An Evaluation on Geometric Parameters of Helical Coil from the Viewpoint of Heat Transfer

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1. Introduction

SMART (System-integrated Modular Advanced ReacTor), is an integral nuclear reactor for sea-water desalination and electricity generation [1]. The reactor assembly of SMART contains the major primary systems: fuel and core, OTSG (Once-Through Steam Generator), a pressurizer, reactor coolant pumps, and control rod dive mechanisms. Helically-coiled OTSGs were introduced due to the internal space restriction of the integral reactor. Adoption of the helical coiled tubes offers several advantages from a design point of view such as compactness, structural stability and a compensation for the thermal expansion. Eight steam generators are located at the upper circumferential periphery with an equal spacing inside the reactor pressure vessel. NSSS design/operation requirements and available internal install space are starting points for the OTSG design. The OTSG should be designed to guarantee the performance at the rated condition and be installed inside the reactor vessel concurrently.

Thermo-hydraulic analyses using the ONCESG program are carried out to evaluate the effect of the geometric parameters on the heat transfer in this study.

2. ONCESG Program

To calculate the pressure drop and heat transfer rate through the effective heated coil region, the ONCESG program is utilized [2]. ONCESG is a thermal hydraulic design and performance analysis computer program for the OTSG using the helically coiled tubes. ONCESG has thermo-hydraulic models for the primary and secondary sides of the heated coil, and the coil wall. The secondary side consists of an economizer, evaporator, and superheater region, each of which has a separate thermo-hydraulic model. The effective heat transfer section of the OTSG is represented by one characteristic tube in the ONCESG program as shown in Figure 1. A fully developed sub-cooled nucleate boiling region and a mist evaporation region are also simulated.

The ONCESG program calculates the exact locations of the phase boundaries, based on which new numerical nodes are regenerated for every iteration step. Within each of the three major heat transfer regions, an arbitrary number of control volumes can be specified. The control volume boundaries are adjusted after every iteration step so that the boiling boundaries between the economizer and the evaporator regions, and between the evaporator and the superheater regions coincide with the respective control volume boundaries. Well known correlations for the friction factors and the heat transfer correlations were implemented into the program. Also a stable and robust numerical algorithm was developed for the unique solution. The ONCESG program is benchmarked against the design data of the OTSG of an integral reactor MRX, detail description of which can be obtained from reference [2].

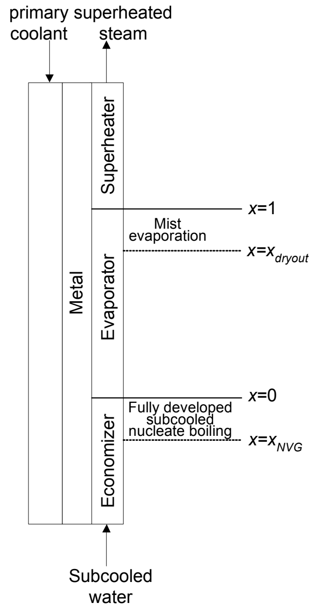

Figure.1 Heat transfer regions in a characteristic tube

3. Results

Geometric parameters such as the diameter and the number of tubes, and the radial/axial pitches of the tubes were considered from the viewpoint of the heat transfer. Smaller diameter of tube is preferred for the effective heat transfer as the heat transfer area per the unit volume generally increases with a smaller tube diameter. However it was known to be difficult to carry out the in-service inspection with the small diameter of tube. The currently available in-service inspection equipments require that the tube inner diameter should be not less than 12 mm [3]. The innermost coil diameter is also limited with related to the in-service inspection requirement. The tube diameter and coiling diameter were determined based on these reasoning.

As shown in Figure 2, the total number of tubes has a large effect on the effectiveness of the heat transfer, which is mainly related to the secondary flow condition. A reduction of the number of heated tubes requires the increase of feedwater with a larger pressure drop through the tube-side, which diminishes the temperature difference potential of the saturated region, and consequently requires larger heat transfer area. On the contrary, an increment of their number makes the feedwater velocity low and again increases the required heat transfer area. Due these competing effects, there exists optimum number of heated tubes for an effective heat transfer.

Figure 3 shows the calculated primary side pressure drop and coolant velocity as a function of the tube radial pitch. The shell-side pressure drop has large value for the small radial pitch value, which increases the required RCP head. The capacity of RCP is confined due to the characteristics of the integral reactor, so the overall pressure drop through the OTSG should be confined within the some value.

As the axial pitch decreases, the shell-side heat transfer coefficient increases for the current design range. The original ONCESG heat transfer coefficient was modified using the arrangement factor described in reference [5]. Figure 4 shows the calculated effective tube length and height as a function of the tube axial pitch. The SG effective height is proportional to the axial pitch, so a low value of axial pitch is preferred for the purpose of a compactness.

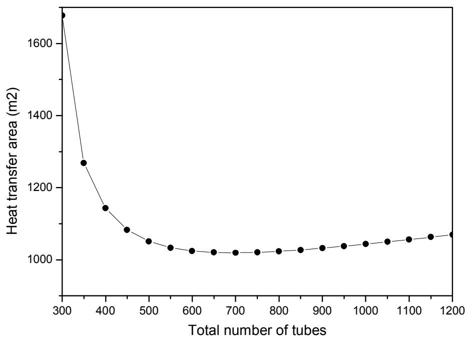

Figure.2 Calculated OTSG effective height as a function of total tube number

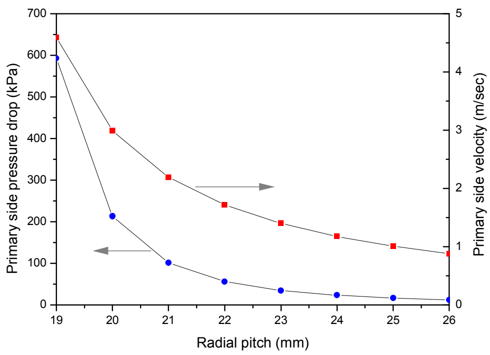

Figure.3 Calculated primary side pressure drop and coolant velocity as a function of tube radial pitch

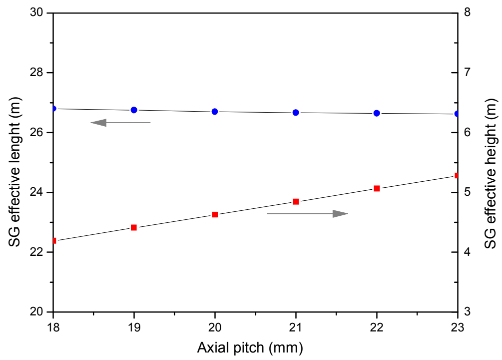

Figure.4 Calculated OTSG effective tube length and height as a function of tube axial pitch

3. Conclusions

The effects of the geometric parameters of the helical coil were studied in this study. A small diameter of the tube is preferred with a limitation of the in-service inspection requirement. There exists an optimum number of tubes due to the thermo-hydraulic condition of the secondary side. The axial and radial pitches should be determined by considering the space and hydraulic requirements of the steam generator.

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