Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 12-13, 2016

P*X* – Siphon Tube for an Unmanned Reactor Cooling

Sung-Jae Yi*, Sung Uk Ryu, Hyun-Sik Park, Ki-Yong Choi
Korea Atomic Energy Research Institute,
Deadeok-Daero 989-111, Yuseong-Gu, Daejeon, Korea.
**Corresponding author, E-mail : sjlee2@kaeri.re.kr*

1. Introduction

A fast heat transfer mechanism for the reactor cooling after trip is one of the important issues to design the innovative pressurized water reactor (PWR). Up to now, typical cooling method of pool boiling has been used for removing the decay heat of reactor. The heat transfer rate of pooling boiling is not so fast compared with spray jet cooling. Therefore a high heat flux mechanism has been studied for the decay heat cooling over several years. Through this work, an innovative feat cooling concept has been developed as the name of P*X* [1]. As one of the research results, a new cooling mechanism of siphon tube is introduced in this paper. It is a unique concept that adopts both an ultimately fast heat transfer mechanism for a small containment to take advantage of the potential, thermal, and dynamic energy of the cold water in the containment effectively. It can realize the rapid cooling of the containment and long-term cooling of the decay heat. By virtue of this innovative concept, a nuclear fuel damage event can be fundamentally prevented. The siphon tube heat transfer mechanism contributes to a minimization of the heat exchanger size and containment volume.

2. Cooling concept of "Siphon Tube"

In this work, a new heat transfer mechanism of siphon tube is introduced. That is one of the fast heat transfer mechanism in the field of two-phase flow with spray jet quenching and condensation in the vertical siphon tube at steam pressure as shown in Figure 1. The order of magnitude for this heat transfer rate is above 10 times that of another method such as two-phase pool boiling [2, 3, 4, 5] in Figure 2, (a). A sprayed droplet is evaporated on the outer surface of the primary heat exchanger tube (hot water supply) and the steam is condensed inside the tube. At the same time, the vaporized hot steam in the siphon tube is condensed on the outer surface of the secondary heat exchanger tube (cold water supply) in Figure 2, (b) , at the same time the water in the lower part of the siphon tube is boiling. Finally, the energy of the secondary side is removed through the ultimate heat sink such as sea water or air cooler out of the containment side. The heat transfer rate by virtue of this mechanism is very fast and sufficient enough to transfer the heat of the siphon tube into the atmosphere without a bottleneck of the heat transfer between the reactor and atmosphere. This fast heat transfer mechanism can reduce both the sizes of the containment and heat exchanger and it does not require any additional cooling system such as a safety injection system or a containment cooling system.

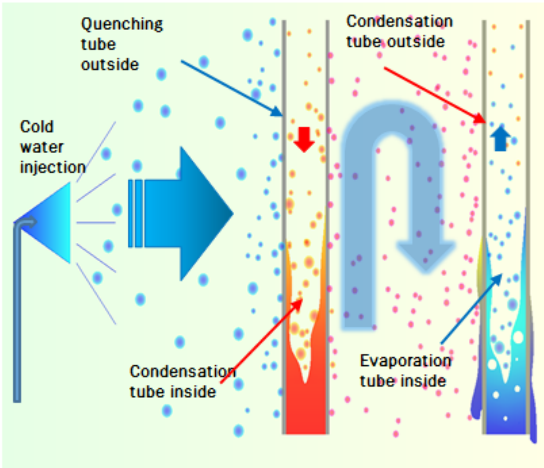
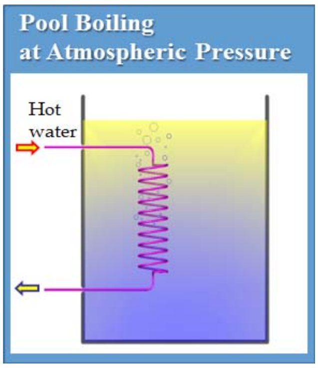
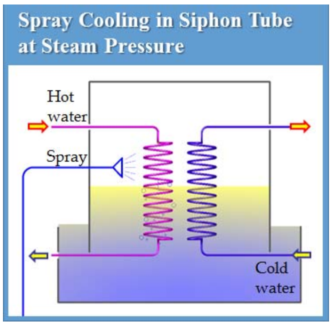


Figure 1. Fast heat transfer mechanism in siphon tube



(a)



(b)

Figure 2. Typical heat transfer mechanisms in shell and tube type heat exchanger

3. Feasible Applications of Siphon Tube System for PWR

In order to realize the innovative cooling concept of siphon tube, a feasible design is suggested for the conceptual design. Figure 3 shows one of the feasible design applications of siphon tube. In this paper, an LOCA(Loss of Coolant Accident) is considered as a base accident scenario as it is one of the most important accident scenarios that use a fast cooling mechanism. The feasible design concept of P*X* is summarized briefly as follows:

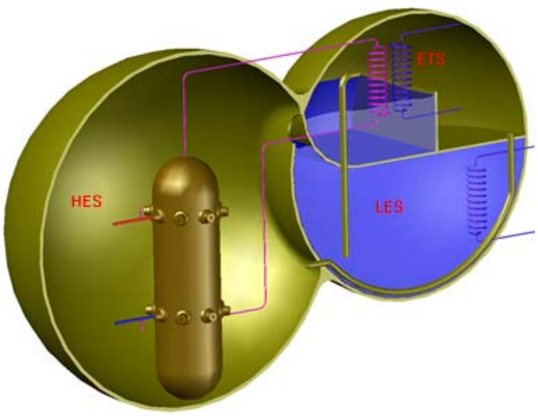
1) Underground location

- To use ultimate heat sink (easy to use the water fro m sea or river)
- Small double & twin containments (for a measure a gainst external disasters)

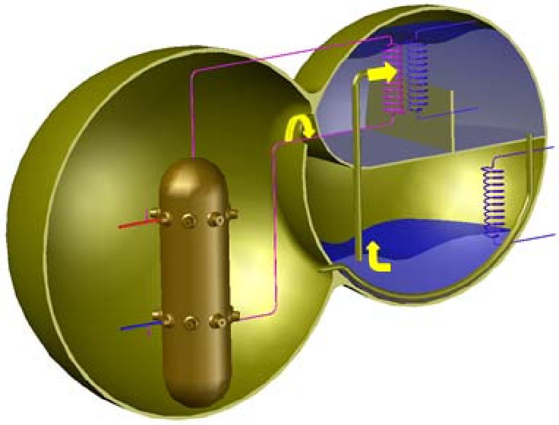
2) Simple unified safety system (no safety injection and containment spray)

3) Self-diagnosis for the accidents

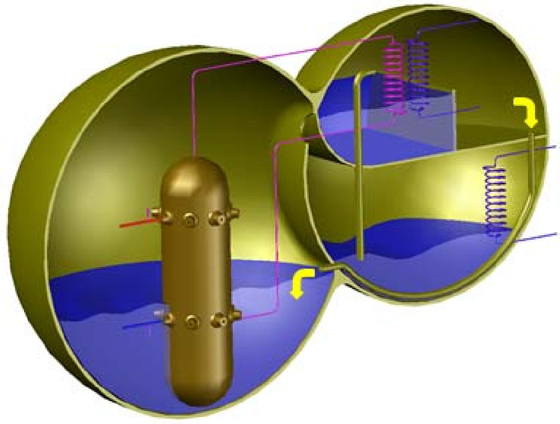
4) Long-term cooling with natural circulation through HES(High Energy Space), LES(Low Energy Spase) and ETS(Energy Transfer Spase)



(a) Normal operation phase



(b) Fast cooling phase



(c) Long term cooling phase

Figure 3. Feasible design and flow pattern of P*X* for LOI accidents

The general working concept of a feasible system of siphon tube was already mentioned in the description of the concept of P*X* [1]. In the case of an LOCA, the detailed sequences of events are described as follows:

1) At the beginning of a break accident in the HES, the air in the HES goes into the entrance fabricated on the wall between the HES and LES, and it pushes the water in the LES into the ETS. This water is injected onto the surface of the primary heat exchanger, as shown in Figure 3(b).

2) After a certain period, the reactor is tripped and the isolation valves are opened according to the given conditions for the reactor protection. After that, the high temperature steam circulates between the reactor vessel and primary heat exchanger. At the same time, a fast heat transfer occurs between the primary and secondary heat exchangers by virtue of a spray jet supplied from the LES.

3) If the pressures of the left- and right-hand side containments become equal, the water in the upper part of the ETS goes down into the HES due to gravity and

cools down the outer surface of the reactor vessel in the HES.

4) The reactor pressure decreases continuously, finally, the pressure becomes equal to the containment (HES, LES and ETS), and another circulation flow then occurs due to the opening of the isolation valve installed on the primary heat exchanger instead of spray injection flow from LES.

5) The energy of the ETS is eliminated by the secondary heat exchanger during an accident.

6) The binary natural circulation mode is the ultimate long-term cooling mechanism in order to fundamentally prevent severe accidents. Therefore, this final safe cooling mode(Natural circulation phase mode between HES and ETS) will be continued by virtue of an unlimited heat sink such as water from a sea or river.

4. Conclusions

A fast heat transfer mechanism for removing the decay heat was developed at KAERI. This innovative concept has unique characteristics of ultimate heat transfer mechanism. It can make the containment size small and ultimate long-term cooling possible. Additionally, this concept for a reactor cooling system has the distinguished ability of self-diagnosis operation for most accidents. With some additional optimized accident management, unmanned reactor operation will be possible in the near future. Finally, this new innovative concept will contribute to economic competitiveness and inherent safety, especially for a small modular reactor.

REFERENCES

[1] Sung-Jae Yi, Chul-Hwa Song, and Hyun-Sik Park, "PX - An innovative safety concept for an unmanned reactor," Nuclear Engineering and Technology, Vol. 48, 2016

[2] S. K. W. Yu, P. R. Farmer and W. E. Coney, "Meth od of correlations for the prediction of quenching rates on the hot surfaces," Int. J. Multiphase flow, Vol. 3, 19 77

[3] Bahman Abbasi, Jubgho Kim and Andre Marshall, "Dynamic pressure based prediction of spray cooling he at transfer coefficients," Int. J. Multiphase flow, Vol. 36, 2010

[4] R. Panneer Selvamm, Lancho Lin and Rengasamy P onnappan, "Direct simulation of spray cooling : Effect of vapor bubble growth and liquid droplet impact on he at transfer", Int. J. Heat & Mass Transfer, Vol. 49, 2006

[5] Ruey-Hung Chen, Louis C. Chow and Jose E. Nave do, "Effects of spray characteristics on critical heat flux in subcooled water spray cooling", Int. J. Heat & Mass Transfer, Vol. 45, 2002