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

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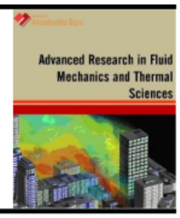

Preliminary Experiment of Vertical Straight Wickless-Heat Pipe as Passive Cooling System in Irradiator

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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 0.03 °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

The use of nuclear energy as a new energy source to fulfill the world's energy needs is very important because other energy sources tend to decrease [1, 2]. In addition, the use of nuclear energy can also be used for health [3], food security, and other applications.

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

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quality must be maintained at the time of storage and distribution process [4]. 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 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 [5, 6]. 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 [7]. Their results showed 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 their research has 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 [8]. Alizadehdakhel *et al.,* [9], Kafeel *et al.,* [10], and Tung *et al.,* [11] have 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.,* [12], and Fu *et al.,* [13] 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.,* [14] have conducted an experimental investigation using large-size LHP to cool the residual heat generated in the AP1000 reactor SFSP. The results indicated 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.,* [15]**.** 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*. Their 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 [16].

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.

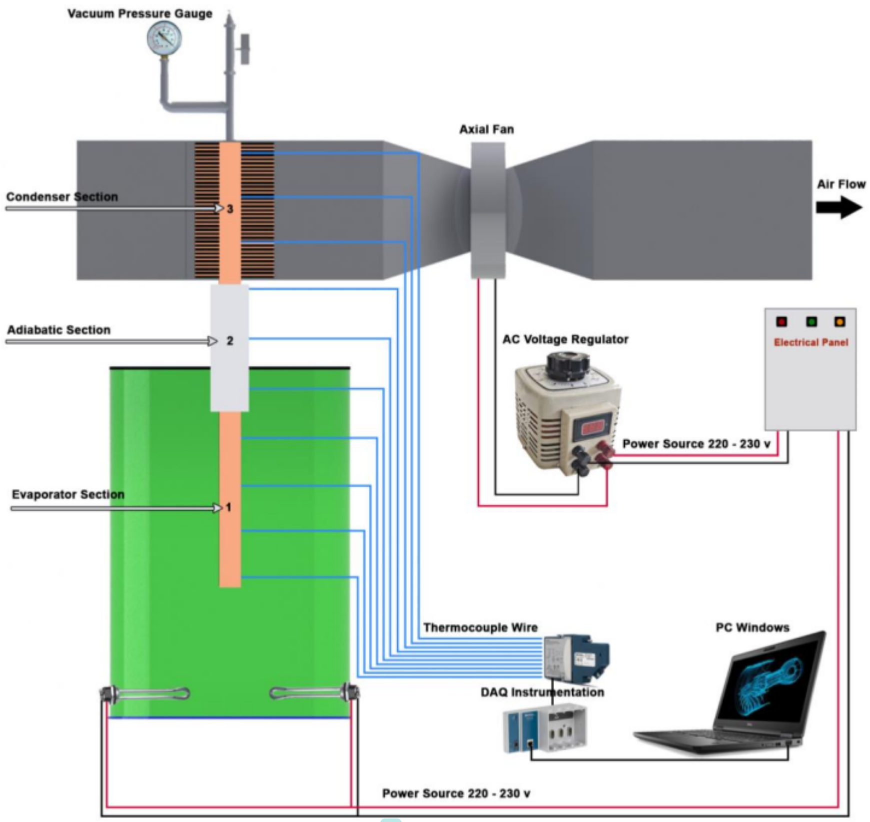

Fig. 1. Experimental setup of vertical straight wickless-heat pipe

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 400 mm, adiabatic along 300 mm, and condenser along 300 mm. The evaporator will be heated by using hot water that is varied at 60°C, 70°C, 80°C and 90°C. The hot water is accommodated in a cylinder container with diameter and heigh are 58 cm and 85 cm, respectively. Heaters which has maximum power 6000 Watt will be applied as a heat source of hot water that can be adjusted using temperature control with accuracy ±1°C to maintain its desired constant temperature. Demineralized water is used as working fluid and charged into heat pipe with filling ratio of 55%. The adiabatic part of the heat pipe is located in the middle. This section will also be wrapped with thermal insulation material in the form of polyurethane in order to reduce heat lost to the environment.

At the top section of condenser is equipped with 32 pieces of cooling fins in order to remove heat. The fins are blown with an air cooling 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 to have 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. 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 are placed 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 position of each thermocouples on heat pipe can be seen in Figure 2. The experimental parameters are varied in this research, which are summarized and shown in Table 1.

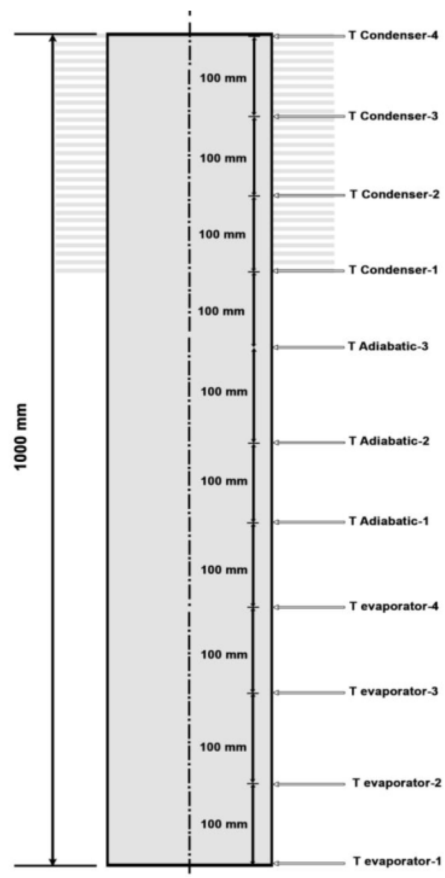

Fig. 2. Position of thermocouples at experimental equipment of heat pipe

Table 1
Experiment matrix of vertical straight wickless-heat pipe

Filling Ratio (%)	Pool Temperature (°C)	Air Coolant Velocity (m/s)
55	60	1
		1.5
		2.1
		2.8
	70	1
		1.5
		2.1
		2.8
	80	1
		1.5
		2.1
		2.8
	90	1
		1.5
		2.1
		2.8

3. Results

3.1 Transient Temperature Distribution

The transient temperature distribution of heat pipe wall that obtained from experiment with variation of pool water temperatures of 60, 70, 80, and 90°C, and air coolant velocity of 1, 1.5, 2.1, and 2.8 m/s is displayed on Figure 3.

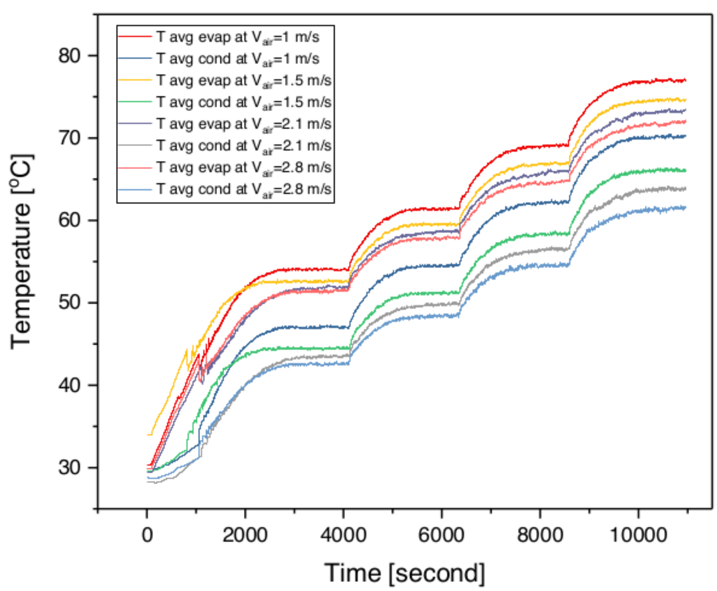

Fig. 3. Transient temperature of heat pipe at a filling ratio of 55 % with variation of pool temperature and air coolant velocity

Figure 3 shows the zigzag and stable phenomena that is obtained from experiment with filling ratio of 55%. The evaporator, adiabatic, and condenser section temperature were increase significantly when higher pool temperature is absorbed by the heat pipe. Heat that absorbed by the evaporator section will then boil the working fluid inside the evaporator. Vapour produced in the evaporator then flows to the condenser section naturally because of its buoyancy effect. Latent heat of vapour in the condenser section was distributed to the fin. The heat in the fin then remove to the environment by the cooling air that passes through the fins. The decrease of vapour temperature will change the vapour to the fluid phase. With the gravitational force, the condensation fluid then flows down to the evaporator. This phenomena occur continuously until stable condition. The stable condition indicate natural circulation process in the heat pipe is run properly. The phenomena obtained has similar temperature distribution pattern with Wang *et al.,* results [17].

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 with air velocity of 1 m/s were 6.99, 6.91, 6.87, and 6.83°C, respectively. For air velocity of 1.5 m/s were 8.13, 8.34, 8.52, and 8.54°C, respectively. For air velocity of 2.1 m/s were 8.35, 8.82, 9.19, and 9.46°C, respectively. For air velocity of 2.8 m/s were 8.76, 9.45, 10.05, and 10.43°C, respectively. The results obtained shows that higher hot water temperature would increase the temperature difference between evaporator and condenser section. The lowest air cooling velocity was resulted the higher evaporator and condenser temperature, which mean the lowest heat removed to the environment.

3.2 Thermal Resistance

The thermal resistance calculation that obtained from experiment was showed in Figure 4. It can be seen from it that the lowest thermal resistance was 0.03 °C/W 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 remove 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 thermal resistance of vertical straight wickless-heat pipe obtained has lower value than others heat pipe thermal resistance [18-22]. It is showed that vertical straight wickless-heat pipe has higher thermal performance to remove heat to the environment. The lowest thermal resistance values obtained in this experiment 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.

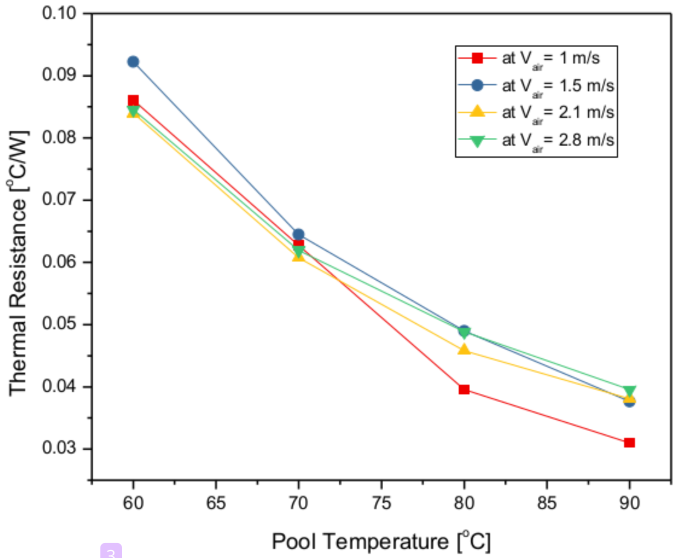

Fig. 4. Thermal resistance of vertical straight wickless-heat pipe

4. Conclusions

The thermal resistance of vertical straight wickless-heat pipe is obtained at 0.03 °C/W, when it operated at pool temperature of 90°C and air coolant velocity of 1 m/s. It is mean that the higher thermal performance of vertical straight wickless-heat pipe is obtained when the heat pipe is operated at higher pool temperature and air coolant velocity.

Based on the results obtained, it can be mentioned 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.

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