Heat Transfer And Fluid Flow Analysis Of Pressure Tube In Candu 6 Nuclear Reactor Using Supercritical Water

Lakshmana Kishore.T [#1], Dr. Kiran Chaudhari [*2], Dr. G. Ranga Janardhana [#3]

[#1]Assistant Professor of Mechanical Engineering, JNTUK University College of Engineering, Vizianagaram
[*2] Professor of Mechanical Engineering, MCT's Rajiv Gandhi Insitute of Technology, Mumbai
[#3] Professor of Mechanical Engineering, JNTUA University college of Engineering, Anantapuramu

Abstract — *The heat transfer and fluid flow analysis of the pressure tube in the primary circuit of CANDU 6 nuclear reactor is performed by using Supercritical fluids (SCF's) as working fluid. Currently available CANDU 6 nuclear reactor uses heavy water as the working fluid in the primary circuit. In order to increase the heat transfer and for better performance, supercritical fluids (SCF's) are selected as the working fluid. The supercritical fluid used is water (H_2O). Heavy water is used as the moderator. The pressure tube of the reactor is modelled and analysis is performed using ANSYS-CFX. The solution of the problem is validated using working fluid as heavy water. The pressure drop, velocity variations and the various factors affecting the heat transfer are analysed for the supercritical fluid selected and comparison is made between them.*

Keywords — *CANDU 6, Super Critical Fluids (SCF's), Pressure Tube, Nuclear Reactor*.

I. Introduction

The CANDU 6 Nuclear Reactor is using Heavy Water as the working fluid. In this paper the pressure tube of the Nuclear Reactor is studied using Supercritical Water as the working fluid. The dimensions of the pressure tube taken, are same as that of the CANDU 6 Nuclear Reactor.

A. CANDU 6 Nuclear Reactor Pressure Tube:

CANDU 6 is the Generation III, 700 MW class heavy-water moderated and cooled pressure tube reactor. Heavy water (D_2O) is a natural form of water that is used as a moderator to slow down the neutrons in the reactor, enabling the use of natural uranium as fuel. Same D_2O is used as the working liquid, responsible for transportation of heat. The dimensions used in the analysis is taken from [1] and [2].

B. Supercritical Fluid:

Supercritical fluid is any substance at a pressure and temperature above its critical point, where distinct liquid and gas phases do not exist. Supercritical fluids combine useful properties of gas and liquid phases. Their behavior is near gas from some aspects and near liquid in terms of different features. A supercritical fluids provides a gas like characteristic when it fills a container and it takes the shape of container. The motion of molecules are quite similar to gas molecules. On the other hand, a supercritical fluid behaves like a liquid because its density property is near liquid and, thus supercritical fluid shows a similarity to liquid in terms of dissolving effect. The formation of a supercritical fluid is the result of dynamic equilibrium.

When a material is heated until its specific critical temperature in a closed system, which means at constant pressure, a dynamic equilibrium is generated. This equilibrium includes the same number of molecules coming out of liquid phase to gas phase by gaining energy and going into liquid phase from gas phase by losing energy. At this particular point, the phase curve between liquid and gas phases disappear and supercritical material appears.

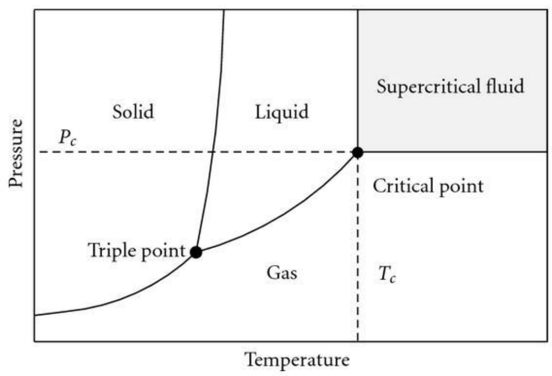

Fig 1: Pressure Vs Temperature for a supercritical fluid

In the phase diagram, the field above critical temperature and critical pressure values is defined as supercritical region. The characteristic properties of a supercritical fluid are density, diffusivity and viscosity. Supercritical values for these features take place between liquids and gases

II. Modelling of the Pressure Tube

From [1] the dimensions of the pressure tube of the CANDU 6 Nuclear Reactor is modelled using CATIA V5. The pressure tube contains 12 fuel bundles and each fuel bundle contains 37 fuel rods. The modelled fuel bundle is shown in the figure

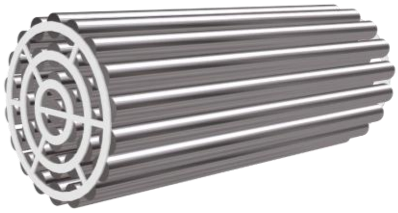

Fig 2: Modelled Fuel bundle in CATIA-V5

The modelled pressure tube is imported to ANSYS-CFX for the analysis using different fluids.

III. Validation of the Problem

The pressure tube imported is solved in ANSYS-CFX using Heavy Water as the working fluid and compared with the existing results [3]. The property values of the Heavy Water taken and the boundary conditions applied are taken from [1] and given in table 1 and 2.

Property	Value
Molar Mass (g/mol)	20.0276
Critical Temperature (K)	643.89
Critical Pressure (MPa)	21.67
Critical Volume (cm^3/mol)	56.3
Acentric Factor	0.364
Boiling Point (K)	374.57

Table 1: Properties of Heavy Water

Boundary Condition	Value
Operating Pressure (MPa)	10.5
Outlet Pressure (MPa)	0
Mass Flow inlet (kg/s)	23.9
Inlet Temperature (K)	539.15
Heat Flux (per bundle) (MW)	9.6

Table 2: Boundary conditions for the pressure tube using Heavy water

The ANSYS-CFX result using Heavy Water matches well with the existing results. The comparison and the error percentage is given in table 3.

A. For one fuel bundle (12th bundle):

Property	Values from analysis	Values from [3]	Error Percentage
Inlet Pressure (MPa)	11.0529	11.04	0.117
Outlet Temperature (K)	586.975	583.15	0.656
Density at Inlet (kg/m^3)	795.607	782.9	1.62
Density at Outlet (kg/m^3)	699.442	692.4	1.017

Table 3: Comparison of outlet parameters for validation

With reference to the above table present model is considered to be validated.

IV. Analysis using Supercritical Water

The validated model of the pressure tube is now used to do the analysis using Supercritical Water as the working fluid. The property values of the Supercritical Water is taken from [4].

The property values which are given as input in ANSYS-CFX is represented in table 4.

Property	Value
Molar Mass (g/mol)	18.01528
Critical Temperature (K)	647.096
Critical Pressure (MPa)	22.064
Critical Volume (cm^3/mol)	55.9
Acentric Factor	0.3443
Boiling Point (K)	373.1243

Table 4: Properties Supercritical Water

The boundary conditions applied for the analysis are given in table 5.

Boundary Condition	Value
Operating Pressure (MPa)	25
Outlet Pressure (MPa)	0
Velocity Inlet (kg/s)	5.83622
Inlet Temperature (K)	623.15
Heat Flux (per bundle) (MW)	9.6

Table 5: Boundary conditions for the pressure tube using Supercritical water

The model is solved using UPWIND Scheme.

V. Results

After the completion of the analysis for the convergence criteria of 1e-07, the results are compared with results of the analysis using D_2O as the working fluid and the following graphs are drawn with respect to the length of the pressure tube.

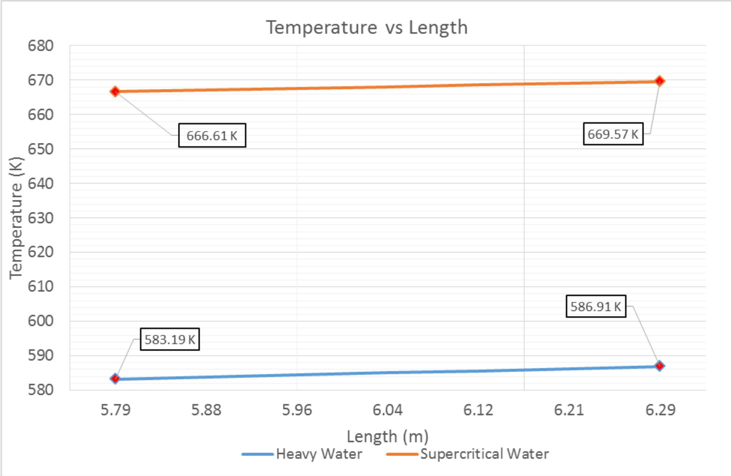

Fig 3: Graph between Temperature Vs Length for the 12th bundle

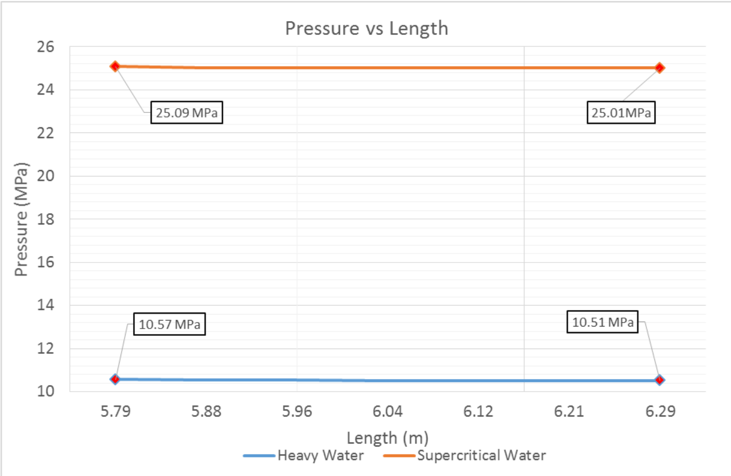

Fig 4: Graph between Pressure Vs Length for the 12th bundle

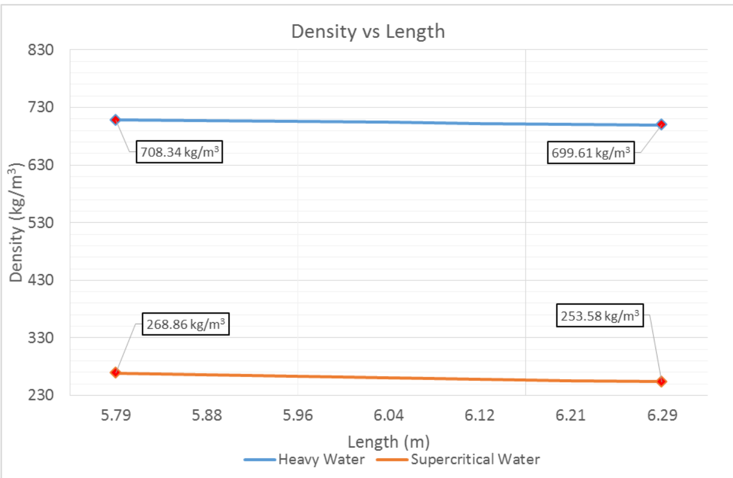

Fig 5: Graph between Density Vs Length for the 12th bundle

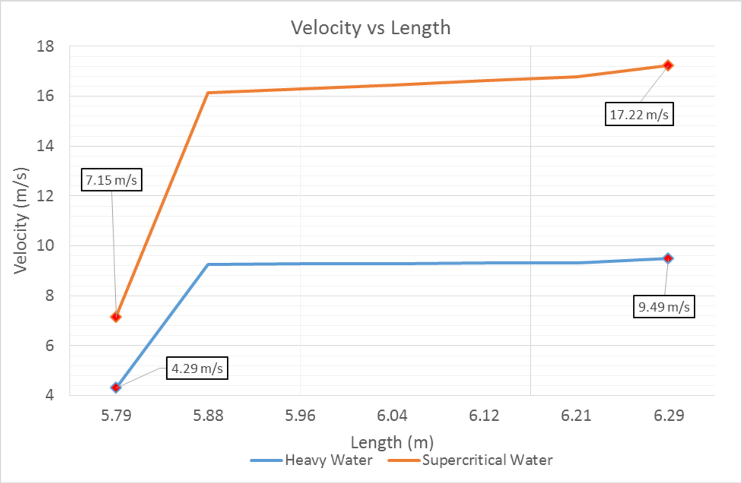

Fig 6: Graph between Velocity Vs Length for the 12th bundle

B. *For the total pressure tube:*

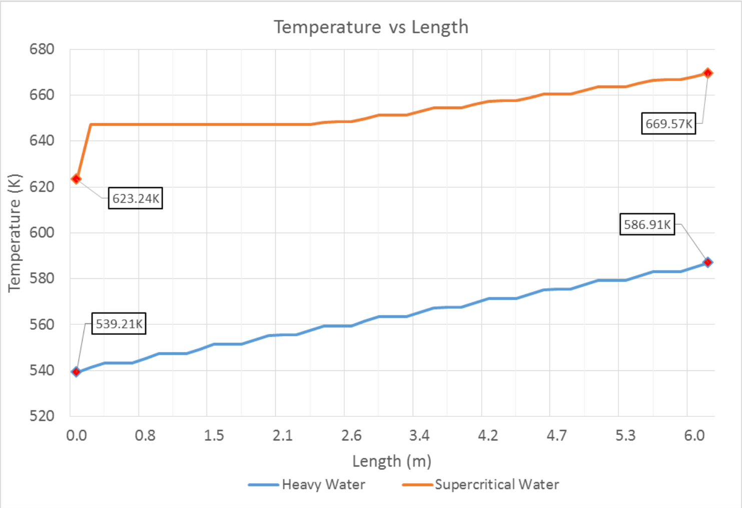

Fig 7: Graph between Temperature Vs Length for the total pressure tube

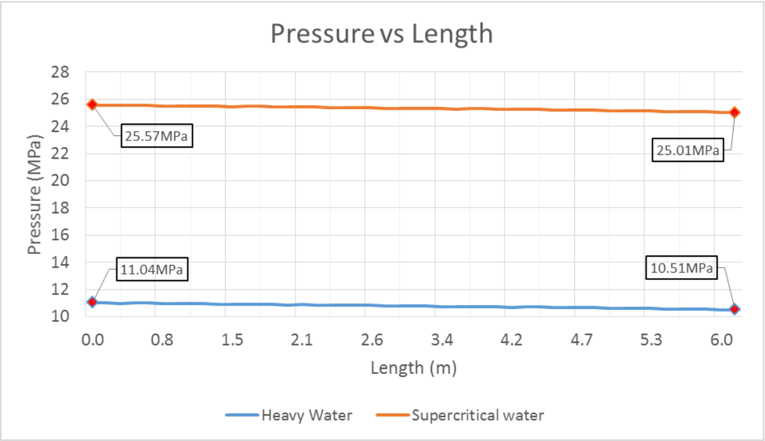

Fig 8: Graph between Pressure Vs Length for the total pressure tube

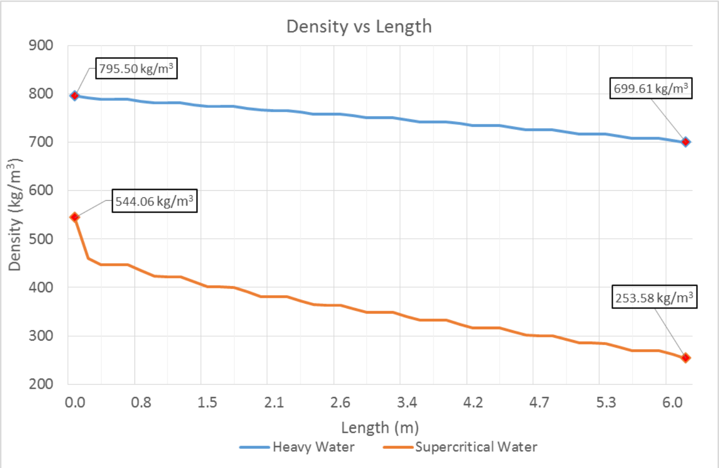

Fig 9: Graph between Density Vs Length for the total pressure tube

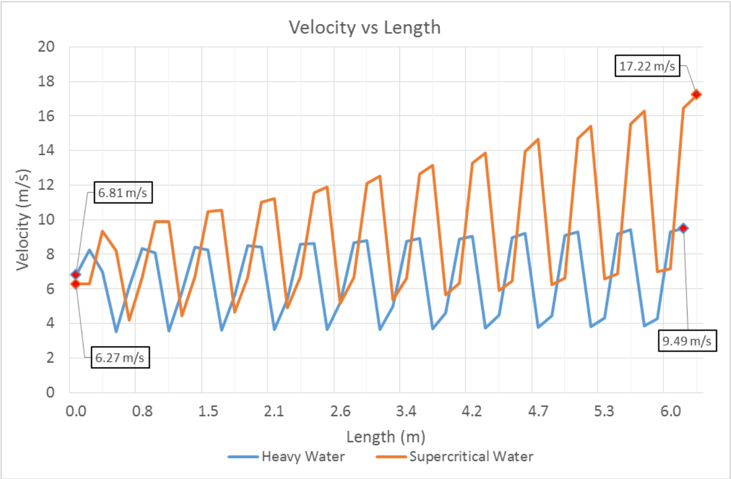

Fig 10: Graph between Pressure Vs Velocity for the total pressure tube

C. Variation of different properties for the pressure tube using Supercritical Water:

For the total pressure tube some of the properties variation are plotted with respect to the length of the pressure tube. These plots are here by shown.

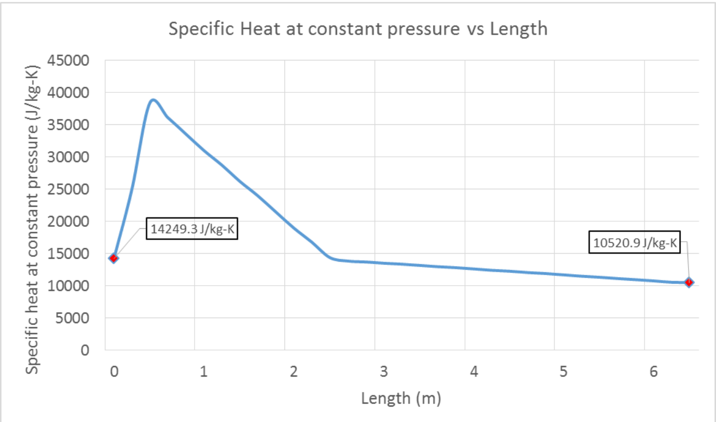

Fig 11: Graph between Specific heat Vs Length for the total pressure tube

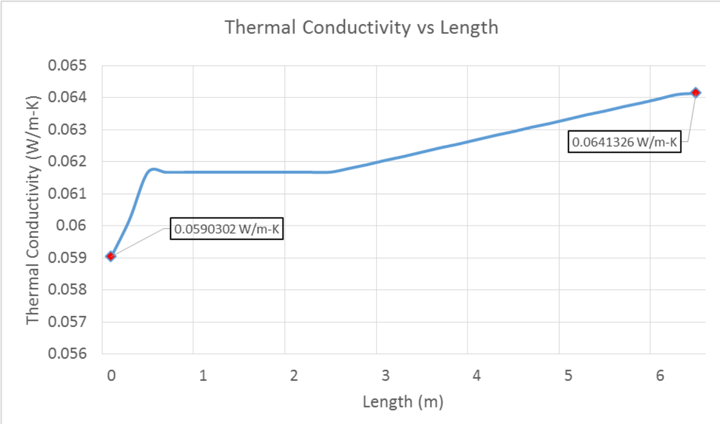

Fig 12: Graph between Thermal conductivity Vs Length for the total pressure tube

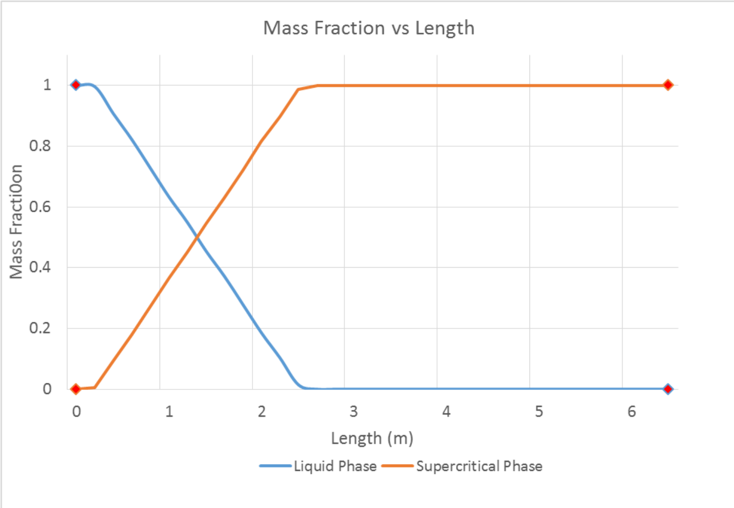

Fig 13: Graph between Mass fraction Vs Length for the total pressure tube

VI. CONCLUSIONS

The model of the pressure tube of CANDU 6 Nuclear Reactor created in CATIA V5 is validated with very less error percentage.

With reference to the analysis using Supercritical Water as the working fluid, more amount of heat transport is done when compared to Heavy Water as the working fluid. In effect the capacity of the Nuclear Reactor can be increased for more power generation.

Even though more pressure to be controlled using Supercritical Water when compared to Heavy Water mass flow rate of the working fluid is getting reduced for the same inlet velocity. So Supercritical fluids show a vast scope of research in future nuclear reactors.

REFERENCES

[1] Wm. J. Garland, *"A text book on the CANDU Nuclear Power Plant Technology", The Essential CANDU*, ISBN 0-9730040.

[2] Dr. Robin Chaplin, *"Genealogy of CANDU Reactors,"* The Essential CANDU, Chapter 2,ISBN 0-9730040, Dec., 2016.

[3] Chun K. Chow, and Hussam F. Khartabil, "CONCEPTUAL *FUEL CHANNEL DESIGNS FOR CANDU-SCWR*,"Nuclear Engineering and Technology, vol.40, Special issue on the 3rd International Symposium on SCWR, Nov. 15, 1999.

[4] NASA Polynomial format for CHEMKIN-II, GRI-Mech Version 3.0 Thermodynamics released 7/30/99.

[5] Alexandru CATANA, Ilie PRISECARU, Daniel DUPLEAC, and Danila NICOLAE, "*COMPUTATIONAL FLIUD DYNAMIC APPROACH FOR CANDU6 AND ACR1000 FUEL CHANNEL COOLANT FLOW*," ISSN 1454-2358, U.P.B. Sci. Bull., Series D, Vol. 72, Iss. 1, 2010.

[6] K. Podila, Y.F. Rao, *"CFD analysis of flow and heat transfer in Canadian supercritical water reactor bundle,"* ELSEVIER, 2014.