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Comparison of two-phase flow pressure drop in helical pipe and straight pipe through CFD analysis

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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 reactor size, and a compact heat exchanger is often utilized to reduce the size further. Among various SMRs, reactors such as SMART and NuScale, which use the integrated reactor concept, adopt a helical steam generator to secure a large heat transfer area in a limited space.

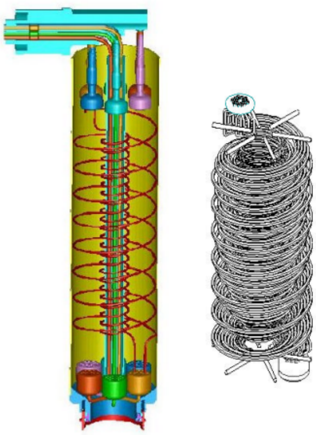

Fig. 1. SMART Helical Steam Generator [1]

In general, in a helical steam generator, since the inside of the tube is secondary side, water flows along the helical tube and becomes superheated steam by receiving heat from the primary side. However, since each layer has different length, if the pressure drop of each layer is not accurately calculated, two phase flow instability such as density wave oscillation may occur, which can cause a problem in the steam generator. It can be seen from the Martinelli-Nelson curve that the pressure drop in the case of a two-phase flow is higher than that of a single-phase liquid and gas flow in a straight pipe. In addition, the behavior of two-phase flow and corresponding flow regimes in helical tubes significantly differ when compared to two-phase flows in straight tubes due to centrifugal and torsion forces [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]. The pressure drop of helical tube appears differently depending on helical tube design variables such as rotational diameter, pitch, tube diameter, and angle. Moreover, in order to evaluate the two-phase instability within the helical tubes, understanding various loss mechanisms is also important.

In this study, two phase flow pressure drops are calculated by CFD for the helical pipe and the straight pipe. It is confirmed that the mass fraction of vapor for both tubes follow the Martinelli-Nelson curve, and the pressure drop values of both pipes are compared.

2. Methods and Results

2.1 Reference steam generator

The reference 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 helical tube CFD calculation. 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. For the straight pipe, analysis was performed by extending the boundary by 10D at the inlet and outlet of 1m pipe. Water and steam properties at 5.2MPa and 266.4 °C are used for the fluid, which are the property values in saturated state.

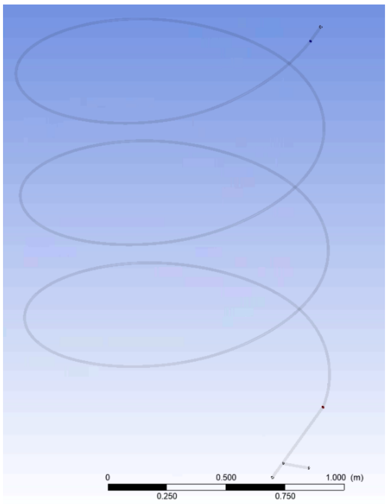

Fig. 2. 17th layer Helical pipe shape for CFD

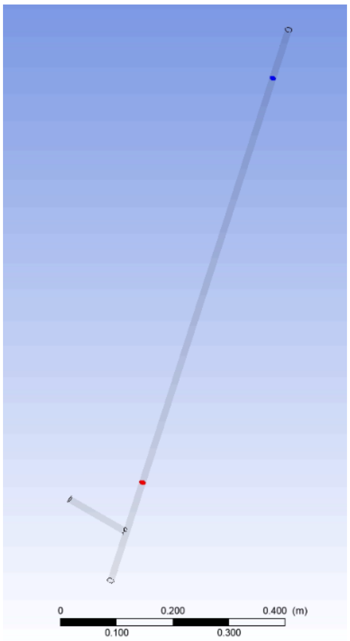

Fig. 3. Straight pipe shape for CFD

Other input data for CFD analysis is shown in the following Table II. In this study, the pressure drop is checked by changing the inlet vapor mass fraction. The analysis results are shown in Table III and Table IV. The total length of helical pipe is 12.36m and the straight pipe is 1m.

Table II: CFD-pre Input

Analysis Type	Steady State
Inlet Boundary	Mass flow rate – 0.0633
Outlet Boundary	Average Pressure – 5.2 MPa
Turbulence	Shear Stress Transport
Wall function	Automatic in CFX
Heat Transfer	Isothermal

Table III: Helical Pipe Two Phase Pressure Drop CFX Analysis Result (12.36m)

Mass Quality [%]	Inlet Pressure [kPa]	Outlet Pressure [kPa]	Total Pressure drop [kPa]
Water (0)	5203.77	5200.03	3.74
20	5203.28	5270.75	67.47
40	5202.89	5271.46	68.57
60	5203.54	5313.50	109.96
80	5212.20	5538.64	326.44
Vapor (100)	5300.34	5206.99	93.35

Table IV: Straight Pipe Two Phase Pressure Drop CFX Analysis Result (1m)

Mass Quality [%]	Inlet Pressure [kPa]	Outlet Pressure [kPa]	Total Pressure drop [kPa]
Water (0)	5200.25	5200.61	0.36
20	5201.79	5206.38	4.59
40	5202.99	5211.09	8.10
60	5204.17	5213.84	9.67
80	5205.14	5213.27	8.13
Vapor (100)	5206.89	5213.75	6.86

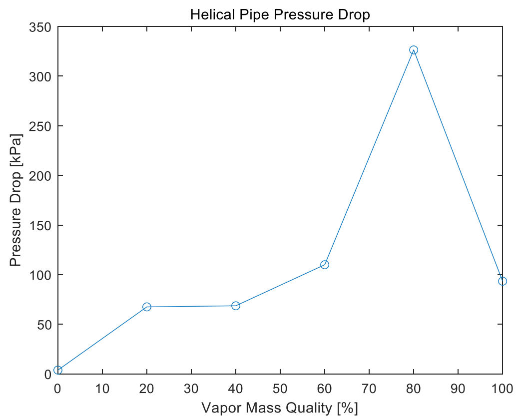

Fig. 4. Helical Pipe Pressure Drop

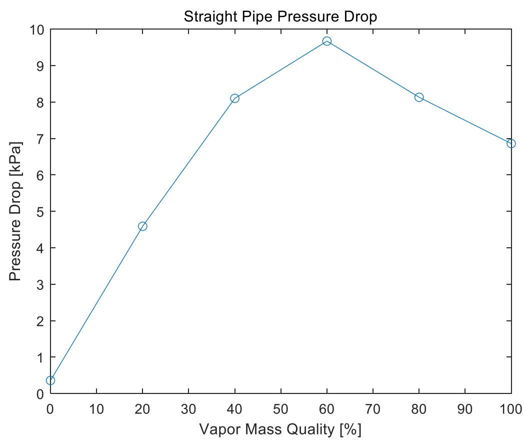

Fig. 5. Straight Pipe Pressure Drop

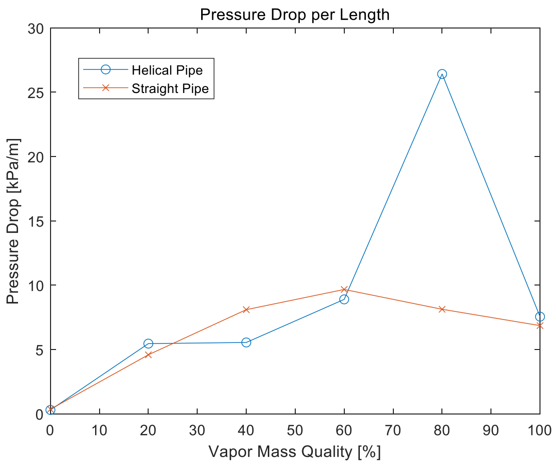

Fig. 6. Helcial Pipe and Straight Pipe Pressure Drop per Length

As a result of the CFD analysis, it is obtained that the two-phase pressure drop value was higher than that of single-phase in both the helical tube and the straight tube. Moreover, it is confirmed that the Martinelli-Nelson curve can recreated with the CFD analysis.

3. Conclusions

From the CFD analysis results, it is confirmed that the two-phase pressure drop peak is specially high in the mass quality 80% region for the helical tube. In addition, when observing the pressure drop per length, it is found that the pressure drop in the straight pipe is comparable to that of the helical pipe in low quality regions. In general, it is expected that the pressure drop of the helical tube will be higher than that of straight pipe. Currently, it is speculated that this phenomenon may have occurred due to the separation of water and vapor by the centrifugal force due to the helicity of helical tube. Further analysis and more CFD results will be reported in the conference presentation.

ACKNOWLEDGEMENT

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