Design of passive decay heat removal system using thermosyphon for low temperature and low pressure pool type LWR

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1. Introduction

Low temperature and low pressure pool type LWR is commonly used for research reactor due to its safety. The reactor is not suitable for electric power production because low coolant temperature makes low efficiency. In seawater desalination process which doesn't need high temperature steam, the reactor has profitability. KAIST has be developing the new reactor design, AHR400, for only desalination. For maximizing safety, the reactor requires passive decay heat removal system. In many nuclear reactors, DHR system is loop form. The DHR system can be designed simple by applying conventional thermosyphon, which is fully passive device, shows high heat transfer performance and simple structure. DHR system utilizes conventional thermosyphon and its heat transfer characteristics are analyzed for AHR400.

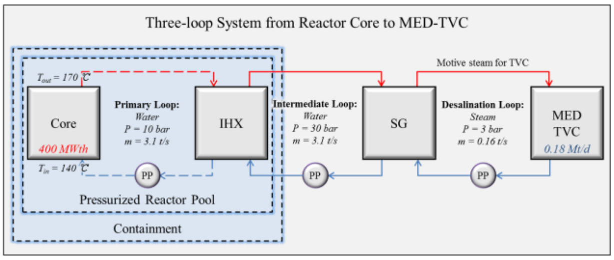

Fig. 1. Concept of AHR400 for only desalination.

2. Decay heat removal system design

To analyze DHR system, DBA has to be constructed. AHR400 has 400 MW of thermal power and the system consists of 3 parts, nuclear reactor, intermediate loop, and desalination process. The DBA is loss of heat sink caused by failure in intermediate loop or desalination process; LOCA isn't considered.

2.1 Heat removal requirement

The heat removal requirement is 3.2MW. This result comes from the constraint prohibiting boiling of coolant in nuclear reactor. The decay heat rate after shutdown follows ANS decay heat curve and the total coolant volume in reactor is assumed 400m^3. The DHR system is assumed to be operated after shutdown instantly. The 3.2MW of continuous heat removal doesn't allow the coolant temperature to exceed saturation temperature of designed pressure. The DHR system has 4 trains and each train takes 50 % of requirement.

2.2 DHR system configuration

The DHR system divides into two parts, evaporator and condenser. Evaporator is submerged in hot pool which has high temperature for maximizing temperature difference between heat source and heat sink, and condenser is exposed to heat sink. The heat sink is water for satisfy requirement. Temperature difference between reactor coolant and atmosphere is low (about 130K), so air heat sink needs large heat transfer area (~4,000m^2) for removing 100% of required performance. The heat transfer area of PAFS is 300m^2, therefore air heat sink is not reasonable. Water heat sink makes the required heat transfer area 40~60m^2.

During normal operation, coolant in heat sink and condenser are isolated from each other, then heat loss is 1% of DHR requirement. During accident, coolant is injected to heat sink tank by gravity.

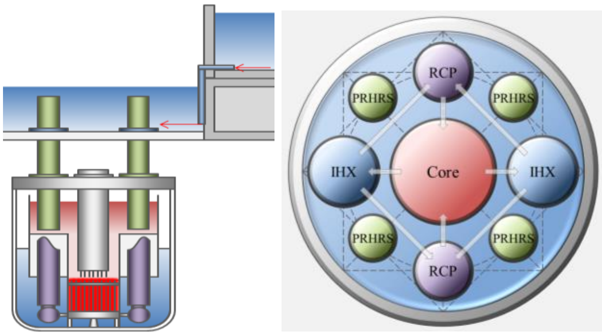

Fig. 2. Layout of passive decay heat removal system for AHR400

2.3 Thermosyphon design

The thermosyphon is manufactured by copper which has low corrosion with water and high thermal conductivity. Heat transfer characteristics is analyzed in 6 parts; natural convections on thermosyphon outer wall, conductions in thermosyphon wall, evaporation and condensation of working fluid.

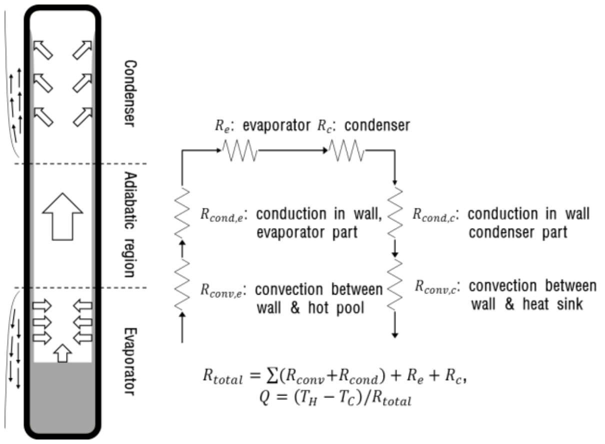

Fig. 3. Thermal resistance model for thermosyphon analysis

The thermal resistance model for analysis is shown in Fig. 3. Natural convection is analyzed by Churchill and Chu's correlation. Evaporation of working fluid is by Imura's correlation and condensation of working fluid is by Seban and Faghri's theory. The analysis is performed by iteration process in Matlab.

Temperature of heat source is 175℃, hot pool, and the heat sink tank is water, and heat transfer between heat sink and atmosphere is neglected. Then, heat sink temperature rises its saturation temperature, 100℃. Therefore, the analysis is performed when heat sink is 100℃.

Heat transfer is interfered when the heat flux exceeds entrainment limit, over which liquid film swept away by the strong vapor flow. The entrainment limit is analyzed by Imura's research. When length of evaporator is 14 times of diameter and length of condenser is 22 times of diameter, the thermosyphon shows maximum heat transfer rate under entrainment limit.

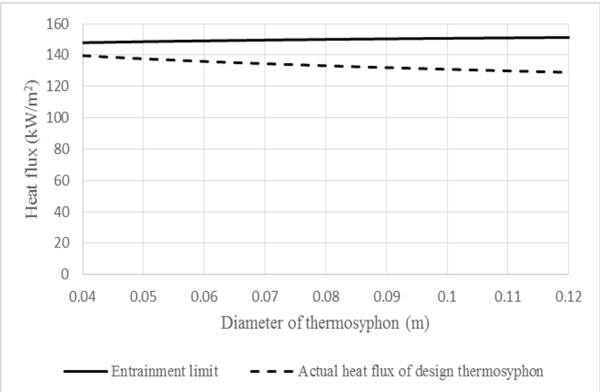

Fig. 4. Entrainment limit and heat flux on evaporator of designed thermosyphon. The thermosyphon shows heat transfer performance closed to entrainment limit. This result comes when the heat sink temp. is 35℃, because of its initial condition.

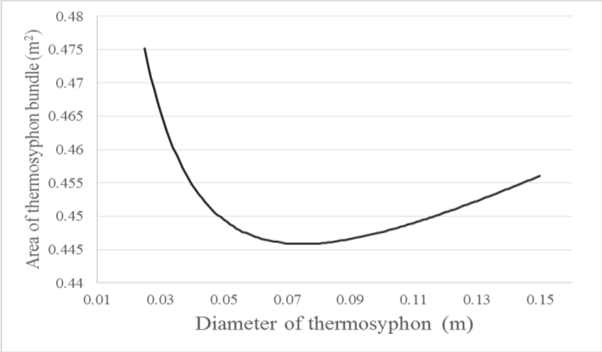

Fig. 5. Section area of thermosyphon bundle by changing diameter of thermosyphon

2.4 System optimization

One single thermosyphon has large volume for providing heat transfer area to remove 50% of required performance. Therefore, the configuration of the decay heat removal system is a bundle of thermosyphon for securing enough heat transfer area. Gap between thermosyphons is 3 times of boundary layer thickness of natural convection on wall, which one doesn't affect heat transfer of the others. Fig. 5. shows that 7cm diameter thermosyphon holds minimized section area.

3. Conclusions

For maximizing safety of the reactor, passive decay heat removal system are prepared. Thermosyphon is useful device for DHR system of low pressure and low temperature pool type reactor. Thermosyphon is operated fully passive and has simple structure. Bundle of thermosyphon get the goal to prohibit boiling in reactor and high pressure in reactor vessel.

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