NQe

KAIST Nuclear & Quantum Engineering

Sensitivity Analysis on Steam Generator Volume to Feedwater Temperature for Small Modular Reactor

Jun Ha Hwang , Semin Joo, Jeong Ik Lee *

Department of Nuclear & Quantum Engineering, KAIST, 373-1 Guseong-dong Yuseong-gu, Daejeon 305-701, Republic of Korea

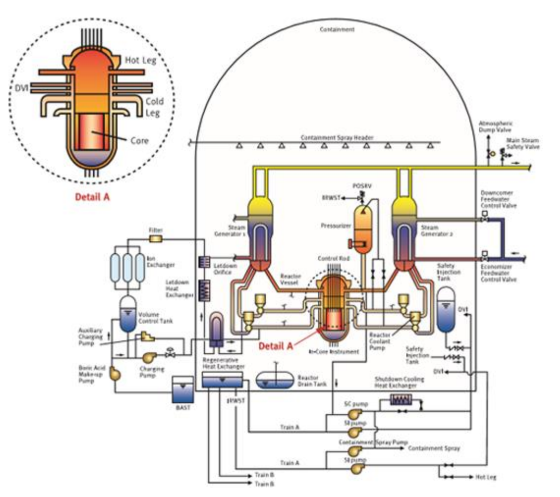
*Corresponding author: jeongiklee@kaist.ac.kr

Introduction

▣ This study focuses on the Pressurized Water Reactor (PWR)-type Small Modular Reactor (SMR) and investigates how varying feedwater temperatures influence the size of the steam generator.

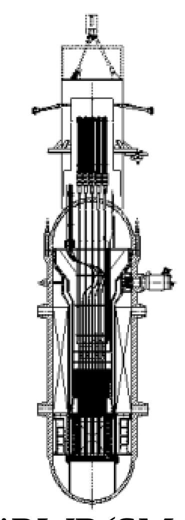
▣ This research employs a one-dimensional Finite Difference Method (FDM) design tool to analyze the impact of changes in feedwater temperature on the volume of the steam generator.

▣ By understanding these dynamics, the aim is to enhance the design and compactness of steam generators in SMRs.



▲ *Schematic of APR 1400*

▲ *Image of APR 1400 SG*

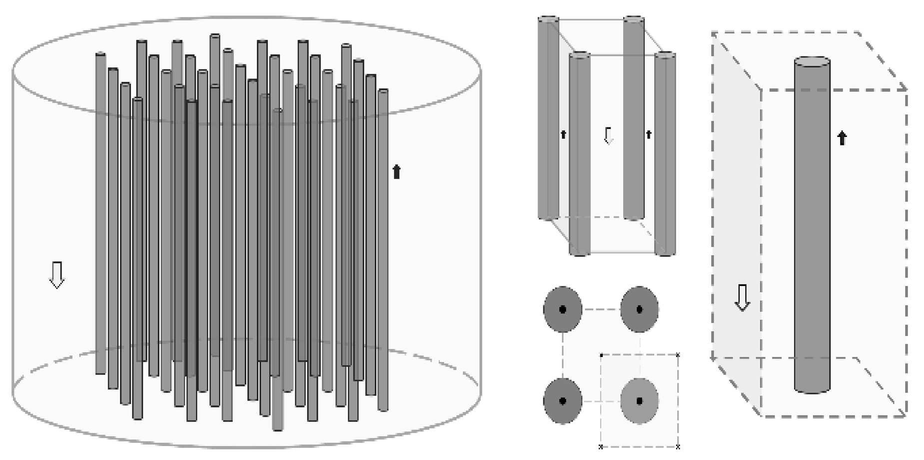


▲ *Image of iPWR(SMART-330)*

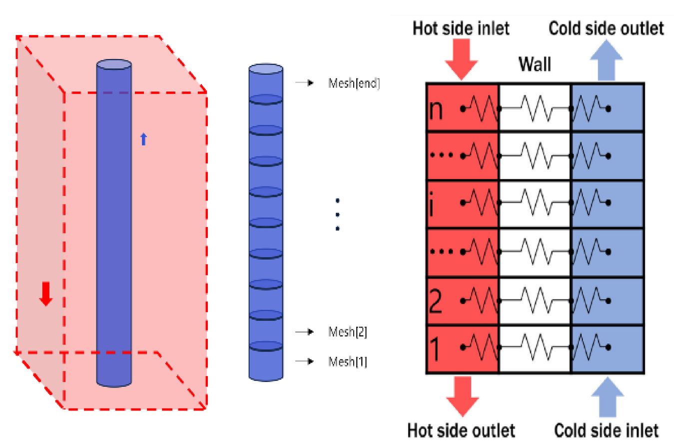
Design Approach of SG

▣ The steam generator (SG) type considered in this study is a Once Through Steam Generator (OTSG), in which a counterflow heat transfer occurs through straight, vertical tubes.

▣ Assuming steady-state conditions and all channels being homogeneous, a unit channel is considered to have the same amount of heat transfer rate.



▲ *unit subchannel from overall Steam Generator*



▲ *FDM of an unit channel*

▣ The model uses a one-dimensional Finite Difference Method (FDM) to accommodate significant changes in the heat transfer coefficient across different meshes due to various flow regimes, from sub-cooled to superheated steam, on the secondary side.

▣ The minimum volume of steam generator, $V_{SG,\,minimum}$ can be calculated by multiplying parameters.

$$\boldsymbol{V_{SG,\,minimum} = N_{2nd,channel} \times L_{height} \times P_{2nd,channel}{}^{2}}$$

▣ The primary loop was modeled to the value of SMART (PWR-type SMR), and the secondary loop was modeled to an assumed condition.

SG reference design parameters

Parameter	Primary loop	Secondary loop
SG inlet temperature [C]	323	200
SG outlet temperature [C]	295.7	296.4
Operating pressure [MPa]	15	5.2
Mass flow rate [kg/s]	2062.47	161.55
SG Heat transfer rate [MWt]	330	
Number of channels	18000	
Height of channel [m]	3.84	
Diameter of channel [mm]	12.7	
Length of pitch	25.4	
Tube thickness [mm]	1.2	
Tube thermal conductivity [W/m*k]	16.3	
P/D ratio	2	

Computation Model Description

▣ The heat transfer coefficient for each mesh is calculated using equations based on dimensionless numbers and thermodynamic parameters such as cold side wall temperature, heat flux, and void fraction, with the flow regimes divided into six cases, including the post-critical heat flux state.

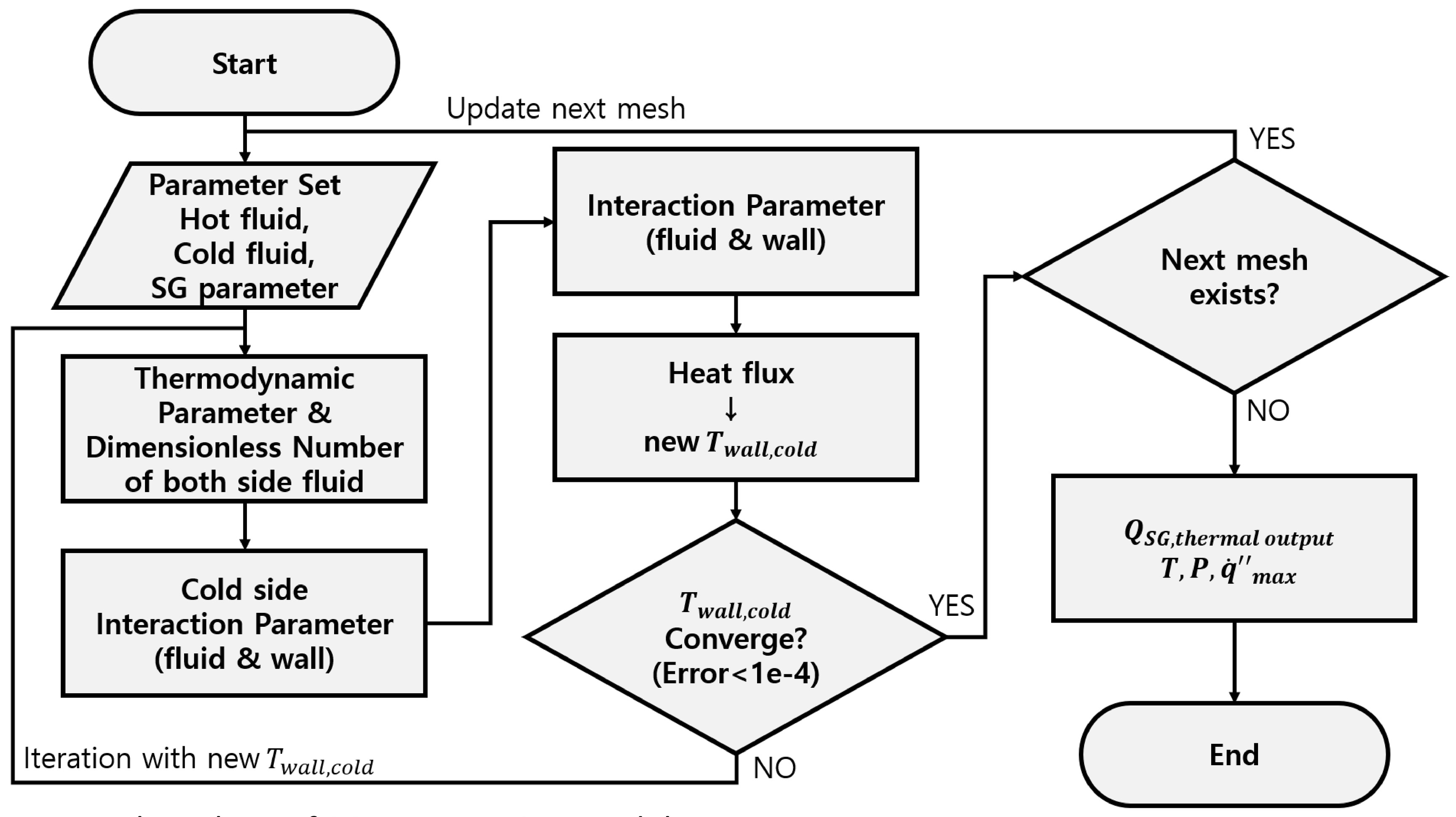
Equations for heat flux according to flow patterns

Case	Equation	Used correlation or data for HTC
Single phase (Newton)	$\dot{q}''_{Newton} = h(T_w - T_c)$	Sleicher & Rouse
Inverted annular film Boiling	$\dot{q}'' = h(T_w - T_{sat}) + \dfrac{\sigma_{SB}(T_w{}^4 - T_l{}^4)}{\dfrac{1}{\varepsilon_l\sqrt{1-\alpha}} + (\dfrac{1}{\varepsilon_w} - 1)}$	Fung & Cachard
Inverted slug film Boiling	$\dot{q}'' = x(2-x)\dot{q}''_{IAFB} + (1 - x(2-x))\dot{q}''_{DF}$	
Dispersed flow	$\dot{q}'' = \dfrac{k_g}{D_h} Nu_{wg,FC} * \Psi_{2\Phi}(T_w - T_g) + F_{wl}\sigma_{SB}(T_w{}^4 - T_{sv}{}^4) + F_{wg}\sigma_{SB}(T_w{}^4 - T_{sg}{}^4)$	Sleicher & Rouse & Filonenko & Gnielinski
Nucleate boiling	$\dot{q}'' = h_{wl}(T_w - T_{sat}) + (\dfrac{h_0 F_P}{\dot{q}''_0{}^{n}})^{\frac{1}{1-n}}(T_w - T_{sat})^{\frac{1}{1-n}}$	Gnielinski

▣ The calculated heat flux is a key parameter for mesh's overall heat transfer coefficient of cold side, which will be used for calculating the overall heat transfer rate (Q) and the overall thermal resistance (U)

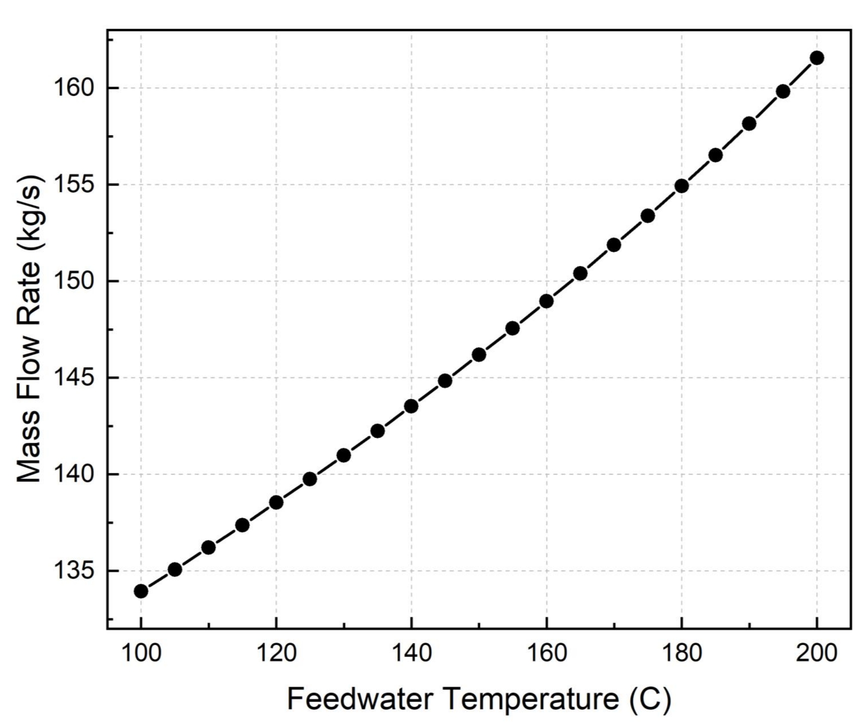
$$Q = UA\Delta T$$

$$U = \frac{1}{\dfrac{1}{(hA)_{hot}} + \dfrac{\ln\left(\dfrac{D_o}{D_i}\right)}{2\pi \cdot k_{wall} \cdot dl} + \dfrac{1}{(hA)_{cold}}}$$

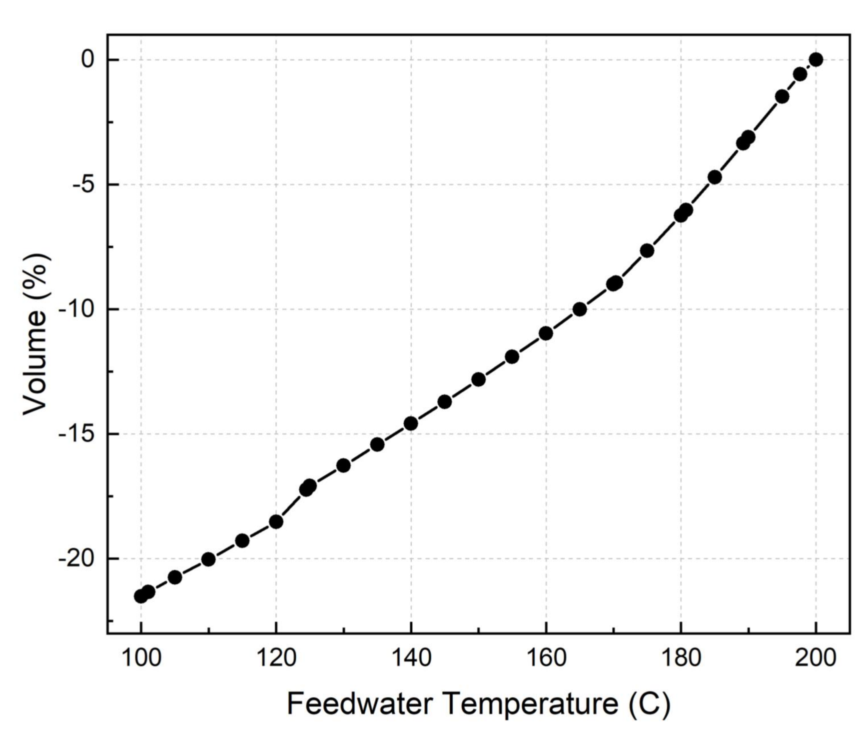


▲ Flow chart of SG computation model

Results and Discussion



▲ Feedwater mass flowrate of SG by feedwater temperature at 330MWt thermal output



▲ Minimum volume ratio of SG by feedwater temperature at 330MWt thermal output

▣ Lower feedwater temperatures result in a smaller required steam generator (SG) volume for the same heat transfer at a fixed turbine inlet temperature, with the regression yielding a relative error under 1% for the heat output at a constant superheated steam temperature.

▣ Simplifying the SG model to straight tubes overlooks the complexities of the real world and ignores factors such as pressure drop and structural components such as orifices that affect flow and heat transfer.

▣ Future efforts will focus on validating these findings with experimental data and further analyzing the sensitivity of the SG volume to various parameters, including the pitch-to-diameter (P/D) ratio, the number of tubes, and pressure drop, to optimize SG design