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An Uncertainty Analysis of Temperature Distribution on Loop Heat Pipe Prototype

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Abstract

To improve safety and normal operation aspects to be more economical, the NuScale type power reactor has the potential to be added passive cooling system technology. The technology is a loop heat pipe (LHP) with a wick made of a collection of capillary tubes. To determine the thermal performance of the LHP technology properly, the supporting analysis was needed before the experiment is carried out. One of the necessary supporting factors were to know the accuracy of measuring the temperature distribution on the LHP. The objective of this study was to determine the value of the uncertainty of the thermocouple used in the LHP experiment. By knowing the accuracy of the measurement of the temperature distribution, it is hoped that the resulting data is good and accurate. Data measurement was carried out using the National Instruments data acquisition system. The temperature distribution data retrieval was carried out under the condition that the LHP was in a steady state at the temperature of the hot water as the source of the LHP temperature of 35˚C, 45˚C, 55˚C, and 65˚C. Data collection was carried out within approximately 10 hours of the LHP experiment. The recorded temperature distribution data is then compared with temperature data using a well calibrated derived standard thermocouple. The calculation of the uncertainty value is carried out by statistical methods commonly used to determine the uncertainty of the temperature distribution measurement. The measurement results show that the average temperature value obtained is within the range of the standard uncertainty values of the thermocouple used. The uncertainty value obtained at all measurement points on variations in hot water temperature have value below the standard uncertainty value of the derived standard thermocouple used, which is 0.1°C. Based on these results, it can be concluded that the thermocouple used in the LHP experiment is feasible and has very good accuracy so that it can produce accurate and good LHP temperature distribution data.

Keywords:
uncertainty analysis, thermocouple, loop heat pipe, passive cooling system, nuclear reactor

1. Introduction

The NuScale power reactor, a small modular reactor is one of the candidates for the nuclear power plant that potentially will be built in Indonesia. This power reactor fully involves a passive cooling system as its heat sink into the pool water and immerses the reactor. In its operation, the Nuscale reactor uses cooling water that circulates naturally, and it makes the reactor not use pumps. If a station blackout incident occurred, the reliability of the NuScale reactor can be better than the reactor that uses forced convection dominance in its primary cooling system [1].

With the technology development in the energy conversion field, much potential can be utilized to increase the safety aspect of NuScale operation. One of them is by adding loop heat pipe (LHP) technology into the pool that immerses the reactor [1]. The addition of LHP is expected to assist in releasing the heat accumulated in the pool that submerges the reactor. Therefore, the reactor operation will be safer and have more economic value. From an economic value, LHP is assumed to reduce the pool's water evaporation rate; thus, make-up water in the pool will not be added in a large quantity.

Loop heat pipe, as a type of heat pipe, is an extremely effective absorber and heat sink technology. It works by utilizing the natural circulation that occurs in it without needing an active-driven from the outside [2]. The heat pipe absorbs heat from a heat source through the evaporator section and dissipates heat to the environment through the condenser section [1,3–5].

The literature studies indicated that the heat pipe is a superconductor as a heat transfer technology. It can transfer heat very effectively because it uses a two-phase heat transfer mechanism. The heat pipe is widely used in the field of electronics and aerospace and it is presently being viewed as a technology that will be utilized as a heat transfer in the nuclear field, such as a micro reactor design that exploits a heat pipe as a heat transfer from the reactor core to the steam generator [6–11].

Studies on the heat pipe's potential as a technology that will be added to nuclear installation have been widely carried out, although currently, it is still only a technology concept. Vertical straight wickless-heat pipe concept on a spent fuel storage pool, cooling tank on the small modular reactor, and gamma irradiator, U-shaped heat pipe on condenser for a gas-cooled reactor, LHP on a spent fuel storage pool, hybrid heat pipe on reactor core, and others. Those studies revealed that the heat pipe could be adapted its shape to the heat source geometry that existed. Whatever its heat pipe type, it can absorb and release heat well to the environment, or the heat that is sunk can be used as another energy generator (for example, it is used as a heat source in thermal desalination) [4,12–15].

According to the literature studies conducted, LHP is highly potential to be used as a passive cooling system in a water pool that immerses the NuScale reactor. The selection of LHP type is based on the geometric shape of the heat source in the Nuscale installation, indeed with its novelty from the LHP that is designed. For information, NuScale, which consists of several units in one combined module, is submerged in water as a radiation barrier that may release into the environment and as a heat absorber from the outer wall of the reactor.

Concerning LHP's potential as a passive cooling system in nuclear installation, a study has been carried out regarding the LHP prototype as a passive cooling system in NuScale reactor pool water. This study is a small part of studies on the use of LHP as a passive cooling system in a water pool that immerses the NuScale reactor, which was implemented by the Nuclear Reactor Technology Research Center - National Research and Innovation Agency of the Republic Of Indonesia, with funding from LPDP of the Ministry of Finance of Republic of Indonesia [16].

To support the LHP prototype experiment that was conducted to produce accurate LHP temperature distribution data, therefore it is needed to be analyzed the uncertainty of data distribution temperature measurement through a thermocouple sensor set on the LHP and hot water in the pool. This measurement and test process is highly required for accuracy and precision to obtain accurate and precise data results.

Measurement and test results surely have a measurement uncertainty value [17]. Uncertainty is a calculated value obtained from the repetition and measurement reproducibility represented in the form of standard deviation. Uncertainty states the quality of the measurement or test result. The smaller the uncertainty value, the more accurate and precise the research result [18]. Uncertainty calculation on heat pipe thermal performance has been conducted on the parameters of temperature, pressure, coolant flow rate, and heat load by observing random and systematic uncertainties [19,20]. Evaluation of temperature measurement uncertainty can be done by comparing the read between a standard thermometer and a calibrated thermometer, then measured using the regression equation [21].

This study intended to comprehend the uncertainty value of the thermocouple used in the LHP experiment. Data measurement was conducted using the National Instrument data acquisition system. Data collection of temperature distribution data was done in steady state condition at hot water temperature as a source of LHP temperatures at 35˚C, 45˚C, 55˚C, and 65˚C in about 10 hours of LHP experiment. Temperature distribution data as the result of the record was then compared with the temperature data using a well-calibrated derived standard thermocouple. Uncertainty value calculation was carried out by a statistical method that is generally used to comprehend temperature distribution measurement uncertainty.

2. Methodology

A measurement schematic to comprehend the temperature distribution uncertainty through this thermocouple sensor can be seen in Fig. 1.

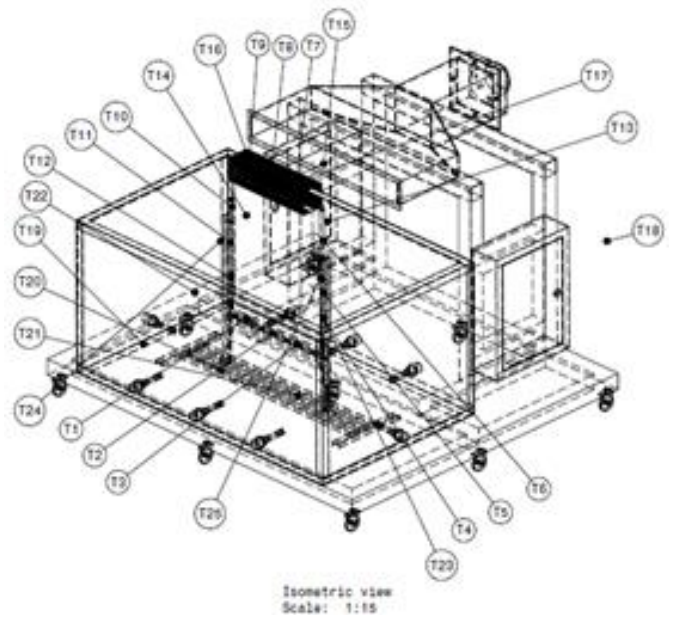

Fig. 1. Thermocouple sensor installation schematic in the pool water

Note:

T1 T HP horizontal	T10 T HP vertical	T18 T air
T2 T HP horizontal	T11 T HP vertical	T19 T water
T3 T HP horizontal	T12 T HP vertical	T20 T water
T4 T HP vertical (wick)	T13 T Glass wool Isolation	T21 T water surface
T5 T HP vertical (wick)	T14 T out air	T22 T out isolation
T6 T HP vertical (wick)	T15 T in air	T23 T out isolation
T7 T HP horizontal (fin)	T16 T back fin	T24 T in isolation
T8 T HP horizontal (fin)	T17 T front fin	T25 T in isolation
T9 T HP horizontal (fin)		

As shown in Fig 1, the type of thermocouples K T19, T20, T21, and T were submerged in a hot water pool. The standard temperature T value obtained will be used as a comparison with the T19, T20, and T21 values. The hot water pool had a length, a width, and a height of 1 m each. Those thermocouples were immersed at a depth of 0.5 m from the pool top surface and were in a parallel position with the distance between the thermocouples being 0.25 m**.** By immersed at this depth, it was assumed that the effect of ambient air did not gave a significant effect on the value of water temperature distribution that was recorded.

The experiment data value recording using the National Instrument data acquisition system, which was connected to a computer. This record interface used a virtual instrument that connected data acquisition and the LabVIEW program.

The measurement of pool water temperature distribution followed the LHP experiment matrix, as shown in Table 1.

Table 1. LHP experiment matrix

LHP Filling ratio, %	LHP Initial Pressure, cm Hg	LHP working fluid	air velocity to the fins, m/s	Hot water temperature, ˚C
100	-74	Demineralized Water	2.5	35, 45, 55, 65

In this study, the uncertainty analysis of pool water temperature measurement was done by using the equation that is commonly used to measure the uncertainty value of a measurement data, as follows [19,21]:

$$u_c\left(y(x_1, x_2, \dots x_n)\right) = \sqrt{\sum_{i=1,\dots n} c^2 u(x_i)^2} \tag{1}$$

where:

$u_c\left(y(x_1, x_2, \dots x_n)\right)$ = Combination of uncertainty value from variables of x_1, x_2,...x_n

$y(x_1, x_2, \dots x_n)$ = Parameters function of x_1, x_2,...x_n

c = sensitivity coefficient

x_i = ðx/ðv

3. Results and discussion

The temperature distribution data from three thermocouples immersed in a hot water pool can be seen in Fig. 2-4.

From Fig. 2-4, it can be seen that the trend of temperatures distribution data was at a steady state temperature condition; it followed the hot water temperature, which was maintained at operating temperatures of 35˚C, 45˚C, 55˚C, 65˚C. It represented that the thermocouple used had an excellent response to temperature changes provided in hot water.

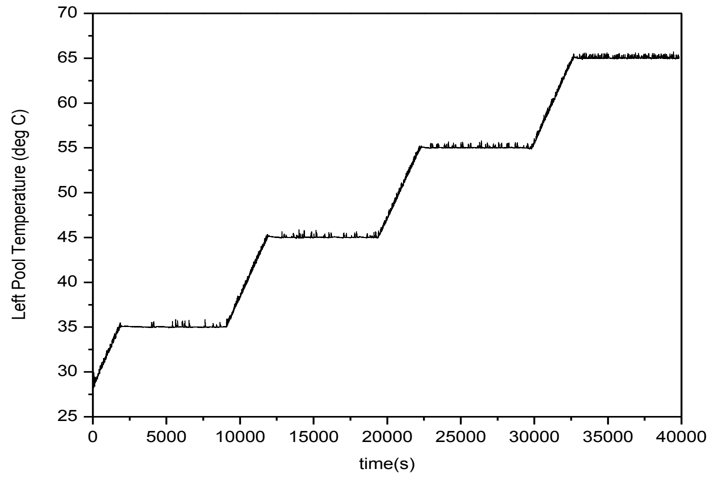

Fig. 2. Left pool temperature distribution

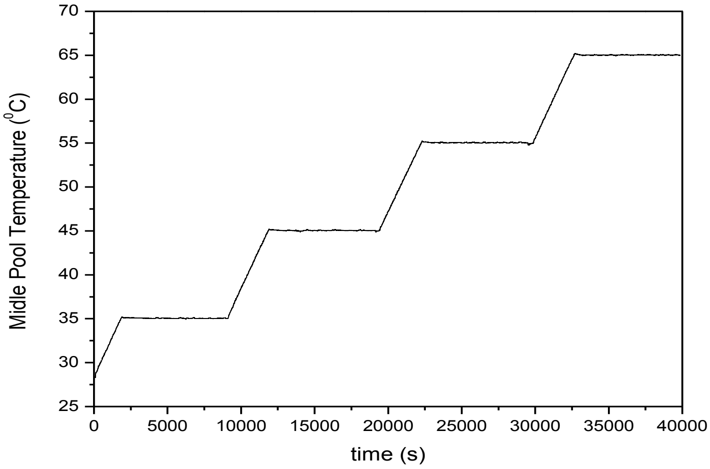

Fig. 3. Middle pool temperature distribution

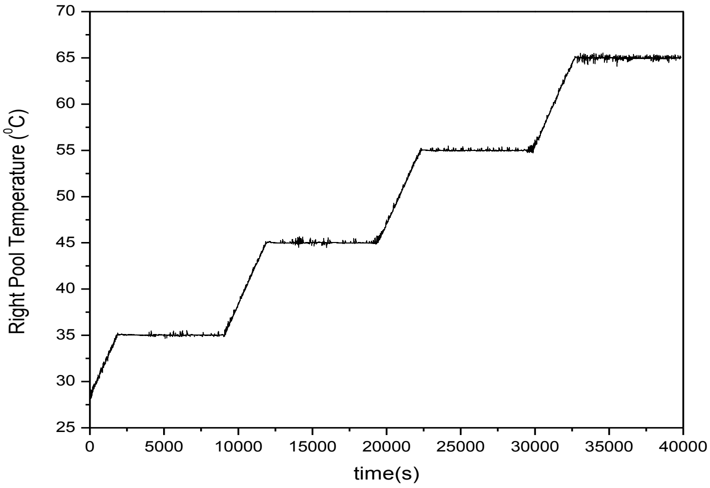

Fig. 4. Right pool temperature distribution

It can be seen from Fig. 2-4 that the temperature data distribution had a fluctuating value. It was indicated that the temperature data could be influenced by the experimental environment, although the experiment room had been maintained as well as possible. Experiment room temperature that was maintained meant by preserving the experiment room to not get or lack too much temperature due to LHP external heat source, both from inside or outside the room.

The fluctuating temperature distribution value obtained from the experiment could also indicate an uncertainty source in temperature measurement. It could happen from the data collection process with thermocouples connected to the National Instrument data acquisition system. Another uncertainty source was the pool condition, which was organized with a specific temperature; it might have a different temperature environmental influence, and the fluctuation of the air velocity on the fin because of the influence of the external environment. These factors could be affected by the temperature measurement fluctuation. To conduct data analysis, the combined uncertainty value was carried out when the pool distribution temperature reached the values of 35˚C, 45˚C, 55˚C, and 65˚C.

In analyzing this uncertainty value, a well-calibrated derivative standard thermocouple was used, with an uncertainty value of 0.1°C. The mean result calculation of the uncertainty value from the pool temperature distribution measurement obtained is shown in Table 2.

From Table 2, it can be seen that the mean value was in the temperature range and reference standard thermocouple uncertainty. The uncertainty values at each position (T19, T20, and T21) had a smaller value than the reference thermocouple standard uncertainty used.

Table 2. The result of the thermocouple uncertainty value

Thermocouple position	Mean temperature of derivative standard thermocouple, °C	Mean temperature of pool water thermocouple,°C	Uncertainty value, °C
T_{19} (left pool)	35,010	35.037	0.000958
	45,010	45.047	0.001139
	55.010	55.042	0.001709
	65.020	65.067	0.001497
T_{20} (middle pool)	35.001	35.057	0.000383
	45.010	45.054	0.000410
	55.002	55.041	0.001277
	65.002	65.029	0.000264
T_{21} (right pool)	35.001	35.031	0.000707
	45.010	45.019	0.001011
	55.010	54.973	0.001552
	65.015	64.99485	0.001293

According to the analysis above, it can be stated that the thermocouple used in this LHP experiment had an extremely good response and extremely small uncertainty value. The smaller the uncertainty value, the more accurate and precise the measurement result. From the results obtained, it can be seen that the thermocouple used as a temperature sensor in the LHP experiment is feasible to use to produce accurate data.

4. Conclusion

Based on the uncertainty analysis on the experiment of LHP prototype temperature distribution, it is obtained a description regarding measurement data quality of the experiments conducted. According to the calculation and analysis, it is acquired that the thermocouple used in the LHP experiment had a highly small uncertainty value compared to the standard derivative thermocouple used. The value was obtained at 0.001017°C, far below the uncertainty value of 0.1°C from a well-calibrated derivative standard thermocouple. The experiment result also indicated that the thermocouple set in the LHP was highly responsive to the temperature change that was provided. Thus the thermocouple used in the LHP experiment is feasible and has highly good accuracy so that it can produce accurate LHP temperature distribution data.

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