Determination of thermal-hydraulic operating condition for the shutdown cooling water subsystem in HECTAR

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1. Introduction

HTGR, High Temperature Gas-cooled Reactor, is one of the Generation IV nuclear reactor concepts. HECTAR is a 90 MWt HTGR whose design has been initiated by KAERI. SCS(Shutdown Cooling System) is a non-safety grade decay heat removal system being considered for HECTAR, intended for use during shutdown or refueling periods. It consists of a SCHE(Shutdown Cooling water-helium Heat Exchanger) and a helium circulator. The SCS is connected to a SCWS(Shutdown Cooling Water Subsystem) which consists of water pump, water-air heat exchanger and surge tank as shown in Fig. 1[1].

During SCS cooling operation the peak temperature will occur in the hottest tubes of SCHE[2]. Local boiling in SCHE will result in flow instabilities and possible tube failure due to dry out. Therefore, the thermal-hydraulic operating condition of SCHE such as temperature and pressure should be decided by considering appropriate margin to boiling.

In this study, the thermal-hydraulic operating conditions of SCWS in HECTAR are determined based on the available data of other international HTGRs using the previously presented methods and procedures[1].

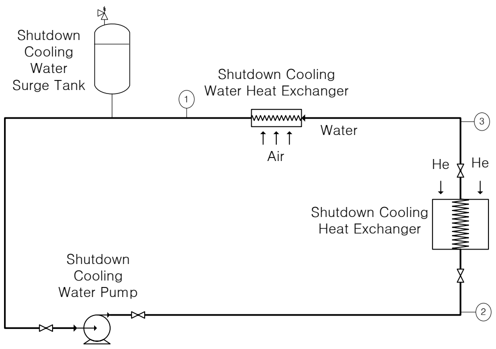

Fig. 1 Schematic diagram of SCWS

2. Analysis Method

The heat loss and pressure loss within the system as shown in Fig.1 is neglected. The mass flow rate($\dot{m}$) can be determined based on the enthalpy differences between the inlet($h_2(T_2, P_2)$) and outlet($h_3(T_3, P_3)$), as well as the thermal duty($\dot{Q}$) of SCHE as described in eq(1). NIST REFPROP[2] is used to calculate the coolant properties at various temperature and pressure conditions on each numbered point.

$$\dot{m} = \frac{\dot{Q}}{h_3(T_3,P_3) - h_2(T_2,P_2)} \quad (1)$$

The thermal duty and inlet temperature SCHE of HECTAR is 6.1 MWth and 45℃, which are tentative values and may be changed with the design progress. The temperature and the pressure at the inlet(#2) and outlet(#3) of SCHE should be determined. In order to determine the operating condition of SCWS, the available data of international HTGRs are collected and summarized in Table 1.

As shown in the table, thermal duty and operating conditions of international HTGRs are highly diverse. Those operating conditions were analyzed with respect to the design margin to prevent local boiling at tube outlet of SCHE. And the operating condition for SCWS of HECTAR were determined.

Table 1 Operating condition of shutdown cooling water system of various HTGR [3,4,5]

Parameters	Values		
	MHTGR	HTTR	HTR50S
Thermal duty (MW)	23.9	3.5	4.0
Tube inlet temp. (℃)	43	100	47
Tube outlet temp. (℃)	222	150	100
Pressure (MPa)	4.83	2.13	N/A
Flow rate (kg/s)	31.25	18.2	18

3. Results

Fig. 2 shows the boiling temperature margin(BTM) map and saturation pressure margin(SPM) map at various pressure and temperature conditions. The map was generated based on the procedures as introduced in Ref[1]. The dotted line and solid line represent BTM and SPM, respectively. As shown in the figure the available operating range of pressure and temperature without coolant boiling increases as BTM and SPM decreases. By referring to this map, the designer can set the operating condition(temperature and pressure) without coolant boiling through the determination of BTM and SPM.

Fig. 3 illustrates the operating condition of various HTGRs in SPM map. X axis and Y axis represents the operating pressure and the operating temperature at SCHE outlet, respectively. As shown in the figure the SPM of MHTGR is about 1.9 and that of HTTR is about 1.7. In case of HECTAR, STM is set to be 2.0. The red dots represent the intersecting points of the BTM=30~110°C lines on SPM=2.0. The pair of temperature and pressure of each dot are the candidates of operating conditions of SCWS having design margin against boiling in HECTAR.

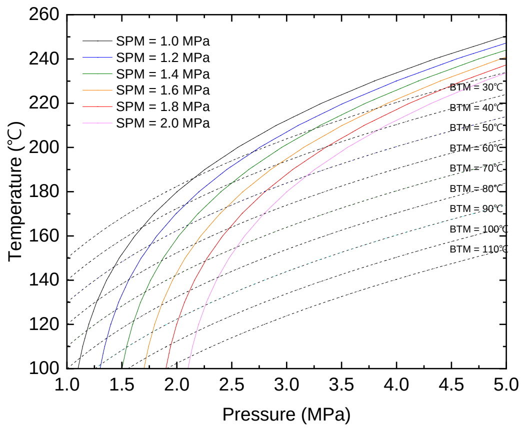

Fig. 2 Map of boiling temperature margin and saturation pressure margin at various conditions

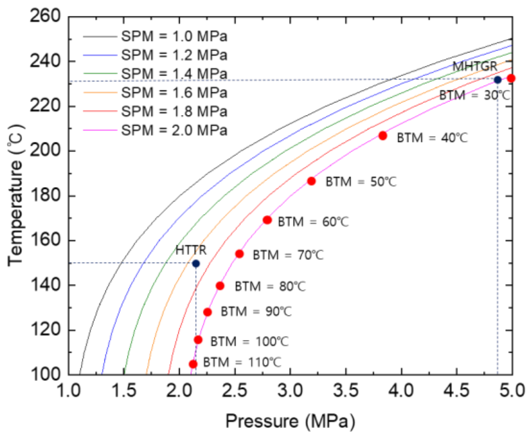

Fig. 3 Operating condition of SCWS various HTGRs in SPM map

In order to select the appropriate condition, flowrate is plotted with respect to temperature differences between inlet and outlet of SCHE. The various HTGR's operating condition is plotted. The black dot represents the flowrate at each candidate condition. As shown in the figure, the flowrate and temperature difference increase as the thermal duty increases. The BTM of HECTAR is determined such that the flowrate and temperature increase rates due to the increase of thermal duty of other reactors are similar. Finally, BTM=100℃ is decided as a design value of HECTAR. The temperature and pressure at BTM=100℃, SPM=2.0MPa is 117℃ and 2.2MPa. The corresponding flowrate is 20.2 kg/s. The finally determined operating condition of SCWS is summarized in Table 2.

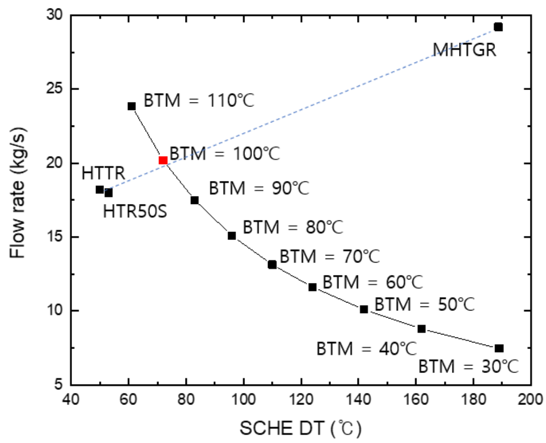

Fig. 3 Flowrate with respect to temperature differences between inlet and outlet of SCHE

Table 2 illustrates the finally determined operating condition of SCWS, which have saturation pressure margin of 2.0 and boiling pressure margin of 100℃.

Table 2 Operating condition of SCWS of HECTAR

Parameters	Values
Thermal duty (MW)	6.1
Pressure (MPa)	2.2
SCHE Water Inlet temperature (℃)	45
SCHE Water Outlet temperature (℃)	117
Flow rate (kg/s)	20.2

4. Conclusions

The saturation pressure margin map and boiling temperature margin map are developed. The procedure to determine operating condition of SCWS in HECTAR using SPM and BTM map is introduced. Final themal-hydraulic operating condition of shutdown cooling water system of HECTAR having enough design margin against coolant boiling is determined.

5. Acknowledgement

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