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# Thermal hydraulic analysis of a double tube bundle steam generator using a numerical method

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## 1. Introduction

To eliminate the IHTS by using a new steam generator, Korea Atomic Energy Research Institute(KAERI) is developing a DTBSG[1] which has two tube bundles that are functionally different and a shell side filled with lead-bismuth. An alloy of lead and bismuth is chemically stable with water and sodium. This configuration means that the possibility of a SWR is negligibly small, and thus an IHTS can be removed.

Sim et al. [1] developed an analytic method for a DBTSG analysis which is dependent on an assumption that the fluid and material properties are treated as uniform and the inlet condition of the water/steam side tube is a uniform mass flux and they also used calibration coefficients for the overall heat transfer coefficient U. The paper explains the mechanism for a reversed heat transfer occurrence in an integrated double-region type generator, and shows the possibility of an occurrence of an undesirable reversed heat transfer not only in the integrated single-region bundle type generator but also in the double-region bundle type generator.

In this work a DTBSG was analyzed with a numerical method by considering a variation of the fluid and tube wall material properties, a convective heat transfer coefficient and a phase change in the water/steam side, and the same pressure difference between the inlet and outlet of the water/steam side tubes for the flow distribution.

## 2. Analysis model and results

### *2.1 The structures of the DTBSG*

The four DTBSG types studied are shown in Fig.1. Each type here is called an integrated single-region bundle type, an integrated double-region bundle type, a vertically separated bundle type and a radially separated bundle type generator. In the figures, all of the tubes are helical, and the black and white colors represent the cold fluid tube and hot fluid tube respectively. Figs. 1b and d show the cross sections of the tube bundle configurations. The shell side is filled with a medium fluid, lead-bismuth, which is circulated by a pump. Heat is transferred from the hot side to the cold side through a medium fluid in two modes. One is that the fluid carries the heat taken from one region to the other region, which is the method for a medium fluid involvement in a separated configuration. This mode of a heat transfer is hereafter called a bulk transfer. The other is that the fluid works as an intermediate heat transfer path between hot and cold fluids in the same region, and it is hereafter called a local transfer.

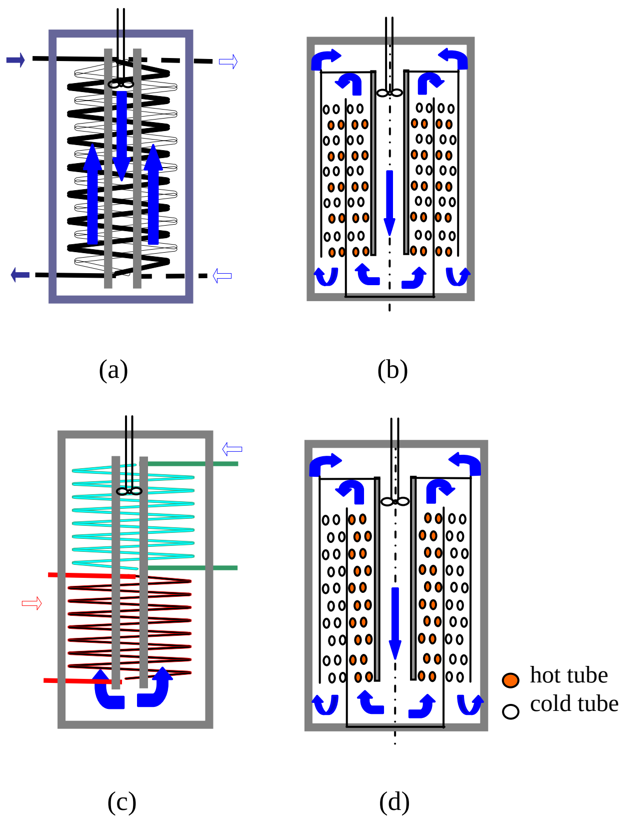


Figure 1. Tube bundle configuration of the DTBSG

### *2.2 Analysis model*

Because a tube's diameter is very small when compared to its length, the thermal-hydraulics of a tube's side are described by a one-dimensional model. The flow rates of sodium and water/steam are distributed evenly to a number of tube's in each region, respectively. A mass conservation equation, one-dimensional energy balance equation, and a pressure loss equation are used for the hot and cold sides of the channels. The governing equations are of a steady state.

The flow distribution of the water/steam side between an inner and outer region in an integrated double region is governed by two boundary conditions. First, all the fluid channels have common inlet and exit plenum pressures and thus the pressure difference remains the same for all the channels. Second, the sum of all the mass flow rates at the channel inlets must be equal to the total mass flow rate supplied to the water/steam tube side. Overall solution method is explained in reference[2].

### *2.3 Design of the DTBSG*

For the performance analysis, a SG was actually designed for each type and an optimization of the geometric parameters and the flow rate were made in a previous work[1].

A design was sought with a condition of a heat transfer rate of 200 MW and a system operation condition which was taken from the reference system design of Ref.[3] and this operational condition is described in Table 1. The design data of the 200 MW DTBSG is listed in Ref.[1]

Table 1. System operation conditions

| | | |
|---|---|---|
| Hot fluid | Fluid | Sodium |
| | Inlet temperature[℃] | 530 |
| | Flow rate [kg/s] | 1,071.5 |
| Cold fluid | Fluid | Water/steam |
| | Inlet temperature[℃] | 230 |
| | Flow rate [kg/s] | 87.725 |

### *2.4 Results*

Table 2 shows a comparison of the performance analysis results for the DTBSG. As shown in the table, the differences in the designs are considerable between the integrated and separated types because of the differences in their heat transfer physics. When the heat transfer efficiency is compared by using the ratio of the heat transfer rate to the heat transfer area, the separated types are about two times more efficient than the integrated types. The efficiency is about 145 $KW/m^2$ for the separated types and about 80 $KW/m^2$ for the integrated types.

The pumping power and the velocity of the medium fluid are quite large in the separated types; whereas they are very small in the integrated types. The high flow rate of 6,500 kg/s results from the high density of the lead-bismuth in the separated types. When the flow rate for a mass is converted to that of a volume, the rate becomes approximately 0.77 $m^3/s$. Since it is possible to transfer the required heat with a very small velocity in the integrated types, the integrated types have a merit in that they can minimize the erosion-corrosion problem of the structures by using lead-bismuth.

Table 2. System operation conditions

| Parameters | Single-region integrated type | Double-region integrated type | Radially separated type | Vertically separated type |
|---|---|---|---|---|
| Heat transfer rate [MW] | 203.2 | 197.3 | 198.9 | 200.1 |
| Pb-Bi mass flow rate[kg/s] | 1,200 | 400 | 6,500 | 6,500 |
| Heat transfer area [$m^2$] | 3,262 | 2,447 | 1,364 | 1,419 |
| Sodium side pumping power [KW] | 874.7 | 972. | 819.6 | 781.2 |
| Pb-Bi side pumping power [KW] | 1.5 | 0.4 | 1,706.1 | 1,269.2 |
| Water/steam side pumping power [KW] | 11.9 | 12.6 | 37. | 35.6 |
| Shell diameter [m] | 2.96 | 2.34 | 1.96 | 1.38 |
| Tube bundle height [m] | 8.9 | 13.1 | 11 | 21 |
| Bundle region height [m] | 8.9 | 13.1 | 11 | 21 |
| Volume [$m^3$] | 61.4 | 56. | 33.2 | 29.8 |
| Weight [Ton] | 356 | 347 | 208 | 194 |
| Shell side velocity (inner/outer) [m/s] | 0.05 | 0.07/0.09 | 2/1.8 | 1.5/1.8 |
| Heat transfer rate per unit heat transfer area [$KW/m^2$] | 62.3 | 80.6 | 145.8 | 141. |

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