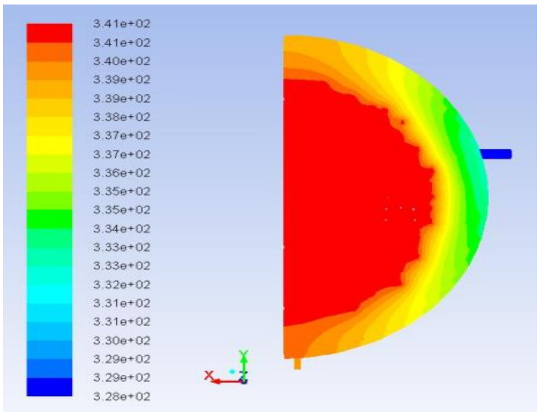

Fig 7: Temp distribution in Calandria for control rod position 60 % of total depth

As shown in the above Fig 7, the moderator temperature at the inlet of Calandria is found to be 328.65 K, heat generated at the center of the Calandria, is carried by the moderator and thus, moderator temperature at the outlet of the Calandria is raised to 339.87 K.

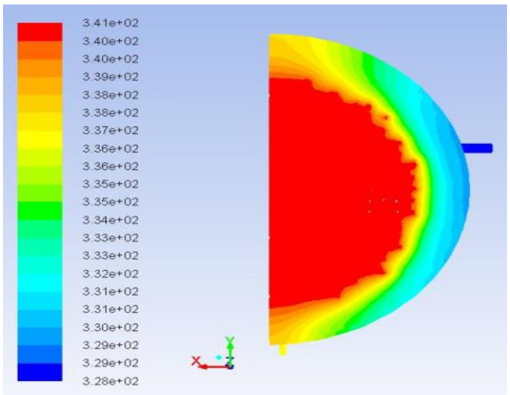

Fig 8: Temp distribution in Calandria for control rod position 70 % of total depth

From the above figure, it is clearly seen that the moderator temperature at the inlet of Calandria is 328.65 K, and moderator temperature at the outlet of the Calandria is obtained to be 339.86 K.

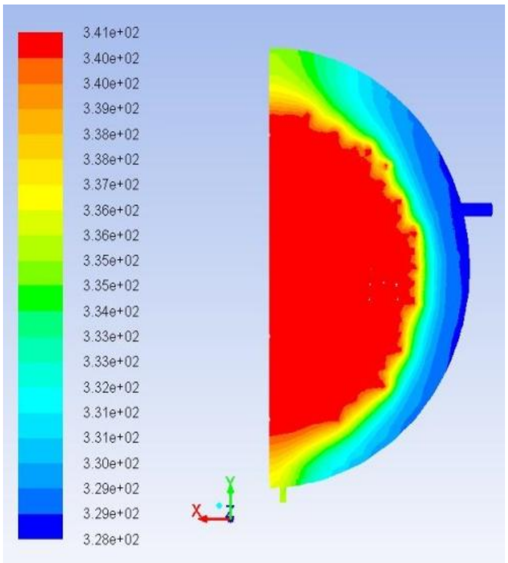

Fig 9: Temp distribution in Calandria for control rod position 80 % of total depth

As is markedly noticeable from the above figure, the moderator temperature at the inlet of Calandria is found to be 328.66 K, heat generated at the center of the Calandria, is carried by the moderator and thus, moderator temperature at the outlet of the Calandria is raised to 339.92 K.

From the above observations, it is seen that the average outlet temperature of Calandria for a moderator mass flow rate of 20 Kg/sec is 339.87 K.

Similarly, simulations were carried out for 50 Kg/sec and 100 Kg/sec in which the average outlet temperature of Calandria was found to be 337.12 K and 335.8 K respectively [7].

The figure given below summarizes the inlet and outlet temperatures of Calandria for various flow rates.

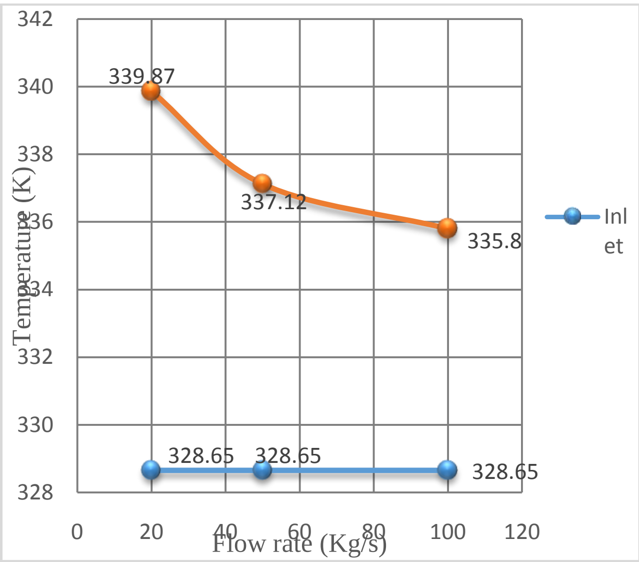

Fig 10: Summary of Temperature distribution in Calandria

4. CONCLUSIONS

The actual outlet temperature of moderator of Calandria with the flow rate being 20 Kg/sec is found to be 338 K [6], whereas obtained through simulations is 339.86 K. Thus giving a deviation of 0.55 % [1].

The parametric analysis of moderator was carried out with a purpose to demonstrate the effect of mass flow rate and control rods positions on the temperature distribution within the Calandria. It is found that an increase in the flow rate of moderator results in a decrease of the average temperature of Calandria.

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