3-Dimensional Fluid Dynamics Analysis Of Bypass Flow In Sub-Channel With Crept Pressure Tube By Aged CANDU Reactor

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1. Introduction

The fuel-channel including bundles in the CANDU reactor determines the power and efficiency of reactor. It is one of the major components associated with the safety issues on CANDU. The fuel-channel operates under extreme conditions such as high temperature high pressure. Those conditions cause more accidents and they are generally connected with the safety of nuclear plants. The fuel-channel accidents can be divided into two kinds: creep and sag. Creep accidents are also classified into the length creep and the diameter creep. Our research aims at the diameter deformation of pressure tube without sag.

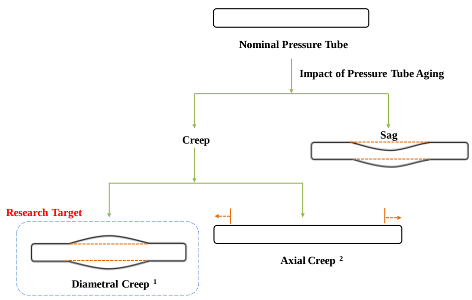


Fig 1 Pressure Tube Deformation and Research Aim

2. Main Geometry Variables Generated By the Design Parameters of Pressure Tube and Bundle of the CANDU Reactor

Mass flow rate is a main variable to decide Reynolds number. It is determined by the design parameters of a real fuel channel in the CANDU reactor. Reynolds number of flow in pressure tube is divided into two categories: one category is the low and medium turbulence and it has the range of ~50*10; the other one is high turbulence and its range is from $10*10^3$ to $550*10^3$ [1]. Reynolds number of inlet part is $56*10^3$ which considered the laboratory conditions.

Table. I. Main Variables Derived from the Fuel Channel Parameters of Wolsong 2, 3 and 4

Wolsong 2, 3 and 4	Main Variables
D_c = 0.103378 [m]	$\dot{m}$ = 4.55 [kg/s]
D_f = 0.01310 [m]	$\dot{Q}$ = 273 [L/min]
$D_e = 7.50x10^{-3}$ [m]	V_i = 0.545 [m/s]
	V_m = 1.34 [m/s]

Flow area, effective diameter, and dynamic viscosity were inferred from the working conditions of Wolsong 2, 3 and 4. In Table 1, main variables are derived from the design parameters of the fuel channel in Wolsong 2, 3 and 4. Average velocity and inlet area are also determined in the same manner. Table 2 shows the main variable comparison of Wolsong 2, 3 and 4 with the acrylic pipes.

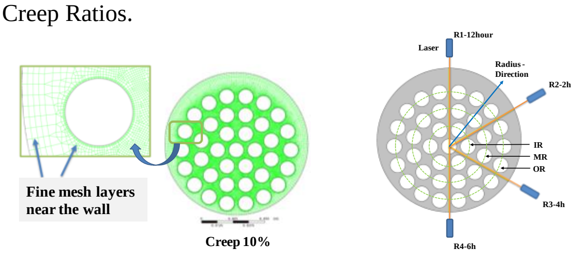
Table. II. Main Variable Within Acrylic Pipes

	Wolsong 2,3,4	Acrylic pipes.
Common	$Re = 10*10^3$ in sub-channel $\dot{m}$ = 4.55 [kg/s] $\dot{Q}$ = 273[L/min]	
Design	D_c= 103.4 e^{-3} [m] D_f = 13.1e^{-3} [m] D_e= 7.50e^{-3} [m]	D_c=104 e^{-3} [m] D_f =12.0 e^{-3} [m] D_e= 9.80 e^{-3} [m]
Derived Values	V_m =1.34 [m/s] V_i =0.545 [m/s]	V_m =1.08 [m/s] V_i =0.541 [m/s]

3. CFD analysis

Mesh is generated for the purpose of flow dynamic analysis in the sub-channel with various crept pressure tubes. We assume that the bundle is not deformed. Fig 2 shows the diameter deformation of pressure tubes with various creep ratios such as 0%, 5% and 10%. IR stands for inner ring, MR middle ring and OR outer ring.

Fig 2 Positions of Bundle in Pressure Tube With Various Creep Ratios.



(a) (b)

Fig 3 (a) Mesh for CFD, (b) Monitoring Positions

Boundary mesh is made of fine mesh for velocity distribution on wall. Nuclear channels have repeatedly the same structure of bundles in the pressure tube, and the shapes of pressure tube and bundle are formed by extrude mesh. Mesh densely formed near the entrance is given to simulate the inlet velocity. Data of mass flux is generated at your 2, 4, 6 and 12 o'clock. The lasers will be installed at the same directions mentioned above. Fig 3 shows the mesh and the observation positions.

4. Results

The X-axis of the graph is divided into r_y and r_{-y} and the unit is cm. r_y is the direction of increasing radius from the center rod at your 2 and 12 o'clock. r_{-y} is the direction of increasing radius from the center rod at your 4 and 6 o'clock. The Y-axis of the graph is mass flux and the unit is Kg/m^2s. In figures 3, 4, and 5, the bypass flow of pressure tube affects the mass flux in the sub-channel at your 2, 4, 6 and 12 o'clock.

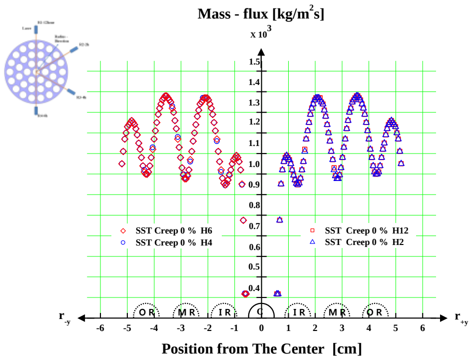


Fig 4 Prediction of Mass Flux Analysis at your 2, 4, 6 and 12 O'Clock in Pressure Tube with Creep Ratio 0%

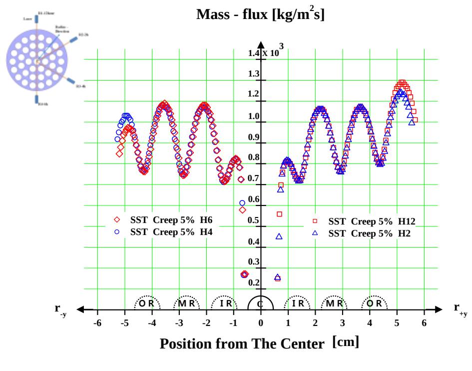


Fig 5 Prediction of Mass Flux Analysis at your 2, 4, 6 and 12 O'Clock in Pressure Tube with Creep Ratio 5%

In the case of creep ratio 0%, Mass flux is higher in the area between IR and MR and between MR and OR than the other areas of the sub-channel. In addition, the peripheral center rod can be seen from the lowest among other areas in the sub-channel. In the case of creep ratio 5%, mass flux is higher in the outer part of the bundle at your 2 and 12 o'clock by increasing diameters of pressure tube. According to increasing creeps ratio, Mass flux is higher outside part of bundle at your 2 and 12 directions which is increased by diameter of pressure tube with creep ratio 10%. This result makes the region of maximum mass flux to move to the outside of OR region and the value of mass flux between IR and OR is decreased.

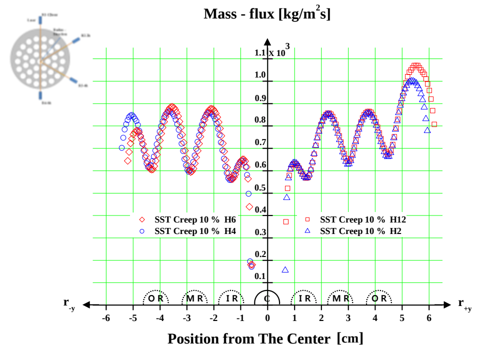


Fig 6 Prediction of Mass Flux Analysis at your 2, 4, 6 and 12 O'Clock in Pressure Tube with Creep Ratio 10%

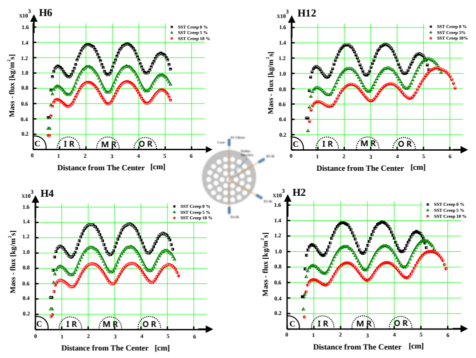


Fig 7 Prediction of Mass Flux Analysis at your 2, 4, 6 and 12 O'Clock with Creep Ratios 0%, 5% and 10%

5. Conclusion

Although the complexity of the entire bundle makes it difficult to observe the flow in the sub-channel and the bypass flow pressure tube with high turbulence, we obtained the possibility of using visualization methods. And we also gained the quantification of mass flux of bypass region and sub-channel. This research provides insight about the minimum region of mass flux in terms of fuel's cooling efficiency. Further, we come up with experimental equipment, measure mass flux in sub-channel and bypass flow by Particle Image Velocimetry (PIV) method, and compare CFD with the data from the Experimental method.

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Acknowledgment

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[1] P.K Vijayn, D.S. Pilkhwal, D. Saha, V. Venkat Raj, "Experimental studies on the pressure drop acreoss the various components of a PHWR fuel channel", Experimental Thermal and Fluid Science 20, pp34~44, (1999)