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# The effect of helical geometry on two-phase flow in a helical tube

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## 1. Introduction

Helical steam generators are being adopted worldwide as steam generators for advanced reactors. Light water small modular reactors such as SMART and i-SMR in South Korea and NuScale in U.S have also adopted helical steam generators to solve both high compactness and the requirement of in-service inspection. However, helical steam generators are known to produce superheated steam by boiling inside the tube, which can cause two-phase flow instability. The U.S. nuclear regulatory commission (USNRC), withheld final approval of the safety of helical steam generators for NuScale with respect to two-phase flow instability, during the standard design approval process [1].

The flow in a straight tube and the flow in a helical tube significantly differ from each other due to centrifugal and torsion forces acting on the fluid induced by the geometry [2]. For a single-phase flow in a helical tube, a secondary flow in the form of circular trajectory of water or steam can be observed as shown in Fig. 1. Furthermore, if two-phase flow occurs in a helical tube, water and steam are separated by the centrifugal force creating an interface different from a straight tube case without centrifugal force.

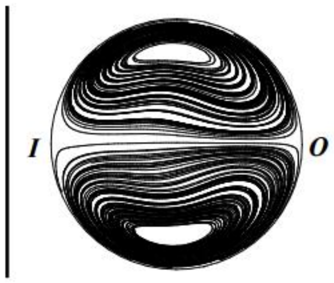


Fig. 1. Streamlines of the secondary flow in a helically-coiled tube [3]

Therefore, the authors have previously evaluated the pressure drop and flow shape of two-phase flow in a helical tube by CFD [4]. However, in the case of helical tubes, depending on the geometry factors such as the angle of the helical tube and the helical diameter, different types of two-phase flow may occur even if the tube has the same inner diameter. In this study, a CFD two-phase flow analysis was performed by changing the geometry of the previously used helical tube, which was based on the steam generator design of SMART. Based on the CFD analysis results, the pressure drop and the interfacial shape were analyzed and compared.

## 2. Methods and Results

### *2.1 Reference steam generator*

In this study, a helical steam generator for SMART, developed by KAERI in South Korea, was chosen as the reference system to evaluate the pressure drop in helical tubes. The pitch, diameter, angle, and thermal hydraulic information of the helical steam generator in SMART can be obtained from publicly available references [5,6,7].

Table I: SMART Helical SG Information

| | |
|---|---|
| Layer number | 17 |
| Helical Angle | 8.5 – 8.8 ° |
| Helical Diameter | 577 – 1297 mm |
| Helical Pitch | 280 – 600 mm |
| Tube Inner Diameter | 12mm |
| Steam Outlet Temperature | 290.5 °C |
| Steam Outlet Pressure | 5.2 MPa |
| Mass flow rate | 20.1 kg/s |

### *2.2 CFD Analysis*

The Ansys-CFX code is based on two-fluid model and calculates liquid and gas phases separately by using governing equations. The Ansys-CFX code reflects the influence of the interaction occurring at the interface between the two phases. The behavior of each phase can be simulated by solving continuity equation, momentum equation, and energy equation simultaneously [8].

- $\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho U) = 0$
- $\frac{\partial (\rho U)}{\partial t} + \nabla \cdot (\rho U \otimes U) = -\nabla \mathrm{p} + \nabla \cdot \tau + S_M$
- $\frac{\partial (\rho U h_{tot})}{\partial t} - \frac{\partial \rho}{\partial t} + \nabla \cdot (\rho U h_{tot}) = \nabla \cdot (\lambda \nabla T) + \nabla \cdot (U \cdot \tau) + U \cdot S_M + S_E$

The 1$^{st}$ layer of SG in SMART with a helical diameter of 577mm and a helical pitch of 280mm was chosen for CFD calculation as the base case. In addition to the previously analyzed helical tube, a tube with larger helical diameter (1154mm) while maintaining the same 280mm helical pitch was analyzed and compared. To minimize the boundary effects at the inlet and the outlet, a CFD analysis was carried out on a tube comprising one and half windings, and the results were used to obtain the pressure drop value for a half turn. Water and steam properties were based on saturation properties at 5.2MPa. The saturation temperature is 266.4 °C. The problem geometry is shown in Fig. 2.

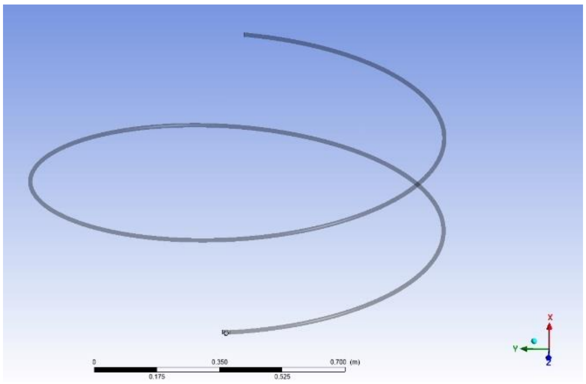

Fig. 2. Helical tube shape for CFD analysis
(Helical Diameter: 1154mm)

A structured O-grid mesh is recognized as the optimal mesh for simulating two-phase flow in tubes. To create an O-grid like mesh for the helical tube, face meshing option and multizone option were used. In addition, to replicate the flow near the tube wall surface, inflation option was used for meshing.

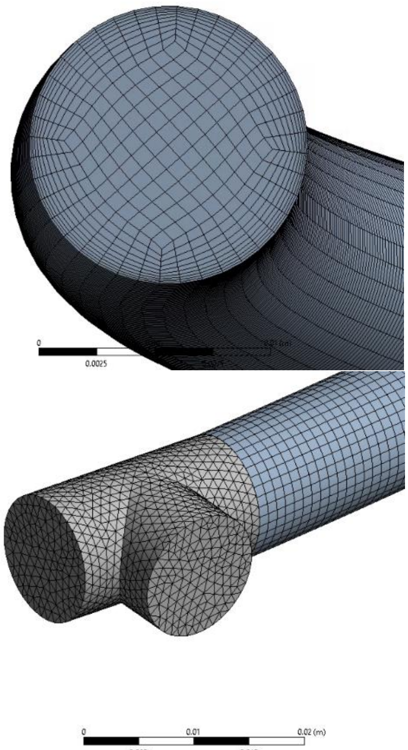

Fig. 3. Helical tube mesh for CFD analysis

Since the effect of gravity and buoyancy is also important in the CFD analysis process, the buoyancy option was used, and other CFD pre-inputs are summarized in Table II.

Table II: Mesh information and CFD pre-input

| CFD-pre Input | |
|---|---|
| Analysis Type | Steady State |
| Inlet Boundary | Mass flow rate – 0.633 kg/s (Total) |
| Outlet Boundary | Average Pressure – 5.2 MPa |
| Turbulence Option | Homogenous model<br>Shear Stress Transport |
| Wall function | Automatics in CFX |
| Heat Transfer | None |
| Turbulence Numerics | High Resolution |
| Free Surface Model | Standard |

The pressure drop curves for two helical tubes with the same pitch but different helical diameters are shown in Fig. 4. It is a well-known fact that the pressure drop in two-phase flow in a straight tube is generally larger than that of single-phase liquid flow. In this study, the analysis result shows that the pressure drop per length does not vary significantly as the helical diameter of helical tube changes.

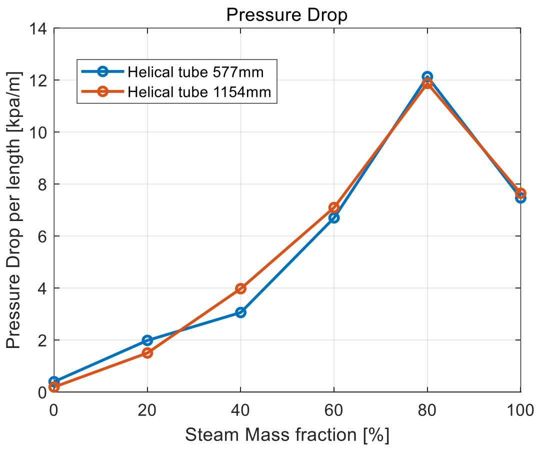


Fig. 4. Helical tube Pressure Drop by CFD calculation

Figures 5-8 present flow density cross-sectional views of two-phase flow CFD simulation results in a 577mm helical tube with varying steam mass fractions. Figures 10-13 show the results for a 1154mm helical tube varying steam mass fractions.

As a result of CFD analysis, it was confirmed that in the helical diameter 577mm tube, the water sticks to the outer wall more because the effect of centrifugal force is stronger. Also, water and steam are separated in a form similar to stratified flow. However, since in the 1154mm tube, water and vapor flow in a larger helical diameter at the same mass flow rate, the effect of centrifugal force is reduced and the effect of gravity becomes stronger. The flow is formed in the form of annular flow, where the liquid water is not only attached to the one side of wall, but distributes around the wall more uniformly.

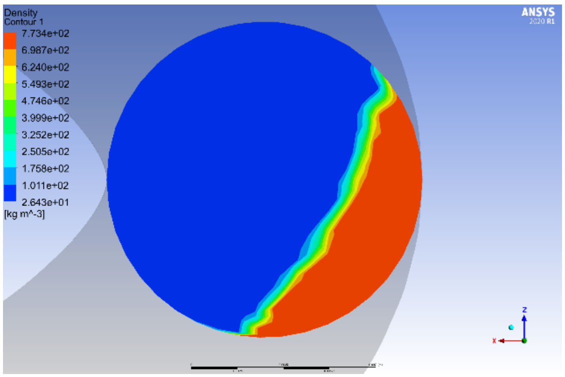


Fig. 5. Density Contour for a cross-section of a helical pipe 577mm (Mass fraction Steam 20%, Water 80%)

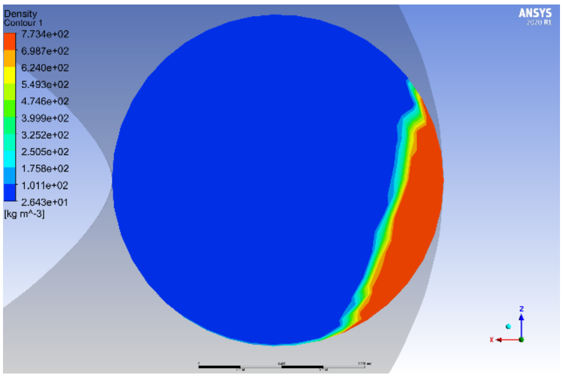


Fig. 6. Density Contour for a cross-section of a helical pipe 577mm (Mass fraction Steam 40%, Water 60%)

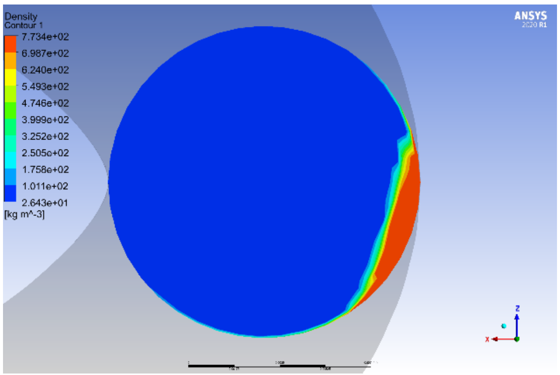


Fig. 7. Density Contour for a cross-section of a helical pipe 577mm (Mass fraction Steam 60%, Water 40%)

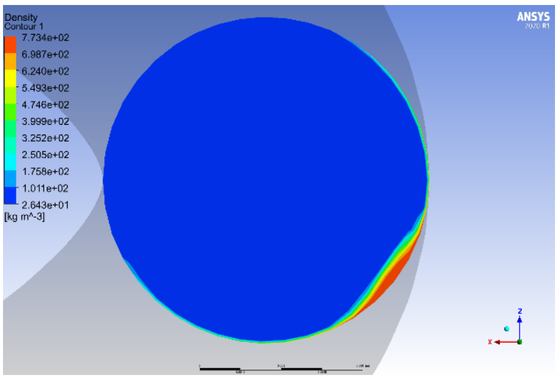


Fig. 8. Density Contour for a cross-section of a helical pipe 577mm (Mass fraction Steam 80%, Water 20%)

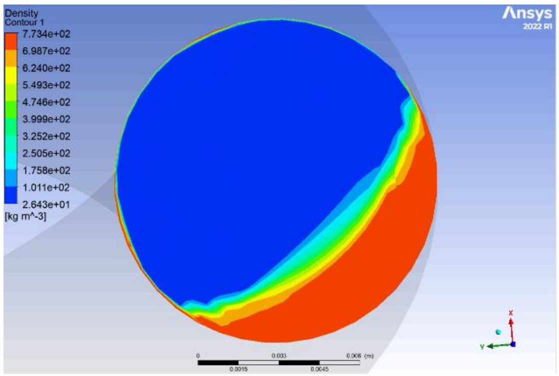


Fig. 9. Density Contour for a cross-section of a helical pipe 1154mm (Mass fraction Steam 20%, Water 80%)

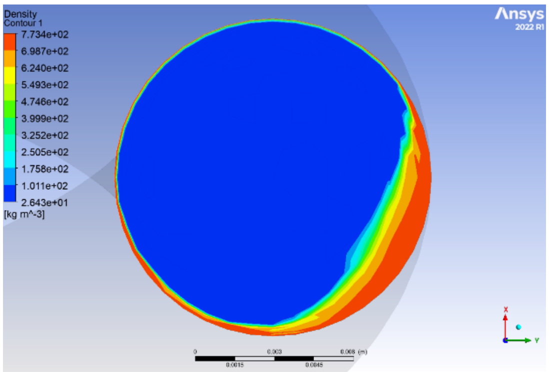


Fig. 10. Density Contour for a cross-section of a helical pipe 1154mm (Mass fraction Steam 40%, Water 60%)

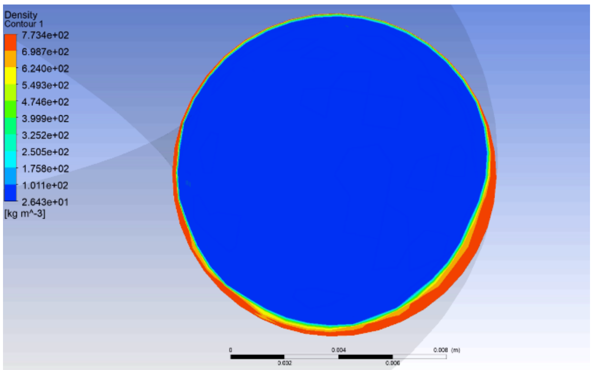


Fig. 11. Density Contour for a cross-section of a helical pipe 1154mm (Mass fraction Steam 60%, Water 40%)

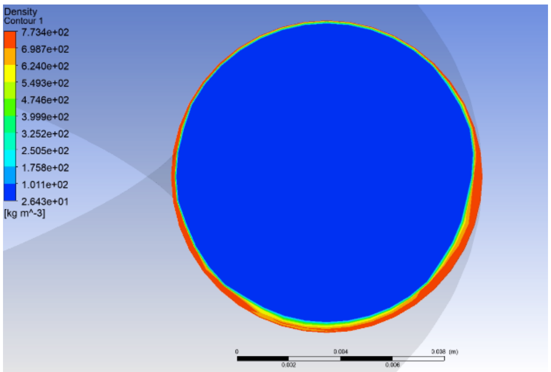


Fig. 12. Density Contour for a cross-section of a helical pipe 1154mm (Mass fraction Steam 80%, Water 20%)

## 3. Conclusions

In this study, a CFD analysis was used to analyze the pressure drop and flow distribution for helical tubes with two different geometries. The analysis was performed to observe the effect of centrifugal force on the pressure drop and the interface geometry in a helical tube. The pressure drop evaluation showed no significant difference in pressure drop values between the two analyzed helical tubes. The flow distribution showed that in the helical tube with a smaller helical diameter, the effect of centrifugal force was stronger, resulting in a form similar to stratified flow where the liquid water distribution is more skewed. For helical tubes with a larger helical diameter, when the mass flow rate of water is high, the water flows outward and downward under the influence of gravity and centrifugal force, but as the mass flow rate of steam increases, a form similar to annular flow appears, where the liquid water distributes more uniformly throughout the wall surface. From this study, it was confirmed that the two-phase flow in a helical tube can appear differently depending on the magnitude of centrifugal force. In the future, the sensitivity to other parameters will be further analyzed to further validate the currently reported results.

## ACKNOWLEDGEMENT

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