Thermal Sizing of Heat Exchanger Tubes for Air Natural Convective Cooling System of Emergency Cooling Tank

Myoung Jun Kim [a], Joo Hyung Moon [b], Youngmin Bae [b], Young-In Kim [b], Hee Joon Lee [a*]
[a]*School of Mechanical Engr., Kookmin University, Jeongneung-ro 77, Seongbuk-gu, Seoul, 136-702, Korea*
[b]*Korea Atomic Energy Research Institute, Daedeok-daero 989-111, Yuseong-gu, Daejeon, 305-353, Korea*
[*]*Corresponding author: joellee@kookmin.ac.kr*

1. Introduction

Recently emergency cooling tank is a great concern of passive cooling system for the safety of nuclear reactor. When an accident occurs in nuclear reactor, passive cooling system is operated to cool down a huge amount of steam by naturally circulating water in condensation heat exchanger which is immersed into emergency cooling tank as shown in Fig. 1 [1]. For the long operation of secondary passive cooling system, however, water level goes down by evaporation in succession at emergency cooling tank. At the end there would be no place to dissipate heat from condensation heat exchanger. Therefore, steam cooling heat exchanger is put on the top of emergency cooling tank to maintain appropriate water level by collecting evaporating steam. Steam cooling heat exchanger is installed inside an air chimney and evaporated steam is cooled down by air natural convection.

In this study, thermal sizing of steam cooling heat exchanger under air natural convection was conducted by TSCON program [2] for the design of experimental setup as shown in Fig. 2.

2. Thermal sizing of a tube

2.1 Thermal Sizing Program TSCON

TSCON solves one-dimensional steady continuity, momentum and energy equations together by nodalizing a tube. Assuming initial local heat load, condensation part of the tube length and mass flow rate are decided. Total pressure is assumed to be constant through the tube. Inner wall temperature of the tube at each node is calculated by a condensation heat transfer correlation. Outer wall temperature of the tube is calculated by one dimensional tube conduction equation. Tube length calculated by the outside pool boiling heat transfer coefficient is compared to the original. If they did not match each other, the inner wall temperature would be iterated. The original heat load up to satisfy overall heat transfer rate is also iterated. Then, the same procedure applies to single phase part of the tube. Inside the tube the Shah's condensation heat transfer correlation was adopted for condensation section and the Dittus-Boelter for single phase [3]. Outside the tube, a natural convective heat transfer correlation on a cylinder is used for an air cooling [4]. Air properties of thermal

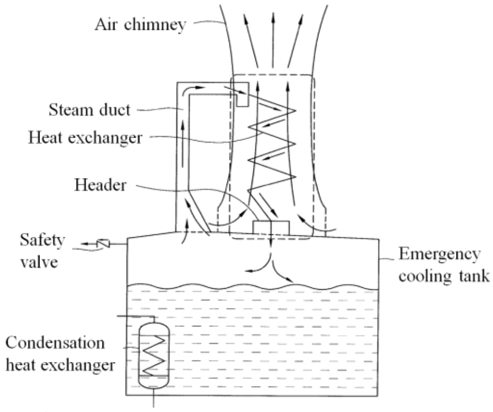

Fig. 1. Schematic of air natural convective cooling system of emergency cooling tank.

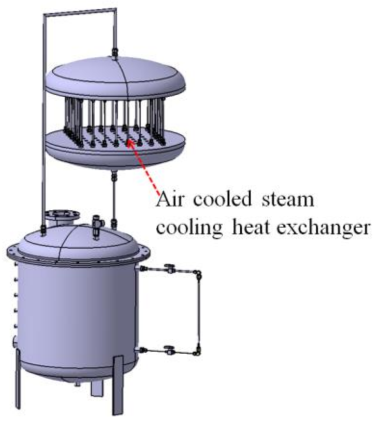

Fig. 2. Drawing of experimental setup.

expansion coefficient for the Grashof and the Prandtl number were obtained from the NIST database [5].

2.2 Experimental setup

Figure 2 shows an experimental setup for air natural convective cooling system of emergency cooling tank. 200 liter emergency cooling tank was manufactured by using 4 mm thickness SUS 304L as a pressure vessel containment. A safety valve was place at the very top of emergency cooling tank side to maintain maximum 1.5 atm steam pressure inside the tank. An immersion heater (~ 5 kW) was mounted to supply heat into water instead of condensation heat exchanger of passive cooling system. At 1.1 atm system pressure condition, the amount of steam generation is 0.83, 1.25, 1.67, 2.08 kg/s

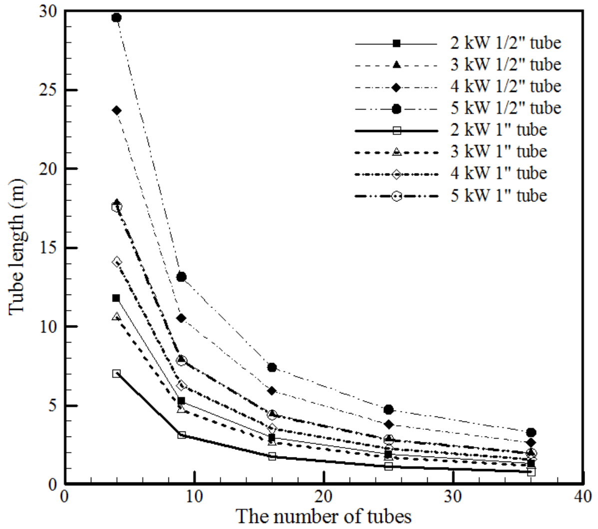

Fig. 3. Tube length vs. the number of tubes of steam cooling heat exchanger.

for 2, 3, 4, 5 kW heating of 100 liter water inside the tank, respectively.

2.3 Thermal sizing procedure using TSCON

The system pressure was set to 1.1 atm in TSCON. The greater system pressure increases, the more convective heat transfer occurs due to the increase of saturation temperature. Therefore, 1.1 atm was chosen as a system pressure between 1.1 and 1.5 atm. Inlet superheating was given as 0.7℃. An iteration was conducted until the outlet subcooling reached within 2℃. The iteration tolerance was 0.001. Ambient air was at 1 atm and 20℃. The steam cooling heat exchanger has a square array type, so that the number of tubes varies from 2^2 to 6^2.

3. Results

Figure 3 shows a tube length versus the number of tube arrays obtained by TSCON. As the number of tubes increases, the tube length decreases due to the increases of heat transfer surface area. Moreover, the greater immersion heater power, the more tube length is required for steam to fully cool down. For the effect of tube outer diameter, 1″ tube length is less than that of 1/2″ tube because that of 1″ tube has greater surface area than 1/2″ and steam flow velocity is lower, which means that steam stays longer inside condensing tube to be cooled down.

There are two constraints to design steam cooling heat exchanger in this experimental. First of all, due to the space limitation, the tube length should be less than about 20000 mm. Secondly, a heat transfer degradation effect was not considered in TSCON program. In other words, TSCON is only applicable to pure steam, not noncondensable gas as a working fluid. In order to count for noncondensable gas effect in the sizing of steam cooling heat exchanger tube, half as many again

Table I: Tube length (mm) sized by TSCON

O.D. (″)	1/2				1			
Power (kW)	2	3	4	5	2	3	4	5
4 tubes	11790	17850	23700	29590	7020	10600	14100	17610
9 tubes	5250	7910	10530	13150	3120	4710	6270	7830
16 tubes	2950	4450	5920	7400	1755	2650	3530	4400
25 tubes	1890	2850	3790	4730	1125	1700	2260	2820
36 tubes	1310	1980	2630	3290	780	1180	1570	1960

of a tube length was selected for the final sizing of tubes in steam cooling heat exchanger.

In Table I, the 1″ tube length is 1125 mm for 36 tubes (5 by 5 square array) at 2 kW heating load. Therefore, 25 - 1″ tubes which has a length 1687 mm (approximately half as many again of 1125 mm) was selected as steam cooling heat exchanger. The width of two tubes is 50 mm where two thermal boundary layers at 1687 mm length tubes are not interfered together.

4. Conclusions

Thermal sizing of steam cooling heat exchanger tube under air natural convection was conducted by TSCON program for the design of experimental setup. 25 - 1″ tubes which has a length 1687 mm was determined as steam cooling heat exchanger at 2 kW heat load and 100 liter water pool in emergency cooling tank (experimental limit condition). The corresponding width of two tubes is 50 mm and has 5 by 5 tube array for heat exchanger.

ACKNOWLEDGEMENT

This work was supported by the National Research Foundation of Korea(NRF) funded by the Korea government (MSIP) (No. NRF-2012M2A8A4025974).

REFERENCES

[1] Y.-I. Kim, K. K. Kim, Y. Bae, J. H., Yoon, J. J. Ha, W. J. Lee, T. Y. Kim, Cooling System of Emergency Cooling Tank and Nuclear Power Plant Having The Same. Korea Patent App. No. 10-2013-0052051, 2013.
[2] Y. J. Ju, H.-O. Kang, T.-H. Lee, C.-T. Park and H. J. Lee, Investigation of Condensation Heat Transfer Correlation of Heat Exchanger Design in Secondary Passive Cooling System, Trans. Korean Soc. Mech. Eng. B, Vol. 37, p. 1069, 2013.
[3] M. M. Shah, An Improved and Extended General Correlation for Heat Transfer During Condensation in Plain Tubes, HVAC&R Research, Vol. 15, p.889, 2009.
[4] F. M. White, Heat and Mass Transfer, Addison-Wesley Publishing Co., Reading, MA, 1988.
[5] http://webbook.nist.gov/chemistry/fluid/