Length effect on thermosyphon thermal performance

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1. Introduction

The severe accident in the Fukushima Daiichi nuclear power plant reminded us importance of management residual heat. After Fukushima accident, many researchers have studied passive cooling system for nuclear plant in order to manage residual heat properly during station blackout (SBO). Among candidates for passive cooling system, wickless heatpipe, we called thermosyphon, have been interested because it has very high thermal performance, simple structure and relatively low price. There have been many tries to predict heat transfer capability and working limitation of thermosyphon, therefore, there are serval correlations equation show a good agreement with experimental data. However, it is very rare about reports of thermal performance of thermosyphon with relatively long length, which can be applied passive cooling system for nuclear plant. For proper design passive cooling system with thermosyphon for nuclear plant, it is essential that predict thermal performance of relatively long thermosyphon. In this study, we did experiment to figure it out length effect on thermal performance of thermosyphon. Two different length type(1m and 3m) of thermosyphons were used and compared experimental data and predicted data by previous correlation equation.

2. Experimental details

In this section, experimental setup details, overall experiment schematic and procedures are described. The experimental set-up details and schematic are given Table1 and Figure1. The filling ratio is calculated by percentage of volume of working fluid divided by volume of evaporator. The experimental procedure is provided in the following.

Table1. Experimental set-up

Material	Stainless steel
Inner diameter [mm]	16.57
Outer diameter [mm]	19.57
Total length [m]	1, 3
Heat load [W]	80-3000
Working fluid	DI-water
Coolant	Water
Coolant temperature [℃]	10-60
Coolant flow rate [Lpm]	0.8-7
Filling ratio [%]	100
Insulation	Glass fiber

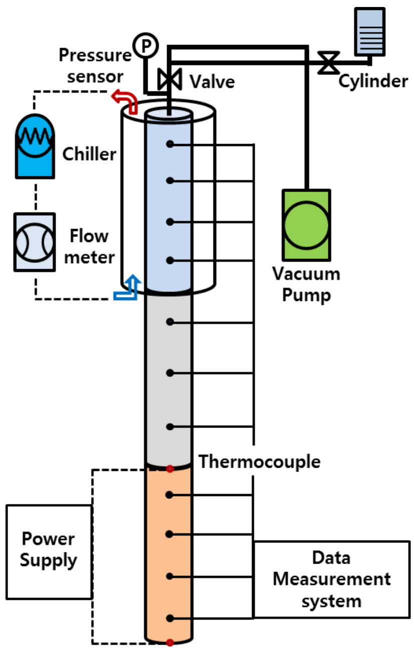

Figure1. Experimental schematic diagram

1) K-type thermocouples are used to measure evaporator and adiabatic surface temperature, T-type thermocouples were used for condenser part.
2) The inside of thermosyphon was vacuumed by vacuum pump before experiment is started.
3) After checking vacuum condition, working fluid was injected to inside of thermosyphon.
4) Coolant fluid was flowed through water jacket, heat load is given by DC power supply.
5) To confirm steady state condition, keep desired heat load and saturation temperature during 5 minute.
6) After checking steady state condition, data were measured during 5 minute with frequency 1Hz by measurement instrument.
7) All experiments were terminated when operating limitation is reached.

The operating limitation was identified when thermosyphon wall temperature was increased with very rapid slope (The operating limitation was shown in Figure2).

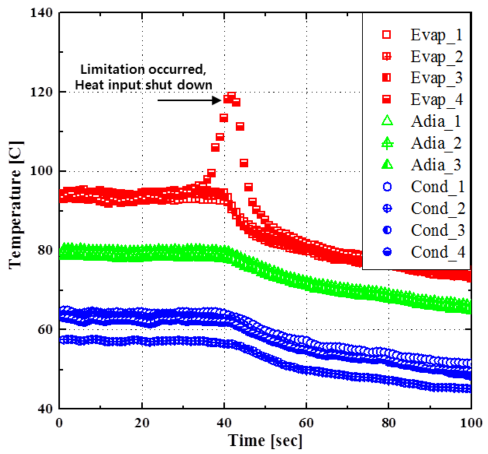

Figure2. Thermosyphon wall temperature distribution when operating limitation was occurred (Total length: 1m, Saturation pressure: 0.50bar).

3. Results and Discussions

3.1. Count Current Flooding Limitation (CCFL)

In this part, we will discuss about length effect on limitation of thermosyphon. There are several kind of operating limitation in thermosyphon. Typically, however, count current flooding limitation (CCFL) is occurred when Filing ratio (FR) is higher than 60%. Therefore, in this study, the occurred limitation was identified as a CCFL. Figure3 shows comparison between present experimental data for 1m and 3m with previous correlations. Most of previous models are based on Wallis model, which considered liquid and gaseous superficial velocities to predict count current flow limitation. Previously, researchers considered filing ratio, inclination angle, L/D effect to expect CCFL accurately. In Figure3, 1m experiment results show it follows Nejat model but it shows deviation as saturation temperature increased. On the other hands, 3m experiment data are followed along ESDU except 0.30bar case. It shows that both of cases showed within previous models but there were no model can incorporate both cases. Recently, however, Seo proposed new model to consider L/D effect on entrainment limitation of thermosiphon, his experimental data also show similar trend with present experimental data. (It was not covered with present study) [1].

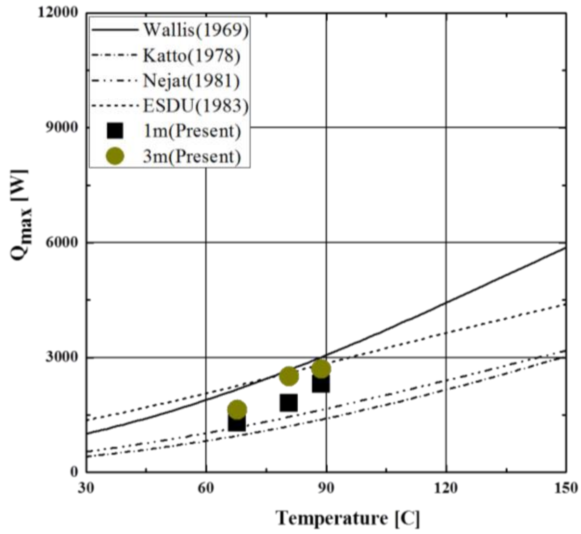

Figure3. Experimental and predicted results for count current flooding limitation (CCFL) of different length thermosyphon.

3.2. Heat transfer for condenser part

In this section, we are going to talk about length effect on heat transfer. The heat transfer for evaporator part would not be covered because it is well modeled based on boiling and film evaporation by many researchers [2] [3]. The heat transfer for condenser part, however, it still have modified to predict in different geometries cases and working fluids, etc [3] [4]. The condensation heat transfer models are generally based on Nusselt film theory. But, in low Reynolds number regions, it could not predict well in thermosyphon cases. Hashimoto [2] considered the effect of entrainment on condensation of thermosyphon, so he proposed new correlation based on Nusselt theory. Also, Jouhara [3] proposed another correlation based Hashimoto model, he considered the effect of film Reynolds number to consider extent of turbulent for condensation heat transfer. As we already mentioned, however, the experimental data of heat transfer for relatively long thermosyphon is rare, so it is valuable to figure it out whether the predicted model can be well match with long thermosyphon case.

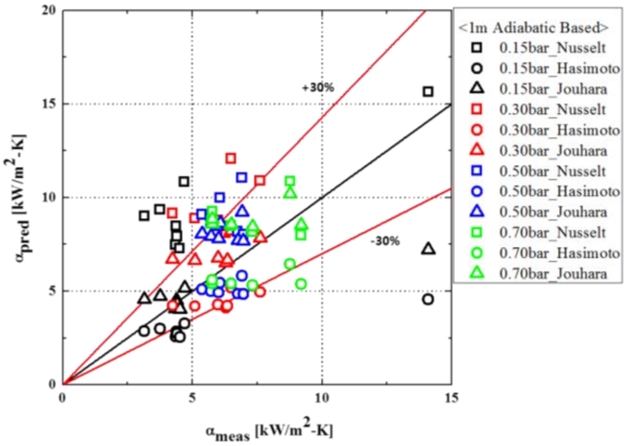

Figure4. Experimental and predicted results for condensation heat transfer with 1m thermosyphon.

The figure4 shows comparison between experimental data and predicted results for condensation heat transfer with 1m thermosyphon case. As we expected, almost all of conditions, the Nusselt model over-predicted condensation heat transfer. Both of the other models, however, showed a good agreement with experimental results. The results are well followed with previous researches [2] [3].

In Figure5, the 3m thermosyphon case, on the other hands, shows different results. All of models over-predicted condensation heat transfer, only Hashimoto model shows around 30% error with experimental data. The results show that length effect on condensation should be considered carefully when the length of thermosyphon is relatively long. It is hard to figure length effect out quantitatively, but we suspected two reasons; 1) as increased thermosyphon length, the extent or type of developed film can be different with relatively short thermosyphon cases, 2) the effect of different developed film may influence on pressure **gradient of condenser part and it can effect on condensation heat transfer.**

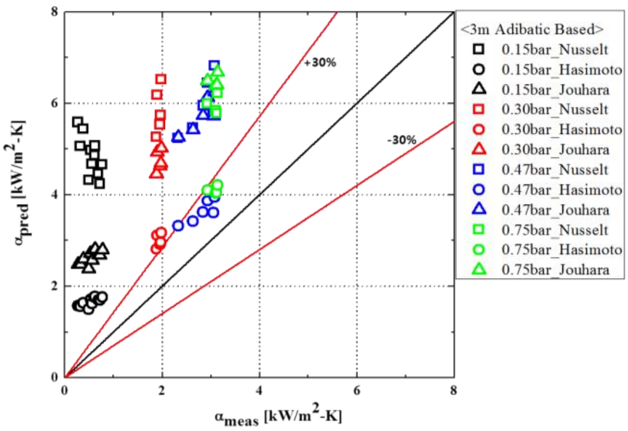

Figure5. Experimental and predicted results for condensation heat transfer with 3m thermosyphon.

4. Conclusions

In this paper, we showed length effect on thermal performance of thermosyphon with different length. Through present study, we can know following points.

1) There is length effect on count current flooding limitation in thermosyphon, therefore, it should be considered when relatively long thermosyphons would be designed. e.g.) Passive cooling system for nuclear spent fuel pool.

2) Excepting Hashimoto model, which shows 30% error with present experiment results, the other models shows very big difference with current experiment data. So, it should be carefully to predict and design condensation heat transfer when length of thermosyphon is relatively long.

3) The reason, which can effect on big deviance between models and present data for condensation heat transfer, can be consider as different extent of developed film and it can have effect on pressure gradient of consider part, which may influence on condensation heat transfer.

But, additional experiments are needed to figure length effect on condensation heat transfer out clearly to propose new correlation.

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