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Preliminary experiment of Vertical Straight Wickless-Heat Pipe as Passive Cooling System in Irradiator

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ABSTRACT

The multipurpose Irradiator in Indonesia with capacity of 2 MCi Co-60 radioactive source was built to support food security. When not operated, the Co-60 is stored in the pool to keep the radiation not to exposure to environment. The decay heat generation of Co-60 could increase the pool water temperature. To improve safety especially during SBO conditions, the pool water should be passively cooled using a vertical straight wickless-heat pipe. The objective of this experimental study is to investigate the heat transfer phenomena and the thermal performance of the vertical straight wickless-heat pipe as passive cooling system in the irradiator pool. Vertical straight wickless-heat pipe with inner diameter of 57 mm and total length of 1000 mm was charged with demineralized water of working fluid with filling ratio of 55%. This experiment was conducted with varied pool temperature, and air coolant velocity in the condenser section. The experiment results obtained that the lowest thermal resistance of wickless-heat pipe is 0.04 °C/W when heat pipe is operated at pool temperature of 90ºC and air coolant velocity of 1 m/s. It can be concluded that the vertical straight wickless-heat pipe has good thermal performance to absorb the heat generation in the irradiator pool. The results of this study are expected to provide a more complete management thermal knowledge to improve the safety of Irradiator.

Keywords:
Vertical straight wickless-heat pipe, passive cooling system, decay heat generation, Iradiator Gamma Merah Putih,

1. Introduction

Food security is the basic needs of human life so it becomes a strategic issue that affects the economic and political development of each country. Therefore, food availability must be continuous, but it is difficult to implement due to dependent on climatic conditions. In addition, food quality must be maintained at the time of storage and distribution process[1]. Irradiation technique is the most appropriate solution to maintain durability of food quality. In order to support food security, Indonesia through the National Nuclear Energy Agency built a Multipurpose

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Irradiator, namely Iradiator Gamma Merah Putih, with a Co-60 radioactive source which has capacity of 2 MCi. The radioactive sources emit gamma radiation rays that can be used for preservation of post-harvest food and medicinal materials, as well as sterilization of medical devices.

Co-60 as a radioactive source will continue release the heat even it is not used in radiation process. When not in use, the Co-60 is immersed on the water of irradiator pool to protect it radiation release to environment and to cool the heat generation. In this case, water has function as radiation shielding and coolant.

When the active cooling system failure to circulated the water pump, for example in the case of loss of station blackout (SBO), the temperature in the irradiator pool became increase because of decay heat generation from Co-60. The increasing of water temperature will cause the evaporation of water and decrease it level on the pool [2, 3]. This event may also result in the non-functioning of cooling water as a radiation barrier and damage the integrity of the Co-60 cladding.

In order to improve the safety of the irradiator, a heat pipe as passive cooling system technology can be used to absorb the decay heat generation from Co-60 in the water of irradiator pool. Putra et al. has conducted investigation on heat pipe as a passive cooling using various working fluids such as demineralized water and nanofluids [4]. Their results show that the heat pipe has a good heat transfer capability and provides hope in handling thermal problems especially in the electronic cooling field. Vasiliev et al. through his research concluded that the heat pipe can be applied to the current heat exchanger because it has a good heat transfer capability and widely applied in the field of industry, electronic technology, utilization of exhaust gases, air heaters, HVAC systems, and utilization of waste heat from the boiler[5]. Alizadehdakhel et al. [6], Kafeel et al. [7], and Tung et al. [8] has simulated the use of a circular heat pipe (LHP) as a heat dissipation of residual decay results generated during an accident. The results show that the heat pipe can be used as an emergency system to remove residual heat resulting from decay resulting from an accident. Ye et al. [9], and Fu et al. [10] has performed a simulation with computational fluid dynamic regarding the use of LHP as a residual heat dissipation produced in SFSP PWR CAP1400 type reactor. The results show that LHP can be used to remove residual heat generated in SFSP and keep the cooling water temperature in the pool not boiling. Xiong et al. [11] has conducted an experimental investigation using large-size LHP to cool the residual heat generated in the AP1000 reactor SFSP. The results show that LHP is able to significantly remove the heat generated in SFSP.

Research on the use of vertical straight wickless-heat pipe as a residual heat dissipation of decay results in SFSP nuclear reactors has been done before by Kusuma et al. [12]**.** This research investigated the thermal performance of a prototype model for a large-scale vertical straight wickless-heat pipe as a passive cooling system for a nuclear research reactor spent fuel storage pool then simulated using RELAP5/MOD3.2 *code*. His research continued with the result that the thermal performance of vertical straight wickless-heat pipe is worthy of being recommended and proposed as a passive cooling system on the nuclear spent fuel pool [13].

In order to improve the safety aspect of irradiator, the vertical straight wickless-heat pipe is proposed to remove the decay heat generation in irradiator pool. Based on the literature study, the vertical straight wickless-heat pipe is never used as passive cooling system to remove the decay heat generation in irradiator pool.

The objective of this experimental study is to investigate the heat transfer phenomena and the thermal performance of the vertical straight wickless-heat pipe as passive cooling system in the Iradiator Gamma Merah Putih pool. Vertical straight wickless-heat pipe with inner diameter of 57 mm and total length of 1000 mm was charged with demineralized water of working fluid with filling ratio of 55%. This experiment was conducted with varied pool temperature, and air coolant velocity in the condenser section.

2. Methodology

The experimental setup of vertical straight wickless-heat pipe as passive cooling system in irradiator pool is shown in Figure 1.

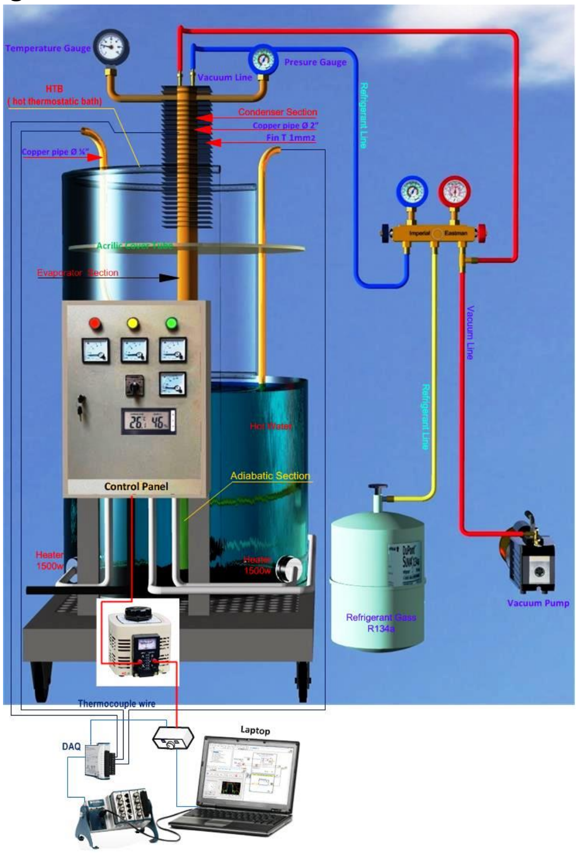

Fig. 1. Experimental setup of *vertical straight wickless-heat pipe*

Vertical straight wickless-heat pipe made of copper pipe with a length of 1000 mm, which has an outer and inner diameter of 58 mm and 57 mm. Heat pipe divided into 3 parts, namely evaporator along 40 mm, adiabatic along 30 mm, and condenser along 30 mm. The evaporator will be heated with hot water that varies at 60°C, 70°C, 80°C and 90°C. The hot water is accommodated in a drum with diameter and heigh are 58 cm and 85 cm, respectively. Heaters which has maximum power 6000 W will be used as a heat source of hot water that can be adjusted by using Autonics temperature control with accuracy ±1°C to maintain its temperature. Demineralized water is used as working fluid and charged into heat pipe with filling ratio of 55%. The adiabatic portion of the heat pipe is located in the center. This section will also be wrapped with thermal insulation material in the form of polyurethane.

In the condenser located at the top section of the heat pipe is equipped with a number of cooling fins that function to remove heat. The fins are blown with a fan that is integrated with the ducting system. The rotation speed of fan is controlled using voltage regulator. Lutron's hot wire anemometer ±5 % accuracy was used to measure the air coolant velocity with varying velocity of air flow at 1, 1.5, 2.1, and 2.8 m/s.

Before the working fluid is inserted into the heat pipe, vacuuming is conducted to remove the non-condensable gas content and determine the initial pressure in the heat pipe to reach -73 cm Hg.

The result of measurement in the form of temperature data will be recorded using temperature module of National Instrument data acquisition system which is connected with Lab VIEW virtual instrument program installed on windows PC. Fifteen channels of K type thermocouples with an accuracy of ±0.1°C are used to measuring the temperature data in the experiment. Four thermocouples on the evaporator outside wall, three thermocouples on the adiabatic outside wall, four thermocouples on the condenser outside wall, one thermocouple for air coolant velocity inlet, one thermocouple for air coolant velocity outlet, one thermocouple on the water pool, and one thermocouple for ambient temperature.

The experimental parameters to be varied in this research are summarized and shown in Table 1. which are temperature of pool water and air coolant flow through finned condenser section with filling ratio 55%.

Table 1.
Experiment Matrix of vertical straight wickless-heat pipe

Air Coolant Velocity (m/s)	Pool Temperature (°C)
1	60
1.5	70
2.1	80
2.8	90

3. Results

3.1 Transient Temperature Distribution

The temperature distribution that obtained from experiment with variation of pool water temperatures of 60, 70, 80, and 90°C, and air coolant velocity of 1 m/s is displayed on Figure 2.

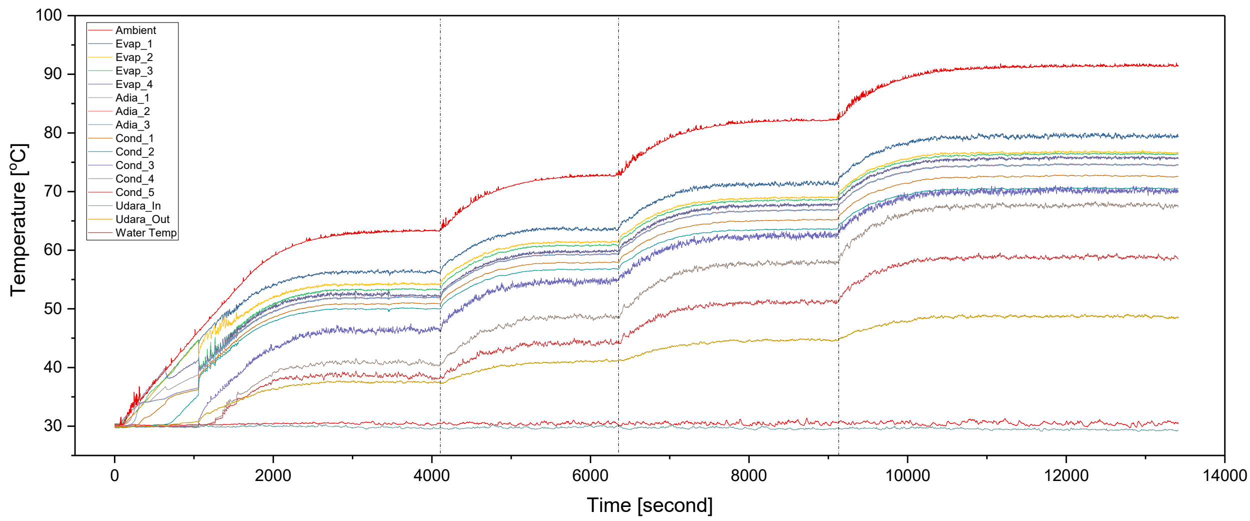

Fig. 2. Transient temperature at variation of pool temperature and air coolant velocity of 1 m/s

It can be seen from Figure 2 that the temperature different between evaporator and condenser at hot water temperature of 60, 70, 80, and 90°C and air velocity of 1 m/s were 7.03, 14.44, 22.19, and 6.86°C, respectively.

The temperature distribution that obtained from experiment with variation of pool water temperatures of 60, 70, 80, and 90°C, and air coolant velocity of 1.5 m/s is displayed on Figure 3.

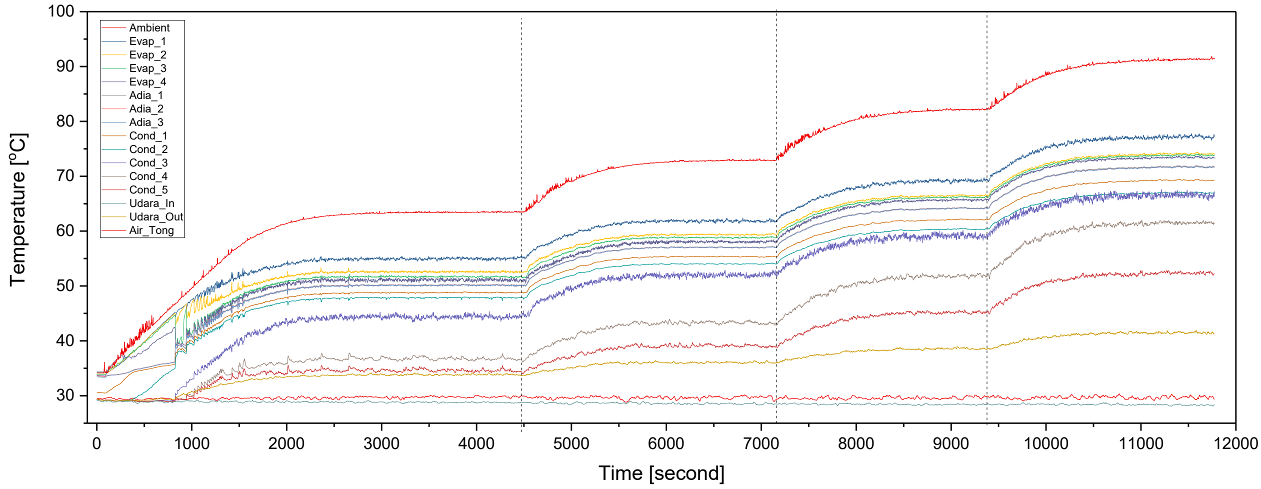

Fig. 3. Transient temperature at variation of pool temperature and air coolant velocity of 1.5 m/s

It can be seen from Figure 3 that the temperature different between evaporator and condenser at hot water temperature of 60, 70, 80, and 90°C and air velocity of 1.5 m/s were 8.17, 8.37, 8.55, and 8.54°C, respectively.

The temperature distribution that obtained from experiment with variation of pool water temperatures of 60, 70, 80, and 90°C, and air coolant velocity of 2.1 m/s is displayed on Figure 4.

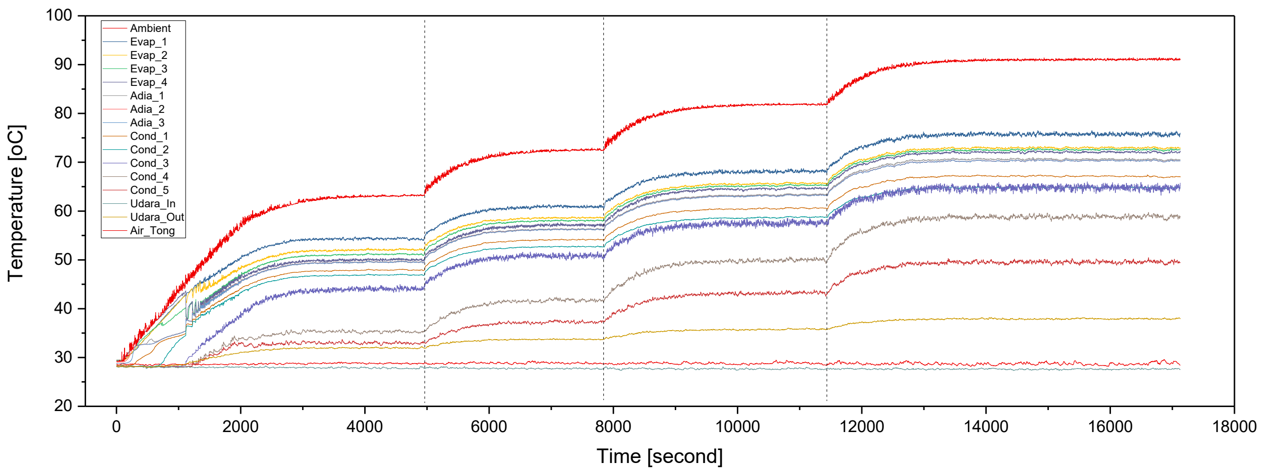

Fig. 4. Transient temperature at variation of pool temperature and air coolant velocity of 2.1 m/s

It can be seen from Figure 4 that the temperature different between evaporator and condenser at hot water temperature of 60, 70, 80, and 90°C and air velocity of 2.1 m/s were 8.36, 8.84, 9.18, and 9.45°C, respectively.

The temperature distribution that obtained from experiment with variation of pool water temperatures of 60, 70, 80, and 90°C, and air coolant velocity of 2.8 m/s is displayed on Figure 5.

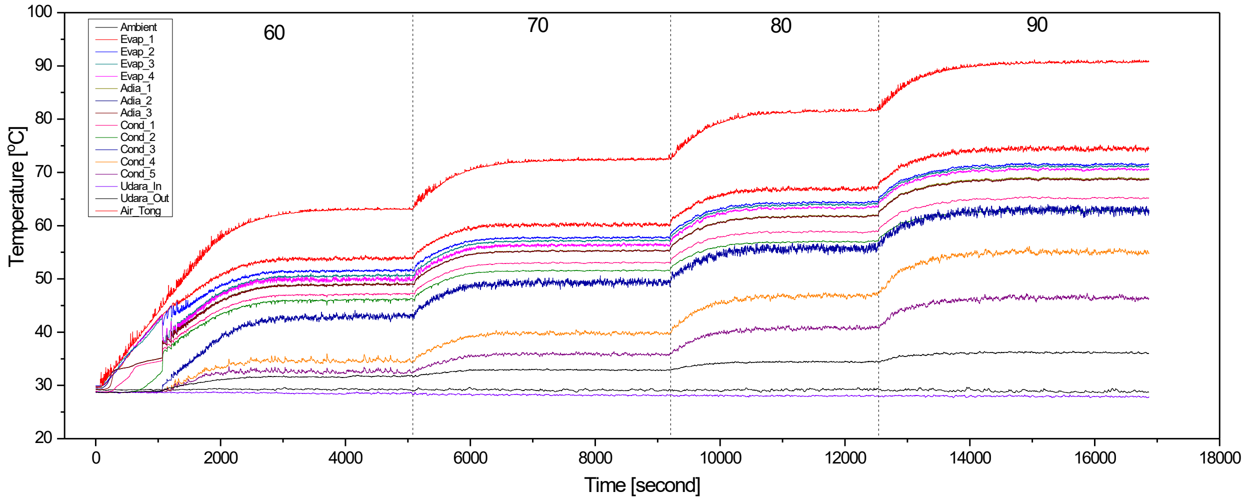

Fig. 5. Transient temperature at variation of pool temperature and air coolant velocity of 2.8 m/s

It can be seen from Figure 5 that the temperature different between evaporator and condenser at hot water temperature of 60, 70, 80, and 90°C and air velocity of 2.8 m/s were 11.96, 12.93, 13.59, and 10.47°C, respectively.

The results obtained in Figures 2-5 show that higher hot water temperature would increase the temperature difference between evaporator and condenser. But the different phenomenon obtained when the highest hot water temperature is given as heat load in evaporator, it is showed that highest hot water temperature will decrease the temperature different of evaporator and condenser.

3.2 Thermal resistance

The thermal resistance calculation that obtained from experiment was showed in Figure 6.

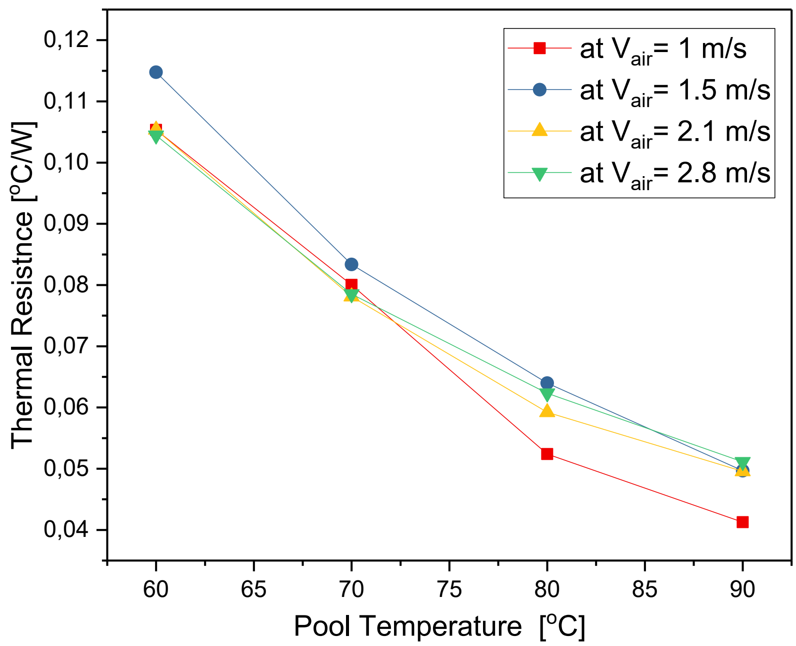

Fig. 6. Thermal resistance of vertical straight wickless-heat pipe

It can be seen from Figure 6 that the lowest thermal resistance was obtained when vertical straight wickless-heat pipe is operated at pool temperature of 90°C and lowest air coolant velocity of 1 m/s. The lowest of thermal resistance obtained in air coolant velocity of 1 m / s because the temperature of the air coolant inlet is relatively lower than the inlet temperature in the variation of other air coolant velocity. The experimental results show that the inlet air coolant temperature at 1 m/s and 2.8 m/s are 29.34°C and 27.87°C, respectively. As well known, the lower coolant temperature that used to take heat in the condenser (at the same heat load value of the evaporator) will result in greater heat that can be transfer into the environment. The lowest value of thermal resistance in air coolant velocity of 1 m/s affected by the temperature of the coolant inlet water is relatively lower than the air inlet temperature in the others varied air coolant velocity.

The lowest thermal resistance values obtained show that vertical straight wickless heat pipe has good thermal performance for removing the heat to the environment. Thus, it can be mentioned that the results of this preliminary research can be used as a basic knowledge for the implementation of vertical straight wickless-heat pipe as passive residual heat removal system in the irradiator.

4. Conclusions

The thermal resistance of vertical straight wickless-heat pipe is obtained at 0.04 °C/W, when it operated at pool temperature of 90°C and air coolant velocity of 1 m/s. It is mean that the thermal performance of vertical straight wickless-heat pipe is obtained when heat pipe is operated at higher pool temperature and air coolant velocity.

Based on the results obtained, it can be mention that vertical straight wickless-heat pipe has good thermal performance to remove the decay heat generation to environment. The characteristics of heat pipe as passive cooling system also can be used as a basic knowledge for the implementation of vertical straight wickless-heat pipe as passive residual heat removal system in the irradiator.

Acknowledgement

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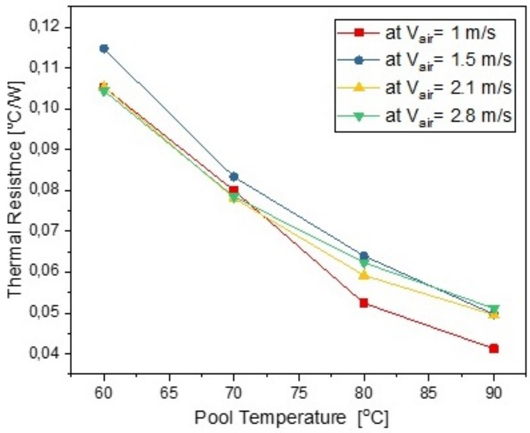

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