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Development of Thermal- Hydraulic Analysis Model of a Once-Through Steam Generator in Modelica

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1. Introduction

Simulators are required for the transient analysis of power plants. However the complex computational fluid-dynamics code, such as RELAP, requires the amount of details, it is not suitable for the studying and understanding the operating characteristics of power plants. The use of the Modelica can offer a practical solution, allowing dynamic simulators that are detailed enough for the study of design, control strategy and operational requirements with limited computational requirements[1].

The PGSFR steam generators are a once-through straight tube bundle design. A thermal-hydraulic analysis model of a once-through steam generator is developed by using Dymola in the Modelica language. The Modelica model for SG component will be used for the dynamic simulation modeling of the SFR nuclear plant. The steady state of PGSFR steam generators are analysed by using the developed model. The steady state analysis results of the model are compared with design data[2]. Representative results of the model calculations are presented.

2. Methods and results

2.1 Modeling of Steam Generator

The steam generator components can be considered as one dimensional, which is justified by the large ratio between the length and the diameter of the tube. Simple model of a steam generator is modeled as two flow channels and one metal tube wall. Flow channels can be represented by the pipe elements[3],[4]. The primary fluid flows on the shell side in the PGSFR steam generators. For the primary side Dynamic pipe model with storage of mass and energy is built from models (Modelica.Fluid.Pipes.DynamicPipe) in the Modelica Standard Library. The sodium liquid flows in shell side. The Modelica Standard Library provides a number of medium models, but sodium properties of SolarTherm library[5] is used for the primary side fluid. In the secondary side it includes single phase flows with water and steam, or two phase flows. Secondary flow channels are represented by one of the pipe model (ThermoPower.Water.Flow1DFV2ph), which is built from the ThermoPower library[6]. The model uses Chen' correlation for two phase heat transfer coefficient. Pipe wall with capacitance (Modelica.Fluid.Examples. HeatExchanger.BaseClasses.WallConstProps) is also built from the Modelica Standard Library, it is assuming radially 1 dimensional heat conduction and constant material properties. Axial heat conduction is ignored, capacitance is lumped at the arithmetic mean temperature. Since the tubes are of cylindrical shape, it is necessary to take account of the thermal resistance of the tube wall by adjusting wall thickness. Fouling factor can be also considered by adjusting wall thickness. The models of the steam generator are presented in Fig. 1. The number of nodes is 20.

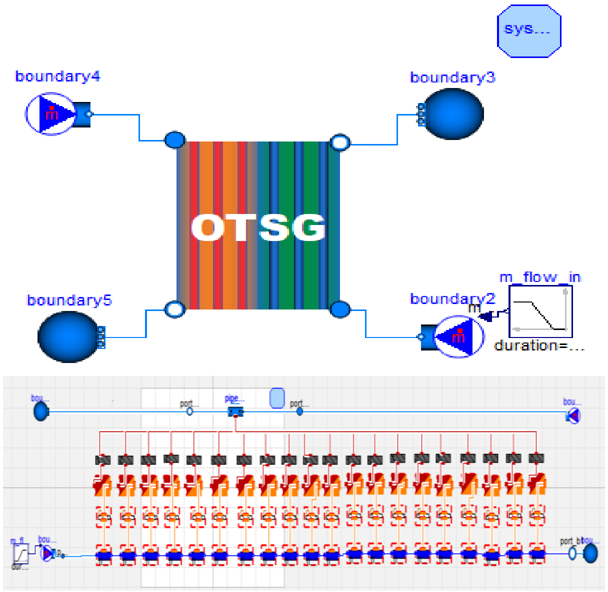

Fig. 1. Modeling of the Steam Generator.

2.2 Steady State Analysis of PGSFR OTSG

The PGSFR steam generator (196 MW per 1 SG) is a 769 tube, counterflow heat exchanger that has the 25.145 m heated length as the OTSG. The tube bundle consists of 12.7-mm- i.d., 17.3-mm-o.d. 9Cr-1Mo tubes, spaced on a 32.3 mm triangular pitch. Table 1. presents sodium exit temperature, steam exit temperature and heat transfer rate of PGSFR design and Dymolar results. Relative errors are within 0.2%.

Table 1. PGSFR Design and Dymolar Results

	design	Dymola	Relative error [%]
Sodium Exit Temperature [℃]	332	331.5	0.2
Steam Exit Temperature [℃]	503	503.9	0.2
SG Heat Transfer Rate [MW]	196.0	196.3	0.2

Figures 2, 3, 4, 5, 6 present temperature, heat transfer coefficients, quality, heatflux and pressure at 100% power.

In Fig. 2 it is seen that the subcooled heating, boiling and superheating occurs within tubes in OTSG, and the steam is superheated close to the inlet sodium temperature. Heat transfer coefficients of sodium side is much higher than water/steam side except boiling region. Pressure drop after boiling increases faster than subcooled heating region. It is because flow velocity increases due to density decrease.

Figures 7, 8, 9, 10, 11 present temperature, heat transfer coefficients, quality, heatflux and pressure at 30% power.

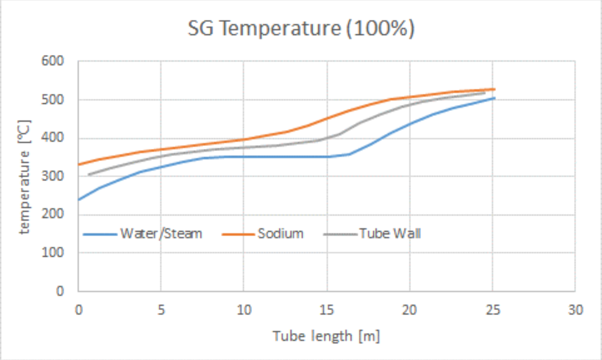

Fig. 2. SG temperatures at 100% power.

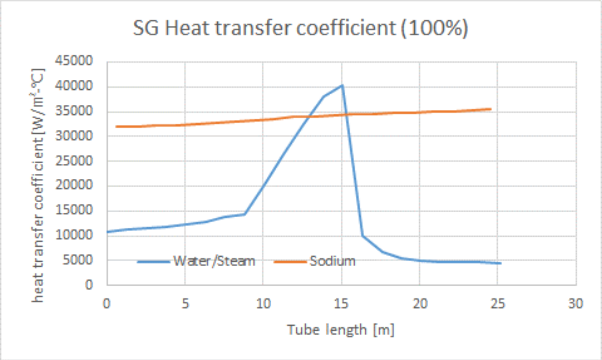

Fig. 3. Heat transfer coefficients at 100% power.

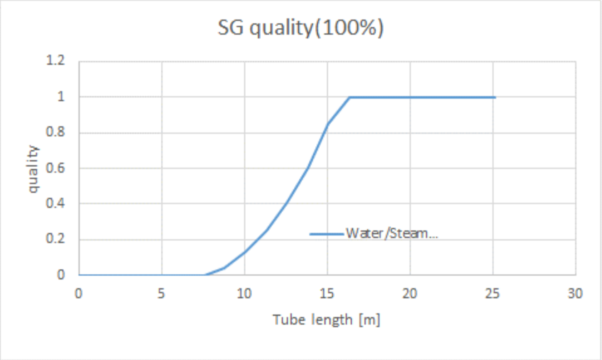

Fig. 4. Quality at 100% power.

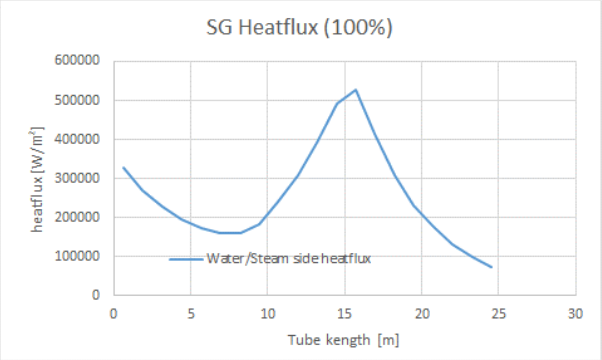

Fig. 5. Heatflux at 100% power.

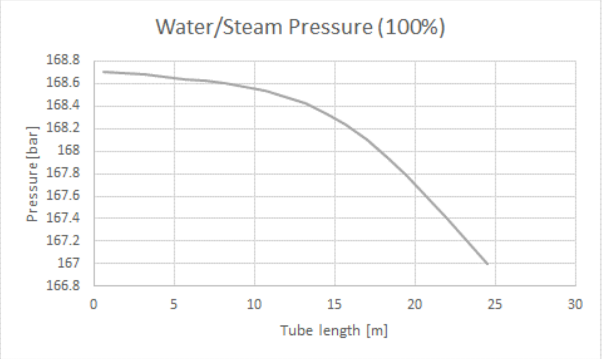

Fig. 6. Water/steam pressure at 100% power.

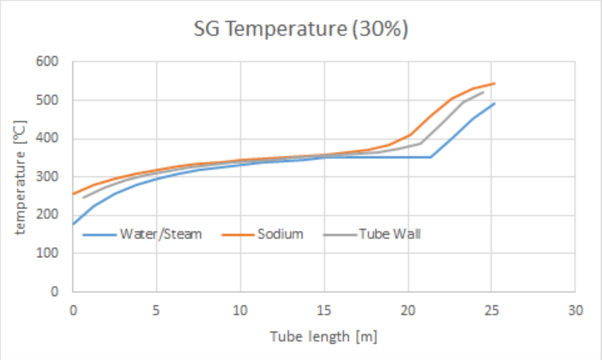

Fig. 7. SG temperatures at 30% power.

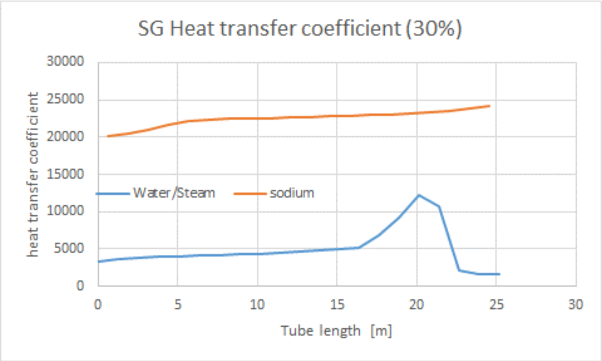

Fig. 8. Heat transfer coefficients at 30% power.

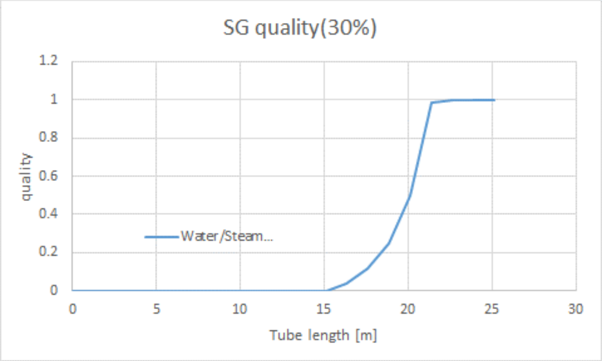

Fig. 9. Quality at 30% power.

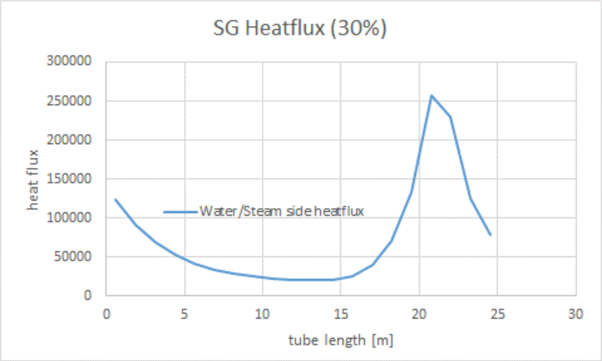

Fig. 10. Heatflux at 30% power.

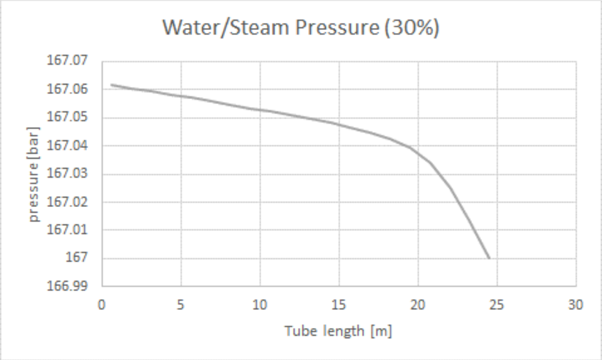

Fig. 11. Water/steam pressure at 30% power.

3. Conclusions

A thermal-hydraulic analysis model of a once-through steam generator is developed by using Dymola in the Modelica language.

The steady state of PGSFR steam generators are analysed by using the developed model. The comparison of results of the model and design data shows that relative errors are less than 0.2%.

The Modelica model for SG component has been developed, and will be applied for the development of the dynamic simulation modeling of the SFR .

ACKNOWLEDGEMENT

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