Thermal hydraulic Analysis of VVER-1000 Condenser by RELAP5 Code

Masoume Maleki Rizi
Department of Nuclear Engineering, Science and Research Branch, Islamic Azad University, Tehran, Iran
Email: masoum_maleki67@yahoo.com

Kamran Sepanloo
Nuclear Science and Technology Research Institute (NSTRI), Tehran, Iran
Email: ksepanloo@aeoi.org.ir

Ehsan Zarifi
Nuclear Science and Technology Research Institute (NSTRI), Tehran, Iran
Email: ezarifi@aeoi.org.ir

Abstract

From the point of view of plant availability, condenser performance is extremely important. It is even more crucial in cases of aged NPPs. Condenser performance plays a key role in nuclear power plant safety. For the analysis of a nuclear power plant, it is essential to have a reliable thermal-hydraulic model of condenser. The aim of this study is to conduct a thermal-hydraulic analysis of a Bushehr VVER-1000 reactor condenser. This paper provides a semi two dimensional thermal-hydraulic model of the condenser using the RELAP5 code. Two main advantages of the present model are the application of a valid nodalization method and a consideration of the cross-flow effects. The obtained results from the RELAP5 steady state analysis were in reasonable agreement with the Bushehr NPP Final Safety Analysis Reports (FSAR).

Keywords: condenser, Bushehr NPP, thermal-hydraulic analysis, RELAP5 code

Introduction

In all nuclear power plants with a pressurized water reactor, an important aspect to consider is the steam production unit. This is particularly the case for a condenser section. However, the inclusion of this section in power plants, as well as in nuclear power plants, is necessary. By setting this system into the heating cycle, the received heat from the hot source is transferred to the cold source environment. Thus, by adding the condenser to the power plant, the fluid cycle is stored in the condenser and is re-pumped into the heat exchanger. Additionally, by using a condenser, a low pressure instead of an atmospheric pressure can be achieved. This results in increased plant efficiency. Practically, taking into consideration the two-phase flow and heat transfer mechanisms through displacement with boiling at the outer surface of the heat exchanger tubes, the process of conducting a mathematical analysis and developing a thermo-hydraulic model is very complex. Using strong nuclear thermo-hydraulic package codes, including RELAP5, TRAC, ATLETH and CATHARE, will greatly help to achieve this modeling. Furthermore, the selection of RELAP5 code to simulate the condenser is due to its capability of analysis of two-phase fluids, as well as the advantage of having the relevant models. In this study, we analyzed and evaluated the results of the Bushehr nuclear power plant condenser calculations using proper RELAP5 nodalization. We compared the results of the code with the plant FSAR.

Methods and materials

1. Description of the Condenser

A condenser is a device used to condense steam so that the latent heat of steam distillation is cooled with water or air (Todreas and Kazimi 1982; 1990). In order to reuse the output steam of the turbine as feed water to the steam generators, the steam must be distilled into water. This is carried out by a condenser. A condenser inlet steam pressure is approximately 0.25 Mpa and its exit pressure is approximately 7.55 kPa. The flow rate of the cooling fluid temperature at 28 0C is equal to 222000 m^3/h (FSAR of BNPP-1, 2003). A condenser is arranged to receive 3600 t/h steam from the turbine. In each condenser, pathways of dual-flow design allow the isolation of one which subsequently leads to the isolation of the cooling water. This is achieved without turning off the turbine and keeping it at 60% of its output. This study provides some of the features of the Siemens built Bushehr nuclear power plant condenser.

Table 1. Technical characteristics of the Bushehr nuclear power plant condenser

Parameter	Value
Heat transfer surface, m^2	76960
Quantity of cooling tubes, pcs	73460
Cooling water flow, m^3/h	222000
Turbine exhaust steam flow, t/h	3316
Condenser pressure, kPa	7.55
Condensate outlet temperature, °C	40.4
Circulating water inlet/outlet temperature, °C	28/35.7
Tube dimensions (diameter and length), mm	∅23x14500
Circulating water velocity in the tubes, m/sec	2.3
Circulating water pressure loss, kPa	60

2. RELAP5 Code

RELAP (Reactor Excursion and Leak Analysis Program) (Ransom et al., 1990) was developed in the Idaho National Engineering Laboratory in the United States. In this code, the fluid model is based on mass and energy balance equations for each control volume. These volumes are connected together by the connections (junctions). The thermo-hydraulic model of a two-phase flow includes cross-border transport process equations of mass, momentum and energy. A RELAP5 analysis of an issue includes

1) collecting, organizing and taking into account the boundary conditions, 2) definition and nodalization, 3) ensuring the quality of the model and 4) running the code and analysis of the results.

3. Condenser Modeling

In general, before presenting any models for a project, it is necessary to know and understand its phenomena. In this way, the model presented for a project can be geometrically consistent with the studied system. In steady state conditions, the results of the model should be consistent with the measured values. Furthermore, in transient conditions, it should accurately express the behavior of the system. The modeling of a condenser is made in primary and secondary parts. The primary part of the condenser is divided into six sections. These are lower plenum, place of the heat exchanger tubes package, upper plenum, vapor input, condensate output and moisture separators. The area of heat exchanger tubes package consists of eight groups of vertical tubes that are modeled by 77 horizontal junctions for simulation of cross-flows. A water level controller is also considered. This shows the condenser water level in different channels at different times. The secondary part of the condenser (73455 tubes) is modeled by two different groups of tubes in RELAP5. Here, eight control volumes are considered for each tube. The input and output are simulated with 13 control volumes of Branch type.

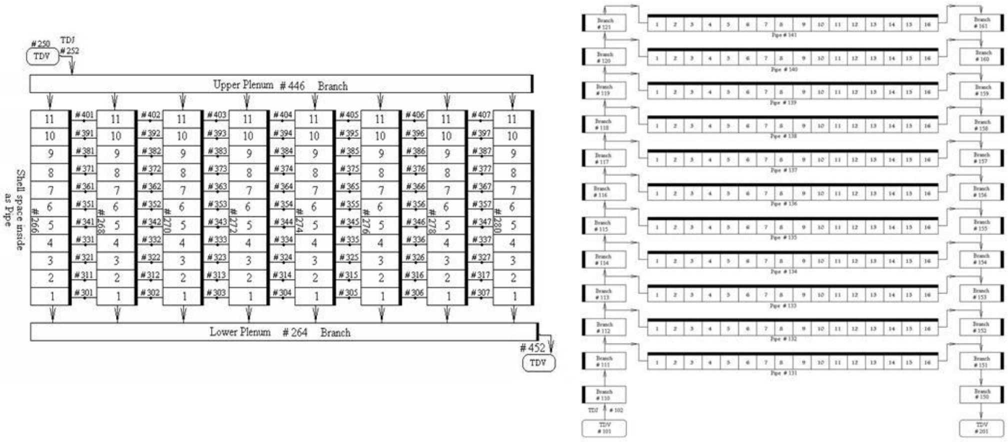

Figure 1. Nodalization of primary and secondary parts of the condenser

4. Results

In Table 2, we compare the results of the calculations performed with RELAP5 code with the design values (FSAR of BNPP-1, 2003). As the table indicates, the results of the modeling almost coincide with the design values. The differences could be related to a modeling error.

Table 2. Comparison between the design values and values calculated by code RELAP5

Parameter	Designed	Calculated
Steam capacity, (kg/s)	61431.84	61430.41
The output of the sea water temperature cycle (^{o}C)	35.7	35.4
Water temperature at the outlet of the condenser vessel (^{o}C)	40.4	40.3
Percent of steam separated	100	99.96

Figure 2 presents the graph of velocity gradient at a middle vertical flow channel and cross-flow junctions. According to this figure, the flow velocity in the cross-flow junctions in different areas is comparable to the velocity of the vertical flow channels. Thus, the cross-flow is essential to achieve acceptable results.

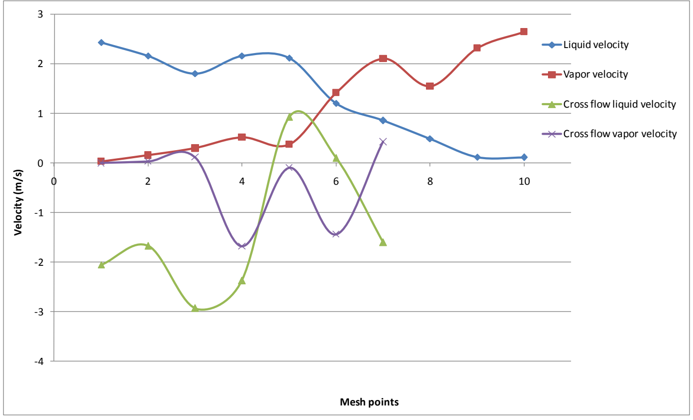

Figure 2. Velocity gradient at a middle vertical flow channel and cross-flow junctions.

In Figures 3 and 4, respectively, the temperature in the tank (condenser steam cycle) and the temperature distribution inside the heat exchanger tubes of the condenser (sea water cycle) are shown.

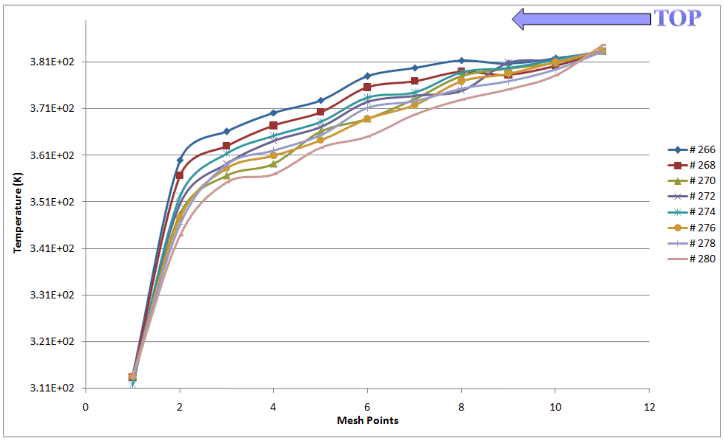

Figure 3. Axial temperature distribution inside the condenser.

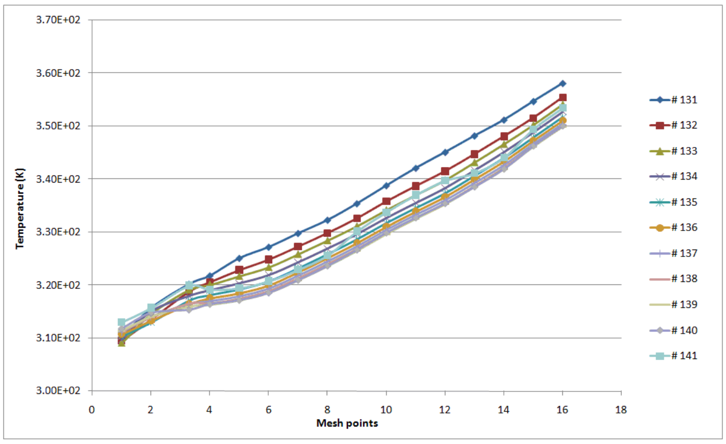

Figure 4. Temperature distribution inside the heat exchanger tubes.

In the above graphs, we can see that heat is transferred from the primary cycle (vapor) to the secondary cycle (sea). This is due to the heat exchange. Inside the condenser, the greatest temperature drop occurs in the lower parts of the condenser. This is because there are only fluid phases in this area. Thus, due to the increased heat transfer coefficient, the most heat transfer occurs in this area. Furthermore, the highest temperature occurs in the lower part of the heat exchanger tubes (tube number 131) which is shown in Figure 4. On the other hand, heat transfer coefficient is very low in the upper parts of the condenser due to the presence of vapor. As a result, the lowest rate of heat transfer occurs in these areas. Figure 5 presents the graph of changes in water levels at different times.

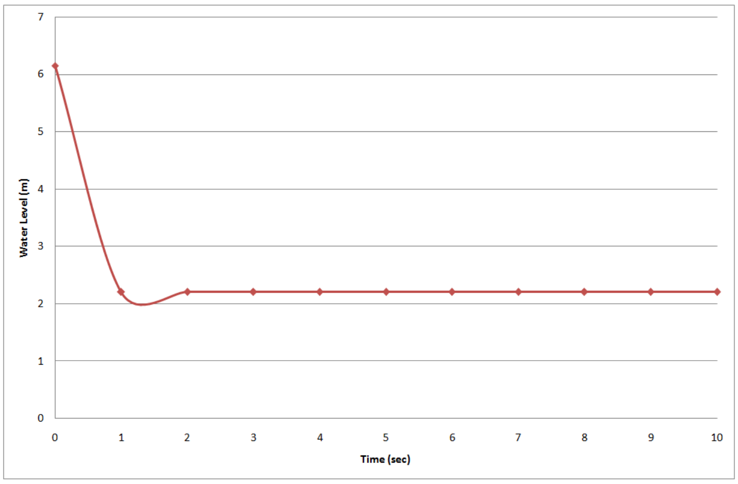

Figure 5. Water levels control at different times using RELAP5 code.

Figure 6 shows the graph of changes in the distribution of void fraction on the vertical flow channels.

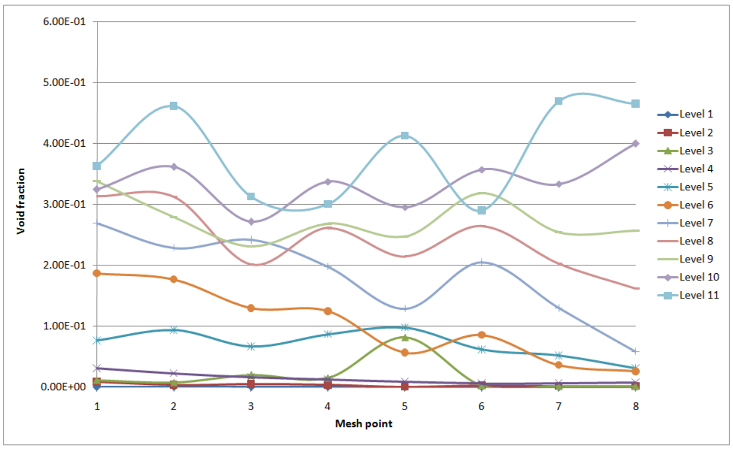

Figure 6. Comparison of the void fraction distribution in different flow channels.

The void fraction shows the highest value in the upper parts of the condenser and the lowest value in the lower parts. The reason for this is that the turbine exhaust vapor is injected to the upper part of the condenser. As a result of the heat exchange, the vapor loses its temperature and turns into water. Therefore due to concentration of the water of vapor condensation in the lower part of condenser, the void fraction reaches its minimum value, i.e., close to zero.

Conclusion

The purpose of this study was to provide a thermo-hydraulic model of a condenser with convection. The results obtained for the thermo-hydraulic parameters were compared with the available reference values to ensure the accuracy of the modeling. Additionally, we conducted a comprehensive analysis of the condenser performance. The output study revealed sensitivity and relation of the different parameters in the thermo-hydraulic results on natural convection regime. It is important to note that, with this model, we can effectively predict the condenser behavior in stable and transient conditions. The cross-flow in the heat exchanger tubes package is one of the advantages of the proposed model, regardless of the fact that it is impossible to achieve acceptable results and get close to the actual flow pattern in the condenser. According to the results of the code RELAP5, in future work, it might be possible to study the influence of geometrical parameters on the condenser design. Furthermore, it might be possible to assess sensitivity analysis, impact of corrosion and deposits in the condenser function, as well as to conduct an analysis of different events (scenarios) on the model. Furthermore, future studies could include analysis of the dynamic behavior of the system.

References

FSAR of BNPP-1. (2003). Final Safety Analysis Report of Bushehr Nuclear Power Plant, Ministry of Russian Federation of Atomic Energy (Atomenergoproekt), Moscow.

Gavin, Henderson. Wenzhong, Zhou, Shripad. and Revankar, T. (2010). Condensation in a vertical tube bundle passive condenser – Part 2: Complete condensation, International Journal of Heat and Mass Transfer, 53 (5–6), 1156-1163.

Hong Gang, Hu. and Chao, Zhang. (2007). A modified k–ε turbulence model for the simulation of two-phase flow and heat transfer in condensers, International Journal of Heat and Mass Transfer, 50 (9–10), 1641-1648.

Ransom, V.H. Wagner, R.J. Trapp, J.A. Johnsen, G.W. Miller, C.S. Kiser, D.M. and Riemke, R.A. (1990). RELAP5/MOD3: Code manual: user guide and input requirements.

Revankar, Shripad T. Oh, Seungmin. Zhou, Wenzhong. and Henderson, Gavin. (2009). Scaling of passive condenser system for separate effect testing, Nuclear Engineering and Design, 239, 1870-1878.

Todreas, N. E. and Kazimi, M.S. (1982). Nuclear system I, Thermal Hydraulic Fundamentals, Taylor & Francis, USA.

Todreas, N. E. and Kazimi, M.S. (1990). Nuclear system II, Elements of Thermal Hydraulic Design, Taylor & Francis, USA.