Performance Comparison of RHR Systems with Different Pump Performance Curves

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1. Introduction

In thermal-hydraulic analyses, safety-related pumps are often modeled as boundary conditions with a certain constant flow rate: their rated flow [1-2]. This stems from the assumption that the pump continuously supplies rated flow rate during operation. However, the assumption might not be appropriate in the case where the system resistance varies during operation. This is because pump operates at the intersection of the pump performance curve and the system resistance curve [3].

The Residual Heat Removal (RHR) system is the typical case in which the system resistance varies during its cooling operation. The properties of the coolant change with it cooled, and it continuously causes the system resistance to vary. This indicates that the pump of the system does not always operate at a rated point, and therefore needs to be modeled as its own performance curve for realistic analysis.

In this study, the performances of the RHR systems were compared. The systems have different pump performance curves which have the different gradients but the same rated point. The comparison of the system performances can help determine whether it is important to model the pump as its own performance curve.

The MARS-KS 1.4, one of the representative system thermal-hydraulic analysis codes, was used to set and solve the problem. The pump model of the code was used to model the pumps as the performance curves. The predictive performance of the pump model was confirmed by comparing it with the analytical pump model in the author's previous work [4].

2. Methods and Results

2.1 The Reactor and the Residual Heat Removal System

For this study, a light water reactor with a RHR system were modeled. The RHR system consisted of one pump, one heat exchanger, and piping. The major specifications of the reactor and the RHR system was summarized in table I; these were determined by referring to the APR1400 design control document [5].

The initial condition of the calculation were based on the condition 14 hours after the reactor trip. The initial temperature and pressure of the reactor were 449.7K and 3.10 MPa, which are the entry condition of RHR system of the APR1400. The decay heat was assumed to be 39.8 MW which is 1.0% of the design power, and it was removed by 305K cold water on the shell side of the heat exchanger. The temperature of the shell side water was determined taking into account the reasonable cooling time of the reactor.

Table I: The Major Specification

Reactor	
Design Power (MW_{th})	3983
Decay Heat (% of the design power)	1.0
Total Coolant Volume (m^3)	453
RHR Pump	
Rated Flow rate (m^3/s)	0.342
Rated Differential Pressure (m)	140.2
RHR Heat Exchanger	
Effective Area (m^2)	776.9
Shell Mass Flow Rate (kg/s)	691.7
Inlet Temperature (K)	305

2.2 The Performance Curves of the RHR Pumps

For the comparison, three pumps with different performance curves were considered. The curves have different gradients but the same rated point: the same rated flow rate and the same differential pressure. The curves were modeled in the form of quadratic equation, and their gradients were determined taking into account the general characteristics of centrifugal pump [3].

Figure 1 shows the performance curves of the pumps: (a) the relatively steep gradient curve, (b) the reference gradient curve, and (c) the relatively gentle gradient curve. Q and H represent flow rate and differential pressure, respectively. The subscript r represents the rated condition.

2.3 Performance Comparison of the RHR Systems

In order to quantitatively measure, the performances of the RHR systems were represented as the cooling time from 449.7K to 372.0K based on the system temperature. 449.7K means the temperature at which the RHR system enters, and 372.0K means the temperature at which the reactor enters cold shutdown mode based on the APR1400.

Figure 2 shows the results of the performance comparison of the RHR systems with different pump performance curves. Compared to the result of (b), the result of (a) showed a difference of 1.88%, and the result of (c) showed a difference of 2.49%. Meanwhile, the biggest difference of 4.52% occurred in the results between (a) and (c) based on the result of (a). The performance curve gradients of these two pumps, (a) and (c), differ the most.

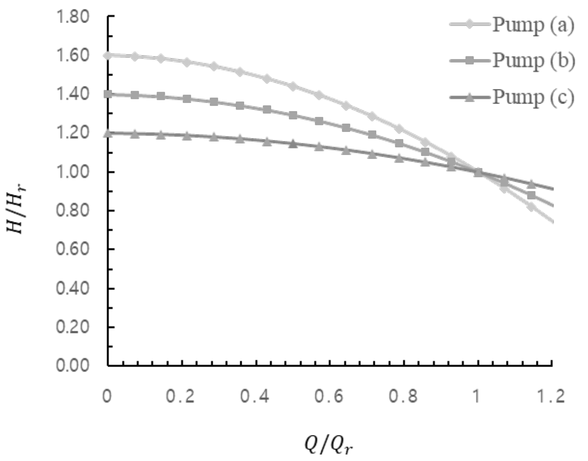

Fig. 1. The Different Pump Performance Curves

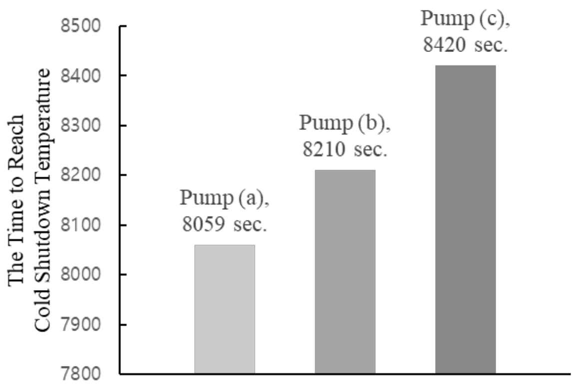

Fig. 2. The Performances of the RHR Systems

It is interesting that the results of the pumps with the same rated point had significant differences: the biggest one was 4.52%. These differences show that the performance curve of the pump has a substantial effect on the performance of the RHR system, and indicate that modeling the pump as its rated flow might not be appropriate to properly reflect the behavior of the pump. In other words, it might be required to model the pump as its own performance curve in order to simulate the behavior of the pump.

3. Conclusions

In this study, the performances of the RHR systems were compared. The three pumps with different performance curves were considered for comparison. The cooling time from 449.7K to 372.0K based on the system temperature was used to represent the performance of the RHR system. This study is summarized as follows.

- Although the three pumps have the same rated flow rate and differential pressure, the performance results of the pumps showed up to the difference of 4.52% depending on their performance curve gradients.

- These results mean that the performance curve of the pump has a substantial effect on the performance of the RHR system, and indicate that modeling the pump as its rated flow might not be appropriate to properly reflect the behavior of the pump.

- Therefore, in order to properly simulate the behavior of the RHR system with the pump, modeling the pump as its own performance curve might be required.

Further study to investigate how the pump performance curves affects the performance of the system will be conducted based on this study.

DISCLAIMER

The opinions expressed in this paper are those of the author and not necessarily those of the Korea Institute of Nuclear Safety (KINS). Any information presented here should not be interpreted as official KINS policy or guidance.

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