Preliminary CFD study of pressure drop in helical tube steam generator for SMR application

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1. Introduction

SMRs (Small Modular Reactors) are being actively developed to meet growing energy demands. To construct SMRs in remote areas, transport by train or truck is an important design requirement. Therefore, many SMRs adopt an integral type reactor to reduce the size, and a compact heat exchanger different from the existing U-tube heat exchanger is often utilized to reduce the size further. However, since in-service inspection of the steam generator is usually required, most developed SMRs usually choose a helical type steam generator.

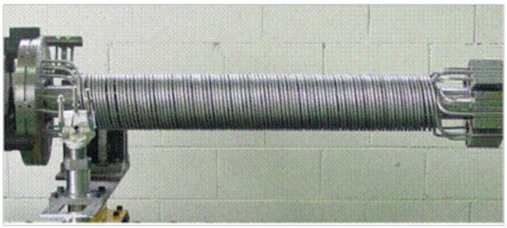

Fig. 1. SMART Helical Tubes for the SG Mock-up [1]

The flow in a straight pipe and the flow in a helical pipe significantly differ from each other due to centrifugal and torsion forces induced by the geometry [2]. In the past, the two-phase frictional pressure drop in helical pipes were investigated by many researchers. As a result of investigation, the modified Lockhart and Martinelli model was confirmed to have errors within 50% of the measured data [3]. Since, the pressure drop appears differently depending on helical tube design variables such as rotational diameter, pitch, tube diameter, and angle, in this study, before evaluating the two-phase flow pressure drop in a helical pipe, the pressure drop for a single phase in a helical pipe was first evaluated with CFD.

2. Methods and Results

2.1 Target steam generator

The target nuclear system to be evaluated for helical tube pressure drop is chosen to be SMART in this study, which is developed by KAERI in S. Korea. From the publicly available references, pitch, diameter, angle, and thermal hydraulic information of SMART helical steam generator can be obtained [4,5,6].

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 CFX Analysis

Among SMART helical SG information, the 17th layer helical pipe with a helical diameter of 1297mm, and a pitch of 600mm is chosen for the model. The geometry and the mesh are prepared with Ansys. In order to reduce the boundary effect, the helical pipe has three windings. In addition, the boundary effect is minimized by having 10D additional flow length at the inlet and the outlet boundaries. Water at 5.2MPa and 200 °C are used for the fluid.

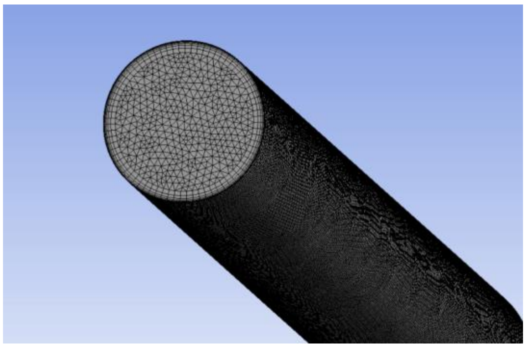

Fig. 2. 17th layer Helical pipe mesh

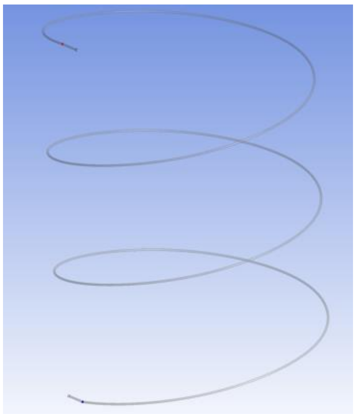

Fig. 3. 17th layer Helical pipe shape for CFD

Other input data for CFD analysis is shown in the following Table II.

Table II: CFD-pre Input

Analysis Type	Steady State
Inlet Boundary	Mass flow rate – 0.0536
Outlet Boundary	Average Pressure – 4.55MPa
Turbulence	Shear Stress Transport
Wall function	Automatic in CFX
Heat Transfer	Isothermal

In this study, the pressure drop is checked by changing the pitch while keeping the same helical diameter to observe the pressure drop changes as the pitch changes. The analysis results including straight pipe are shown Table III. Table IV shows the pressure drop per length with respect to the pitch.

Table III: Pressure Drop CFX Analysis Result

Helical Diameter [m]	Pitch [m]	Pipe Length [m]	Inlet Pressure [kPa]	Outlet Pressure [kPa]	Total Pressure drop [kPa]
1.297	0.3	12.257	5203.48	5200.03	3.45
1.297	0.6	12.356	5203.77	5200.03	3.74
1.297	0.9	12.519	5203.94	5200.03	3.91
Straight Pipe	-	12.0	5203.14	5200.03	3.11

Table IV: Pressure Drop per Length

Pitch [m]	Pressure Drop per Length [kPa/m]
0.3	0.2815
0.6	0.3027
0.9	0.3123
Straight Pipe	0.2592

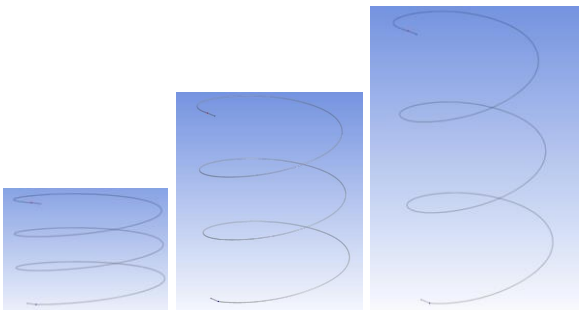

Fig. 4. Helical pipes shape according to the pitch change for CFD analysis.

It can be seen that the pressure drop is larger in the helical tube than in the straight pipe. In addition, it was confirmed that the pressure drop per length increased as the pitch increased for the same helical diameter. As a result of CFD analysis in Fig.5, it can be confirmed that the secondary flow occurred inside the helical pipe, which induces additional energy dissipation due to viscous effect.

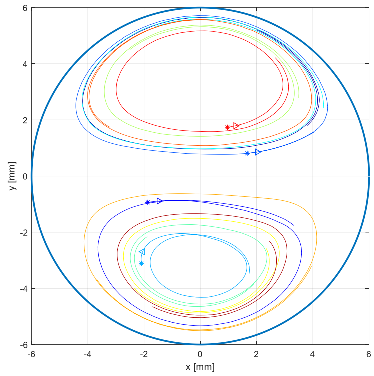

Fig. 5. Helical Tubes Secondary Flow

3. Conclusions

Previously, studies on the pressure drop of helical pipes were mainly performed by fixing the pitch and changing the helical diameter. In this study, the pressure drops in the helical pipe are evaluated by fixing the helical diameter and changing only the pitch. It is confirmed that the pressure drop of the helical pipe is measured to be 10-20% higher than that of the straight pipe. The number of cases will be further increased and two phase flow pressure drop will be also studied in the future.

ACKNOWLEDGEMENT

This work was supported by the Nuclear Safety Research Program through the Korea Foundation of Nuclear Safety (KOFONS), granted financial resource from the Nuclear Safety and Security Commission (NSSC), Republic of Korea (No. 1805004-0522-SB120).

REFERENCES

[1] IAEA ARIS, "Status report 77 – System-Integrated Modular Advanced Reactor (SMART)", 2011
[2] C. Shuai, "CFD Simulation of Two-Phase Flows in Helical Coils", 8, Frontiers in Energy Research, 2020
[3] Colombo, Marco & Colombo, Luigi & Cammi, Antonio & Ricotti, M.E., "A scheme of correlation for frictional pressure drop in steam–water two-phase flow in helicoidal tubes", Chemical Engineering Science, 123, 2015
[4] H.O. Kang, "Thermal Sizing of Printed Circuit Steam Generator for Integral Reactor", Transactions of the Korean Nuclear Society Spring Meeting, 2014
[5] KAERI, "Methodology for Failure Assessment of SMART SG Tube with Once-through Helical-coiled Type", KAERI/CM-1351/2010
[6] C.J. Lee, "Insights from Development of Regulatory PSA for SMART", Transactions of the Korean Nuclear Society Autumn Meeting, 2010