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Investigation of Heat Exchanger Performance in The Heating Tank Section of Loop FASSIP 03 NT

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ABSTRACT

The Passive System Simulation Facility (FASSIP) loop is an experimental test facility for a passive cooling system to recover the residual heat from decay produced by the reactor core during accident conditions. The Heating Tank Section (HTS) is one of the components of the FASSIP 03 NT facility. This component is equipped with a heat exchanger, 3 types of heat exchangers can be applied to HTS. Namely heat exchangers of the Straight Pipe Heat Exchanger (SPHE) type, the Straight Pipe Fins Heat Exchanger (SPFHE) type, and the Helical Pipe Heat Exchanger (HPHE) type. A modification was made to increase the efficiency of HTS, namely replacing the electric heater on the HTS from a ceramic band heater type to an immersion heater type. With this modification, it is necessary to know the performance of the heat exchanger on HTS and its speed in reaching operational temperature. The HPHE-type heat exchanger is more efficient than the SPHE-type and SPFHE-type heat exchangers. The HPHE-type heat exchanger has a much larger length of 5.5 m, so the thermal resistance (Rth) is very small, namely 0.003926 ℃/W. To reach the working fluid temperature in the range of 50 – 90 ℃, the HPHE-type heat exchanger requires 35 – 86 minutes.

Keywords: FASSIP 03 NT, Heating tank Section, Straight Pipe Heat Exchanger, Straight Pipe Fins Heat Exchanger, Helical Pipe Heat Exchanger.

Introduction

The nuclear accident that occurred in Fukushima, Japan, which started due to an earthquake and was followed by a tsunami, made the passive cooling system in the reactor installation something important. The passive cooling system works without requiring electrical energy, so this system can operate when a Station Blackout (SBO) occurs. The Passive System Simulation Facility (FASSIP) test loop is a passive cooling system experimental test facility for recovering residual heat from decay produced by the reactor core during accident conditions [1], [2], [3], [4].

Several simulation test facilities have been created by the Nuclear Reactor Technology Research Center to be used as a means of experimental-based research on passive cooling. These facilities are the FASSIP-01 test facility which was then developed by building the FASSIP-02 test facility and continued with FASSIP-02 mod.1. In 2021, the Passive System Simulation Facility-03

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Nanobubble Transparent (FASSIP-03 NT) test loop design began to be made, while the FASSIP-04 loop and ViSSAR loop began to be made in 2022.

The Heating Tank Section (HTS) is one of the components of the FASSIP 03 NT loop facility. This component is equipped with a heat exchanger. 3 types of heat exchangers can be applied to HTS. These are the Straight Pipe Heat Exchanger (SPHE) type heat exchanger, the Straight Pipe Fins Heat Exchanger (SPFHE) type, and the Helical Pipe Heat Exchanger (HPHE) type. Mechanical strength analysis of HTS has been carried out. The analysis results show that the mechanical stress that occurs in the body of the Heating Tank Section is 1.10 x 10^3 N/m^2, which is smaller than the yield strength of the SS 304 material, which is 1.73 x 10^8 N/m^2. The translational displacement of 3.28 mm is very small compared to the dimensions of the HTS so it does not result in a change in shape. Thus, HTS is safe to use as one of the components of the FASSIP 03 NT loop [5]. Another feature of the HTS is an electric heater. In 2023, modifications will be made to the FASSIP 03 NT loop by replacing the electric heating system with the Heating Tank Section component. Originally using a ceramic band heater-type electric heater, this has now been replaced by an immersion heater-type electric heater.

Replacing the electric heating system aims to further increase the efficiency of heat transfer from the electric heater to the Heating Tank Section (HTS) secondary water. As we know when using a ceramic band heater, the electric heater is installed by attaching it to the outer wall of the HTS. Based on research that has been carried out to determine the efficiency of ceramic band heaters using the visualization method using an Infrared Thermal Imaging Camera. Experimental parameters were carried out by increasing the heater voltage from 150 volts, 160 volts, 170 volts, 180 volts, 190 volts, and up to 200 volts with a heating period of up to 300 minutes. The research results show that the outer insulation performance of the ceramic band heater can function very well with an average efficiency of 97.767% [6]. The results of this research show that environmental heat loss is very small. However, because this type of electric heater is attached to the HTS body, the heat produced is conducted throughout the HTS and even spreads to the HTS piping and supports before being used to increase the temperature of the HTS secondary water. This results in a decrease in the efficiency of the ceramic band heater in increasing the HTS secondary water temperature. With the background of this incident, the electric heater in the HTS was replaced from a ceramic band heater to an immersion heater.

Changing the heater type on the HTS results in a change in the time to reach the operational temperature of the FASSIP 03 NT loop working fluid. This research aims to determine and predict the time required for an immersion heater to reach the operational temperature of the working fluid by applying 3 types of heat exchangers. The preparation of the research matrix can be carried out correctly.

Calculations are carried out using the one-dimensional steady heat conduction equation, while the calculation process uses Matlab software [7], [8]. Based on the calculation results, graphs can be made to make it easier to analyze the calculation results.

Research Methods

Heating Tank Section (HTS) is one of the components of the FASSIP 03 NT loop which functions as a nuclear reactor simulator. So that HTS is a heat source from the FASSIP 03 NT loop facility, data about the FASSIP 03 NT loop is shown in Table 1.

Table 1. FASSIP 03 NT string data specifications

Komponen	Size/Material
Cooler Tank Section	1 m x 2 m x 1.5 m (*carbon steel*, t= 5 mm)
Heating Tank Section	Dia. 20-inch, Sch.40, h= 800 mm (SS 304)
Pipe	Dia. 1 inch, Sch.40 (SS 304)
Transparent pipe	Dia. 1 inch, Pyrex
Heat exchanger tube	Outside Dia. 1 inch, (*Cooper*, SS 304)
Heater (4 pieces)	P=2 kW (total 8 kW)
Height differences (H)	3050 mm
Total loop length (L)	11710 mm
Total loss coef. (K)	8.4

As a heat source, the HTS is equipped with 4 immersion heater-type electric heaters with a total power of 8 kW. This electric heater is used to increase the temperature of the HTS secondary water, which then through a conduction process in the heat exchanger causes the temperature of the working fluid to increase. HTS is designed to be fitted with a Straight Pipe Heat Exchanger (SPHE) type heat exchanger, Straight Pipe Fins Heat Exchanger (SPFHE) type and Helical Pipe Heat Exchanger (HPHE) type. The HTS design is shown in Figure 1 to Figure 3 below.

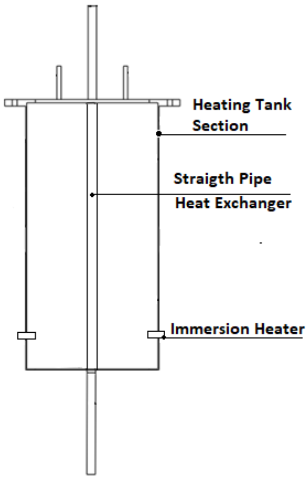

Figure 1. Heating Tank Section with Straight Pipe Heat Exchanger.

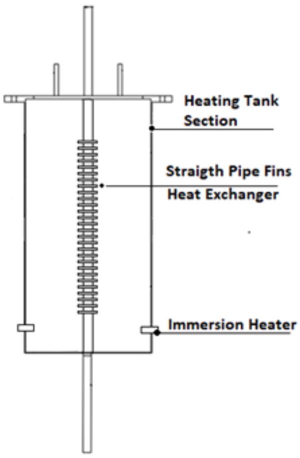

Figure 2. Heating Tank Section with Straight Pipe Fins Heat Exchanger.

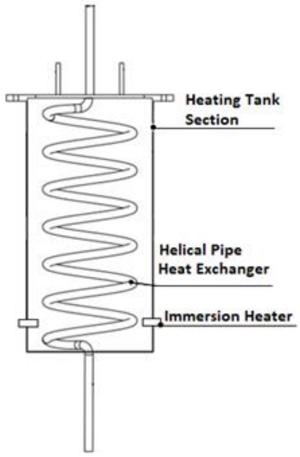

Figure 3. Heating Tank Section with Helical Pipe Heat Exchanger.

Immersion heaters are electric heaters designed for use in tanks or containers to heat liquids such as water, oil, resin, salt solutions, sugar, chemicals, wax, asphalt, paraffin, and solid materials with low melting points. How to use it is by dipping or immersing the immersion heater into the medium to be heated. Immersion heaters have advantages, including product construction that can be adjusted to suit needs, both in terms of heavy-duty and lifetime. However, immersion heaters have weaknesses that need to be considered when using them, namely that they will cause overheating if the heat zone is not submerged in the heated medium and will cause overvoltage [9].

The steps taken to determine the performance of the heat exchanger on the HTS and the time required for operating the FASSIP 03 NT loop until it reaches a working fluid temperature ranging from 50 – 90 ℃ are as follows:

Calculation of HTS secondary water temperature

The first stage carried out in this research activity was to carry out calculations to determine the temperature of the HTS secondary water. Calculations use the one-dimensional steady heat conduction equation with thermal conductivity and natural convection data as shown in Table 2.

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Table 2. Thermal conductivity and natural convection of several materials [10].

Material	Thermal Conductivity (k) (W/m °C)	Natural Convection (h) (W/m^2°C)
Metal		
Aluminum	204	
Carbon steel	54	
Chrome steel	15.1	
Copper	386	
Non-metal		
Asbestos sheet	0.166	
Corrugated cardboard	0.064	
Glass Wool	0.038	
Rock Wool	0.040	
Kapok	0.035	
Silica Airgel	0.024	
Balsa Wood	0.055	
Water		1000
Air		6

The heat flow rate propagates by convection in the HTS secondary water (T_{as}) to the outer wall of the heat exchanger pipe (SPHE, SPFHE, and HPHE) so that the outer wall temperature (T_1) increases. Furthermore, heat conduction propagates within the walls of the heat exchanger pipe (made of copper and SS 304) so that the temperature of the inner wall (T_2) of the heat exchanger pipe increases. Furthermore, heat propagates by convection increasing the temperature of the working fluid (T_{fk}). The heat propagation and electrical analogy are visualized in Figure 4 below.

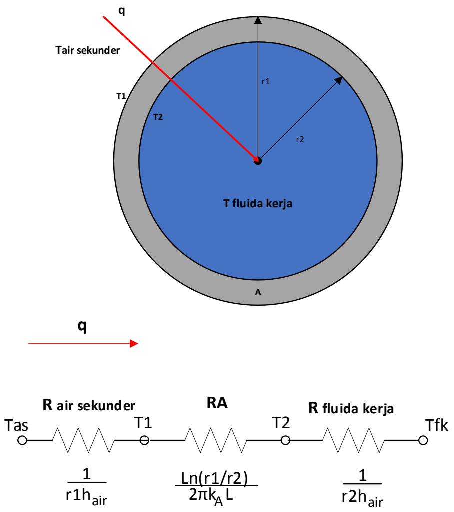

Figure 4. One-dimensional thermal flow through a cylindrical cross-section and its electrical analogy

Based on the scheme in Figure 4, the equation for calculating the HTS secondary water temperature is as follows [7], [11];

$$\frac{q}{L} = \frac{2\pi(T_{as} - T_{fk})}{\frac{1}{r_1 h_{air}} + \frac{ln\left(\frac{r_1}{r_2}\right)}{k} + \frac{1}{r_2 h_{air}}} \quad (1)$$

$$\frac{q}{L}\left(\frac{1}{r_1 h_{air}} + \frac{ln\left(\frac{r_1}{r_2}\right)}{k} + \frac{1}{r_2 h_{air}}\right) = 2\pi(T_{as} - T_{fk}) \quad (2)$$

$$T_{as} = \left(\frac{\frac{q}{L}\left(\frac{1}{r_1 h_{air}} + \frac{ln\left(\frac{r_1}{r_2}\right)}{k} + \frac{1}{r_2 h_{air}}\right)}{2\pi}\right) + T_{fk} \quad (3)$$

$$T_{as} = \frac{q}{2\pi L}\left(\frac{1}{r_1 h_{air}} + \frac{ln\left(\frac{r_1}{r_2}\right)}{k} + \frac{1}{r_2 h_{air}}\right) + T_{fk} \quad (4)$$

$$T_{as} = q\left(\frac{1}{2\pi r_1 L h_{air}} + \frac{ln\left(\frac{r_1}{r_2}\right)}{2\pi L k} + \frac{1}{2\pi r_2 L h_{air}}\right) + T_{fk} \quad (5)$$

$$T_{as} = q\left(\frac{1}{h_{air} A_1} + \frac{ln\left(\frac{r_1}{r_2}\right)}{2\pi L k} + \frac{1}{h_{air} A_2}\right) + T_{fk} \quad (6)$$

$$T_{as} = q\,(R_{konveksi1} + R_{termal} + R_{konveksi2}) + T_{fk} \quad (7)$$

with,

q	=	Heat energy (W)
L	=	Long pipe (m)
T_{as}	=	Secondary water temperature (°C)
T_{fk}	=	Working fluid temperature (°C)
r_1	=	The outer radius of the pipe (m)
r_2	=	Radius in pipe (m)
k	=	Pipe conductivity (W/m °C)
h_{air}	=	Natural convection of water (W/m^2 °C)
$R_{konveksi1}$	=	Secondary water convection resistance HTS (°C/W)
R_{termal}	=	Thermal resistance of pipes (°C/W)
$R_{konveksi2}$	=	Working fluid convection resistance HTS (°C/W)

Data regarding pipe dimensions used in the FASSIP 03 NT loop HTS component and input data for calculations refers to ASME B38.19/JIS G 3459 Sch.10S-Sch.40S as shown in Table 3.

Table 3. ASME B36.19 / JIS G 3459 Sch10S ~ Sch40S [12].

Nominal Size		Outside Diameter		Sch5S		Sch10S		Sch20S		Sch40S	
A	B	JIS	ASTM	mm	kg/m	mm	kg/m	mm	kg/m	mm	kg/m
6	1/8	10.5	10.3	1.0	0.234	1.2	0.275	1.5	0.333	1.7	0.369
8	1/4	13.8	13.7	1.2	0.373	1.65	0.494	2.0	0.582	2.2	0.629
10	3/8	17.3	17.1	1.2	0.476	1.65	0.637	2.0	0.755	2.3	0.854
15	1/2	21.7	21.3	1.65	0.816	2.1	1.02	2.5	1.18	2.8	1.31
20	3/4	27.2	26.7	1.65	1.04	2.1	1.30	2.5	1.52	2.9	1.74
25	1	34.0	33.4	1.65	1.32	2.8	2.15	3.0	2.29	3.4	2.57
32	1-1/4	42.7	42.2	1.65	1.67	2.8	2.76	3.0	2.94	3.6	3.47
40	1-1/2	48.6	48.3	1.65	1.91	2.8	3.16	3.0	3.37	3.7	4.10
50	2	60.5	60.3	1.65	2.39	2.8	3.98	3.5	4.92	3.9	5.44
65	2-1/2	76.3	73.0	2.1	3.84	3.0	5.42	3.5	6.28	5.2	9.12
80	3	89.1	88.9	2.1	4.51	3.0	6.37	4.0	8.39	5.5	11.3
90	3-1/2	101.6	101.6	2.1	5.15	3.0	7.29	4.0	9.63	5.7	13.5
100	4	114.3	114.3	2.1	5.81	3.0	8.23	4.0	10.9	6.0	16.0
125	5	139.8	141.3	2.8	9.46	3.4	11.4	5.0	16.6	6.6	21.7
150	6	165.2	168.3	2.8	11.2	3.4	13.6	5.0	19.8	7.1	27.7
200	8	216.3	219.1	2.8	14.7	4.0	20.9	6.5	33.6	8.2	42.1
250	10	267.4	273.0	3.4	22.1	4.0	26.0	6.5	41.8	9.3	59.2
300	12	318.5	323.8	4.0	31.0	4.5	34.8	6.5	50.0	10.3	78.3
350	14	355.6	355.6	4.0	35.0	5.0	43.7	8.0	69.3	11.1	95.3
400	16	406.4	406.4	4.5	45.1	5.0	50.0	8.0	79.4	12.7	125
450	18	457.2	457.2	4.5	50.7	5.0	56.3	8.0	89.5	14.3	158
500	20	508.0	508.0	5.0	62.6	5.5	68.8	9.5	118	15.1	185

Using Equation (5), the HTS secondary water temperature (T_{as}) can be determined by determining the working fluid temperature (T_{fk}) of 50 – 90 ℃. Calculations were carried out using Matlab software to obtain a graph of working fluid temperature versus secondary water temperature. Based on this graph, it can be seen the secondary water temperature value when the working fluid temperature reaches 50 ℃ to 90 ℃. Next, calculations can be carried out to determine operational time requirements until the working fluid reaches 50 – 90 ℃ with HTS using SPHE, SPFHE, and HPHE.

Calculation of operational time requirements

In the second stage, the initial step is to calculate the volume of HTS material, the volume of HTS tubes, and the volume of secondary water when the HTS is equipped with SPHE, SPFHE, and HPHE. Calculations to determine the HTS mass and secondary water mass when the HTS is equipped with SPHE, SPFHE, and HPHE use the equation [10];

$$m = \rho V \tag{8}$$

With the density shown in Table 4 and the density of SS 304 material being 8000 kg/m^3 [10];

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Table 4. Density of water from 0°C to 100°C [10].

Temperature °C	Density kg/m³	Temperature °C	Density kg/m³	Temperature °C	Density kg/m³
0 (ice)	917.00	33	994.76	67	979.34
0	999.82	34	994.43	68	978.78
1	999.89	35	994.08	69	978.21
2	999.94	36	993.73	70	977.63
3	999.98	37	993.37	71	977.05
4	1000.00	38	993.00	72	976.47
5	1000.00	39	992.63	73	975.88
6	999.99	40	992.25	74	975.28
7	999.96	41	991.86	75	974.68
8	999.91	42	991.46	76	974.08
9	999.85	43	991.05	77	973.46
10	999.77	44	990.64	78	972.85
11	999.68	45	990.22	79	972.23
12	999.58	46	989.80	80	971.60
13	999.46	47	989.36	81	970.97
14	999.33	48	988.92	82	970.33
15	999.19	49	988.47	83	969.69
16	999.03	50	988.02	84	969.04
17	998.86	51	987.56	85	968.39
18	998.68	52	987.09	86	967.73
19	998.49	53	986.62	87	967.07
20	998.29	54	986.14	88	966.41
21	998.08	55	985.65	89	965.74
22	997.86	56	985.16	90	965.06
23	997.62	57	984.66	91	964.38
24	997.38	58	984.16	92	963.70
25	997.13	59	983.64	93	963.01
26	996.86	60	983.13	94	962.31
27	996.59	61	982.60	95	961.62
28	996.31	62	982.07	96	960.91
29	996.02	63	981.54	97	960.20
30	995.71	64	981.00	98	959.49
31	995.41	65	980.45	99	958.78
32	995.09	66	979.90	100	958.05

Calculation of the time required to reach operational temperature with a working fluid temperature of 50 – 90 °C using the energy conversion equation. Where electrical energy is converted into heat energy which is taken by secondary water and HTS components which use SS 304 material. The equation is as follows [7];

$$Pt = Q_{as} + Q_{hts} \quad (9)$$

$$Pt = \left(m_{as}c_{as}(T_2 - T_1)\right) + \left(m_{hst}c_{hts}(T_2 - T_1)\right) \quad (10)$$

$$t = \frac{\left(m_{as}c_{as}(T_2 - T_1)\right) + \left(m_{hst}c_{hts}(T_2 - T_1)\right)}{P} \quad (11)$$

with,

- t = Time (second)
- m_{as} = Mass secondary water period when SPHE, SPFHE, and HPHE are applied (kg)
- c_{as} = Specific heat of water (J/ (kg °C))
- m_{hts} = HTS Mass (kg)
- c_{hts} = Specific heat SS 304 (J/ (kg °C))
- P = Electric heating power (watt)
- Q_{as} = Heat energy absorbed by HTS secondary water (J)
- Q_{hts} = Heat energy absorbed by HTS (J)
- T_1 = The initial temperature of HTS secondary water (°C)
- T_2 = Final HTS secondary water temperature (°C)

Calculations using the equations mentioned above were carried out using Matlab software. The equations used must be converted into the Matlab programming language. The choice of using Matlab software was made because by using this software, repeated calculations with a lot of calculation data can be carried out more quickly and the calculation results can be obtained in graphical form [13]. The analysis is carried out based on the calculation results that have been obtained in the form of graphs so that in the end conclusions can be drawn from the research results.

Results and Discussions

Based on the results of calculations using Equation (6) and Equation (7), the thermal resistance (R_{th}) of Straight Pipe Heat Exchanger (SPHE) and Straight Pipe Fins Heat Exchanger (SPFHE) pipes made of copper is obtained, and the thermal resistance (R_{th}) of Helical Pipe Heat Exchanger pipes (HPHE) with SS 30 material. The calculation results using Matlab software are as follows:

Table 5. Heat exchanger thermal resistance

R_{th} *SPHE* (°C/W)	R_{th} *SPFHE* (°C/W)	R_{th} *HPHE* (°C/W)
0.032711	0.021662	0.003926

Based on the results of the thermal resistance (R_{th}) calculations that have been obtained, it can be seen that the thermal resistance of the SPHE, SPFHE, and HPHE heat exchanger pipes shows a small value (less than 1 °C/W). The smaller the thermal resistance value, the greater the heat transfer that occurs. Based on the calculation results, the thermal resistance value of the HPHE heat exchanger has the smallest value, namely 0.003926 °C/W. This shows that the HPHE heat exchanger produces the greatest heat transfer compared to the SPHE and SPFHE heat exchangers.

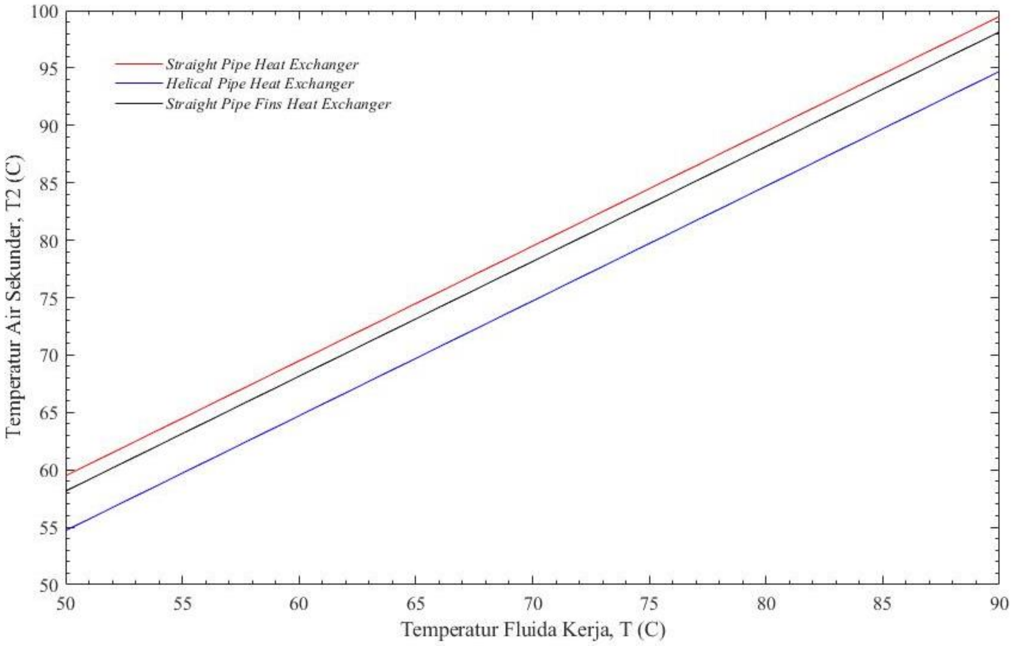

Figure 5. Graph of working fluid temperature versus secondary water temperature

Based on Figure 5, to achieve a working fluid temperature of 50 – 90 °C the HPHE heat exchanger requires secondary water with a lower temperature compared to the SPHE and SPFHE heat exchangers. To achieve a working fluid temperature of 50 °C, the HTS secondary water temperature with an HPHE heat exchanger is required to be 54.81 °C. Meanwhile, to achieve a working fluid temperature of 90 °C, an HTS secondary water temperature with an HPHE heat exchanger of 94.71 °C is required. More complete calculation data is shown in Table 6.

Table 6. Secondary water temperature and working fluid temperature in the heat exchanger

Types of Heat Exchangers	Working fluid temperature	Secondary water temperature
Straight Pipe Heat Exchanger (SPHE)	50 – 90 °C	59.59 – 99.39 °C
Straight Pipe Fins Heat Exchanger (SPFHE)	50 – 90 °C	58.25 – 98.15 °C
Helical Pipe Heat Exchanger (HPHE)	50 – 90 °C	54.81 – 94.71 °C

Based on Table 5, the HPHE-type heat exchanger requires a lower temperature in the secondary water compared to other types of heat exchangers. Thus, the HPHE-type heat exchanger has better performance compared to the SPHE and SPFHE heat exchangers. Next, a calculation is carried out to determine the operational time requirements for the FASSIP 03 NT loop to reach a working fluid temperature in the range of 50 – 90 °C. First, calculations are carried out to determine the water volume and water mass in the HTS and HTS equipped with SPHE, SPFHE, and HPHE heat exchangers. The calculation results are as follows;

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Table 7. Volume and mass of heat exchange water

Types of Heat Exchangers	Water volume (m^3)	Water mass (kg)
Straight Pipe Heat Exchanger (SPHE)	0.143035	142.586125
Straight Pipe Fins Heat Exchanger (SPFHE)	0.143005	142.556132
Helical Pipe Heat Exchanger (HPHE)	0.138622	138.186476

The calculation data shown in Table 6 is used in Equation (11) to calculate operational time requirements. Calculations use Matlab software with the calculation results displayed in graphical form in Figure 6 below.

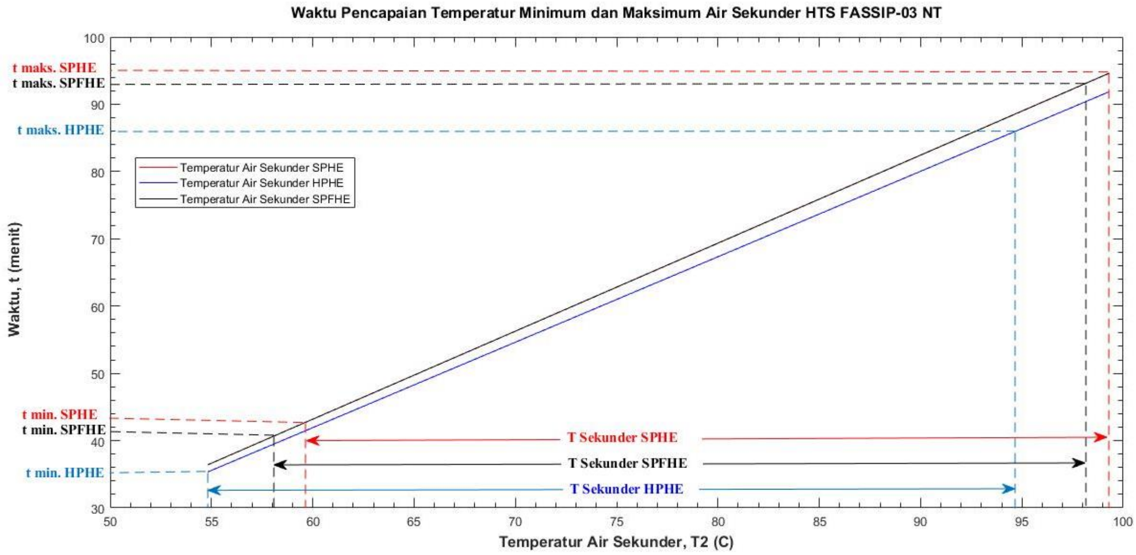

Figure 6. Graph of secondary water temperature versus time

Figure 6 shows that the SPHE secondary water temperature graph coincides with the SPFHE secondary water temperature graph. The red graph is not visible because it is overwritten by the black graph. The overlap of the two graphs is because the volume of secondary water when the HTS is equipped with SPHE only has a very small difference (0.00003 m^3) with the volume of secondary water when the HTS is equipped with SPFHE. The secondary water mass when HTS is equipped with SPHE is not much different from the secondary water mass when HTS is equipped with SPFHE. This results in the heat absorbed not being much different. This condition is very different from HTS equipped with HPHE, where the volume and mass of secondary water have quite large differences. As a result, the heat absorbed by secondary water when the HTS is equipped with HPHE also has a difference, and the secondary water temperature graph does not coincide.

To determine the time required for each heat exchanger to reach an operational temperature in the range of 50 – 90 ℃, is done by referring to the results of calculating the secondary water temperature for each heat exchanger (Table 6). By drawing a line on the graph in Figure 6 parallel to the Y axis towards the top until it touches the graph line, then by drawing a line parallel to the X axis towards the left until it touches the Y axis, the minimum time and maximum time for each heat exchanger are obtained. The minimum and maximum time required for each heat exchanger is shown in Table 8 below

Table 8. Heat exchanger time requirements

Types of Heat Exchangers	Secondary water temperature (℃)	Minimum time (minutes)	Maximum time (minutes)
Straight Pipe Heat Exchanger (SPHE)	59.59 – 99.39 ℃	43	95
Straight Pipe Fins Heat Exchanger (SPFHE)	58.25 – 98.15 ℃	41	93
Helical Pipe Heat Exchanger (HPHE)	54.81 – 94.71 ℃	35	86

Based on Table 8, it can be seen that the Helical Pipe Heat Exchanger (HPHE) heat exchanger requires a shorter time to raise the temperature of the working fluid to reach operational temperature, namely in the range of 50 – 90 ℃. Because the heating electrical power is the same as that used by other heat exchangers, the HPHE heat exchanger only requires a secondary water temperature in the range of 54.81 - 94.71 ℃. The heat transfer produced by the HPHE heat exchanger is more efficient compared to the SPHE and SPFHE heat exchangers. This is because the HPHE has a much larger length, namely 5.5 m, and as a result, the thermal resistance of the HPHE (R_{th}) is very small, namely 0.003926 ℃/W.

As a comparison, other research that has been carried out is research entitled Heating and Cooling Performance Analysis in Passive System Simulation Facility Loops. In this study, an immersion heater with a total power of 20 kW took approximately 28.8 minutes to reach a water temperature of 75 °C [14]. Meanwhile, in the research entitled Heating Tank Temperature Characteristics and Reynolds Number During Natural Circulation Flow in the FASSIP-02 Test Loop, the heating tank uses an immersion heater with a total power of 20 kW. To reach a temperature of 40 ^{o}C takes 23.7 minutes, to reach a temperature of 50 ^{o}C takes 38.8 minutes and to reach a temperature of 60 ^{o}C takes 54.15 minutes [15]. The research entitled Calculation of Thermal Insulator Thickness Design for Water Heating Tank FASSIP-02 Mod.01, uses an immersion heater with a power of 20 kW. This research found that WHT without being equipped with a thermal insulator resulted in heat loss of more than 700 W/m. Heat loss decreases to 50 W/m when WHT is equipped with thermal insulators in the form of silica aerogel, corrugated cardboard, and aluminum [16]. In the research entitled Design of Modified Heater and Water Bath Control System with a Capacity of 9 Liters, a Tubular type electric heater with a power of 1.8 kW was used. Where to increase the temperature from 30 ℃ to 100 ℃ takes 30 minutes [17]. The research entitled Design and Construction of an Automatic Rice Dryer Prototype Based on the AT89S52 Microcontroller uses a Tubular type electric heater with a power of 0.3 kW. In this study, reaching a temperature in the range of 40.11-54.22 ℃ took 10-45 minutes [18]. In the research entitled Calculation and Determination of the Type of Flow in the FASSIP-03 NT Loop During Commissioning Based on Variations in Heating Power, a Band Ceramic Heater type electric heater with a power of 12 kW was used. In this research, the HTS heat exchanger Helical Pipe Heat Exchanger (HPHE) was applied. In the power range of 5,475-10,250 kW reaching a temperature of 40-90 ℃ results in a natural circulation flow rate of 0.000061– 0.000092 m^3/s and a turbulent flow type (Re range: 4305.8 – 7705.4) [19]. The research entitled Characterization of the Prototype Heater Element System on the RCCS-RDNK Test Loop used an Infrared Camera, whereas this research used 25 kW cable wire as an electric heater. To reach a temperature of 200 ℃ on the wall surface of the Heater Element System prototype in the vertical position takes 10 minutes and in the horizontal position takes less than 20 minutes [20]. The study used the FASSIP-01 Mod. 01 loop which aims to determine the characteristics of the heating section using cantal wire as a heating source with a power of 2 kW. The research was carried out for 105 minutes and resulted in the highest temperature in the vertical position being 240.63 °C, while in the horizontal position, the highest temperature was 360.83 °C [21].

Conclusions

In the Heating tank Section (HTS) 3 types of heat exchangers can be applied (heat exchangers namely Straight Pipe Heat Exchanger (SPHE), Straight Pipe Fins Heat Exchanger (SPFHE), and Helical Pipe Heat Exchanger (HPHE). HPHE-type heat exchangers are more efficient compared to SPHE-type and SPFHE-type heat exchangers, although the HPHE-type heat exchanger is made of SS 304 material, the conductivity of which is lower than the conductivity of copper material. This is because the HPHE-type heat exchanger has a much larger length, namely 5.5 m, so its thermal resistance (R_{th}) is very high. small, namely 0.003926 ℃/W. To reach a working fluid temperature in the range of 50 – 90 ℃, an HPHE-type heat exchanger requires 35 – 86 minutes.

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