Transactions of the Korean Nuclear Society Autumn Meeting
Gyeongju, Korea, October 29-30, 2009

The Development of a New Concept for a Double Wall Tube Steam Generator

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1. Introduction

A steam generator for an SFR is one of the most important components needing a careful selection in SFR development, and a key issue of the selection becomes an exclusion of a sodium-water reaction possibility. In order to improve the reliability of a steam generator, steam generators have been developed by using a double wall tube (DWT). Current developments are focusing on an improvement of the heat transfer capability for a DWT and the development of a proper leak detection method before the failure of the DWT during a reactor operation. In this study, the methods are developed to improve the heat transfer capability and to detect the tube failure on-line and in real time. And a helical coil double wall tube steam generator for an SFR with 375MWth capacity is designed thermal-hydraulically by embodying the methods.

2. Development of the New Concepts

2.1 Review of the Literatures

Steam generators for an SFR are mainly of the tube-and-shell type, in which high pressure and low temperature steam flows inside inner tubes heated by low pressure and high temperature sodium on the shell side. If a heat transfer tube is damaged, high pressure water/steam leaking through cracks might come into contact with the sodium, causing a chemical reaction. As a result, a high-temperature corrosive reaction product and a large quantity of hydrogen gas are generated, and the system could be damaged.

In order to improve the reliability of a steam generator, steam generators have been developed by using a DWT having two barriers between the sodium and water [1]. A pre-stressed DWT is both feasible and commercially available, and its heat transfer capability is increased by increasing the residual stress between the inner tube and outer tube. Because of the gap between the two tubes, current developments are focusing on an improvement of the heat transfer capability for a DWT and the development of a proper leak detection method before the sodium and water reaction during a reactor operation [2].

In conventional DWTs, the inner tube and the outer tube are made of the same material, so degrees of thermal expansion are different between the outer tube and the inner tube owing to a temperature difference between the two tubes. Therefore, the higher the temperature difference, the less is the contact pressure between the inner tube and outer tube.

A leak detection capability was achieved by monitoring and analyzing the helium filled in the gap which connects to the plenum formed between the sodium tubesheet and water tubesheet of a steam generator [3]. But the former has a problem when the outer tube breaks, and it is impossible to isolate the broken heat transfer tube separately so that sodium does not flow into the plenum to cause a loss of the leak detection function. In some DWTSGs [4], each heat transfer tube penetrates the shell of the steam generator at the top and bottom head in order to detect separately each tube failure at the outside of the steam generator. Since all heat transfer tubes are exposed on the outside, the probability of causing a serious accident, such as when a steam line breaks, increases. Some DWTSGs are designed with straight double wall tubes, and the integrity of tubes are confirmed by nondestructive tests during a periodical plant inspection [5], but they could not achieve enough reliability because of the absence of an on-line detection system.

2.2 New Concepts for DWTSG

To improve the heat transfer capability of the double wall tube in this research, it is preferable to form the inner tube with the material having a thermal expansion coefficient about 10 to 15% greater than that of the outer tube (Fig. 1).

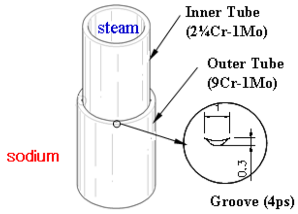

Fig. 1 Double wall tube with the different materials

The double wall tube has the heat transfer efficiency similar to that of room temperature when the temperature difference is about 55℃ between the tubes in normal operating conditions. In an abnormal condition when the tube side is empty while the sodium temperature is 550℃, the stress of about 12MPa was estimated in computer analysis, but this value is lower than the yield stress of those materials.

Second, an on-line leak detection method is developed to detect a heat transfer tube failure whether the heat transfer tube is damaged or not on-line and in real-time. The method is achieved by detection holes that communicate with each of the heat transfer tube gaps in the lower tubesheet as shown in Fig. 2, that the pressure change of the gap is measured separately. It is possible to plug the damaged tube without the loss of function.

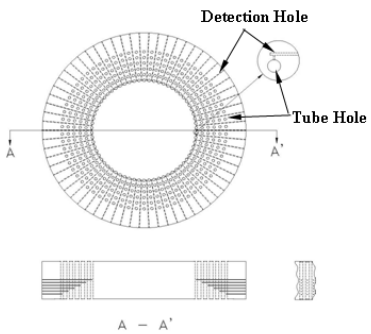

Fig. 2 Concept of the on-line leak detection method

2.3 Design of a Helical DWTSG

A helical coil DWTSG for an SFR with 375MWth capacity is designed thermal-hydraulically to operate in a super steam cycle by embodying the above methods. It is a vertically oriented helical coil, sodium-to-water counter-cross flow shell-and-tube heat exchanger as shown in Fig. 3. The heat transfer tubes are helical DWTs with different materials having 4 grooves between them for leak detection passages. Feed water enters the feed water header, and is heated as it flows upward through the inlet tubes welded to the lower tubesheet, helical coil tube bundle, and the outlet tube assembly connecting to the upper tubesheet which is a part of the steam header.

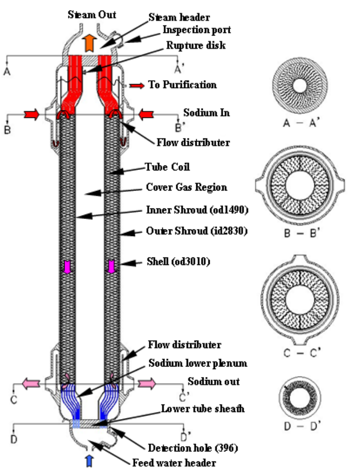

Fig. 3 A 375MW helical DWTSG

This steam generator has several unique design features beside the above mentioned, some of which are shown in this figure. Although the sodium and water reaction which is considered as a beyond-design accident in the steam generator, the internal space of the inner shroud is applied to alleviate a pressure rise by the hydrogen gas generated in sodium-water reaction through a rupture disk. And the steam generator includes an extended outer shroud and a heat-protecting membrane in the cover gas space so as to reduce the temperature fluctuation of the tube surface resulting from the sodium-free surface fluctuation.

3. Conclusions

Methods are being developed to improve the heat transfer capability of a double wall tube and to detect the tube failure by an on-line leak detection method. And a helical coil double wall tube steam generator for an SFR with 375MWth capacity is designed thermal-hydraulically by embodying the methods. This steam generator could improve not only its reliability by the on-line detection method before the sodium water reaction but also the heat transfer capability. What is needed its commercialization is the performance of a feasibility test of the double wall tube, the verification of the helical tube characteristics, and the validation of the steam generator design.

Acknowledgement

This study has been supported by the Nuclear Research and Development Program of the Ministry of Education, Science and Technology of Korea.

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