Effect of Fins on Charging Performance – Release of a PCM-Based Thermal Energy Operating Simultaneously

Muhammad Abdul Musthofa[1]*, Budhi M. Suyitno[2]
1.2Mechanical Engineering Study Program, Pancasila University, Jakarta, Indonesia
* *Email Corresponding Author*: abdulmusthofa4@gmail.com

ABSTRACT

Penggunaan material perubahan fasa atau PCM organik telah secara luas digunakan sebagai material pengisi unit penyimpan energi termal (PET) karena harganya yang relatif murah, mudah didapat dan suhu yang relatif konstan pada saat fase perubahan wujud. Namun disisi lain, material perubahan fasa memiliki konduktivitas termal yang rendah sehingga lambat dalam durasi pengoperasian yang dipandang sebagai sebuah kelemahan. Untuk mengatasi masalah tersebut diusulkan penggunaan sirip yang dimasukkan kedalam PCM pada unit PET yang beroperasi secara simultan. Sirip alumunium jenis plat dan pipa diamati pengaruhnya terhadap unit PET dengan PCM asam palmitat (PA) dan asam miristat (MA) sehingga terdapat empat variasi eksperimen yaitu asam palmitat - sirip plat alumunium (PA1), asam palmitat - sirip pipa alumunium (PA2), asam miristat - sirip plat alumunium (MA1), asam miristat - sirip pipa alumunium (MA2) yang diuji dari suhu lingkungan hingga suhu PCM 90 °C dan kembali ke suhu lingkungan. Hasilnya, secara visual dapat diamati PCM melebur dan membeku lebih awal pada area dinding sirip. Berdasarkan data eksperimen, PA1 lebih cepat 4.5 % dibanding PA2, dan MA1 lebih cepat 8.1 % dari MA2 dari selisih durasi operasi PET, sehingga dapat disimpulkan bahwa penggunaan sirip plat alumunium membuat durasi operasi lebih cepat dibanding sirip pipa alumunium. Sistem operasi simultan menyebabkan suhu pada exhaust meningkat rata – rata 11.1 °C saat proses pengisian, saat pelepasan suhu exhaust menurun rata – rata 14.5 °C dari seluruh unit PET.

Keywords: PCM, Thermal Energy Storage, Simultaneous

ABSTRACT

The use of phase-change materials, or organic PCM, has been widely used as a filling material for thermal energy storage units (PETs) because of its relatively low price, ease of procurement, and relatively constant temperature during the phase change of form. On the other hand, phase-change materials have low thermal conductivity, so they are slow in the duration of operation, which is seen as a weakness. To overcome this problem, it is proposed to use fins inserted into the PCM on PET units that operate simultaneously. Aluminum fins of plate and pipe type aluminum were observed to affect PET units with PCM palmitic acid (PA) and myristic acid (MA) so that there were four experimental variations, namely palmitic acid - aluminum plate fin (PA1), palmitic acid - aluminum pipe fin (PA2), myristic acid - aluminum plate fin (MA1), and myristic acid - aluminum pipe fin (MA2), which were tested from ambient temperature to PCM temperature 90°C and back to ambient temperature. As a result, it can be visually observed that PCM melts and freezes early in the fin wall area. Based on experimental data, PA1 is 4.5% faster than PA2, and MA1 is 8.1% faster than MA2 because of the difference in PET operating duration, so it can be concluded that the use of aluminum plate fins makes the operation duration faster than aluminum pipe fins. The simultaneous operating system causes the temperature in the exhaust to increase by an average of 11.1°C during the filling process, while the exhaust temperature discharge decreases by an average of 14.5 °C from all PET units.

.***Keywords: PCMs, Thermal Energy Storage, Simultaneous***

INTRODUCTION

Fossil energy consumption [1] [2] and carbon emissions are increasing in line with urbanization trends globally [3]. The exploitation of energy that increases greenhouse gases triggers climate change, whose impacts can be felt in real terms such as floods, extreme heat conditions, rising sea levels, storms, and droughts [4]. The energy transition to low-carbon energy is a strategy to address climate change [5]. This energy transition is important because it concerns the issue of climate change, which is mentioned in the NDC (*Nationally Determined Contribution) document of the* Paris Agreement, namely a reduction in greenhouse gas emissions by 29% [6], which indicates the importance of direct climate policy [7].

The energy transition process can reduce fossil energy consumption, although fossil energy is still needed in the energy mix. Awareness of green energy is increasing as a preventive measure to the worsening of the global climate. For example, countries that have been successful in green energy development are Turkey and Mexico, while Brazil and Indonesia have the worst rankings in green energy development [8]. Before the industrialization era, the use of energy, especially heat energy, was only limited to cooking, lighting, and metal processing. But we can already find the use of renewable energy, such as in sea transportation, the use of sails as wind energy catchers, water wheels, and the process of drying agricultural and fishery products using solar energy [9].

As sources of green energy, solar heat and wind energy are quite promising due to their great potential. The potential of solar energy in Indonesia reached 3,294.4 GW based on the update of solar energy data in 2021. The provinces of East Nusa Tenggara, Riau, and South Sumatra have the largest solar energy potential based on data per province [10]. The data show that the potential of renewable energy such as solar energy is huge, but its *intermittent* nature and also natural phenomena such as cloudiness and rain cause uncertain supply, making it one of the weaknesses of solar energy [11][12].

In order to maintain the energy supply, we must implement an energy storage system. Energy storage is intended to store excess energy temporarily and reduce the impact of load spikes and rapid drops, making it possible to be used at a different time and location and to increase capacity reliability [13]. In this case it is a thermal energy store (PET).

Thermal energy storage is differentiated into hot PET and cold PET. Cold PET is usually used for logistics purposes, such as the delivery of foodstuffs such as meat or in the delivery of vaccines that require cold temperatures. The advantage of PET is the ability to store energy each season. Hot PET can store the heat collected from the summer, which is then supplied when winter arrives as a room heater. The application of mature PET technology is exemplified in a power plant with a concentrated solar power (CSP) system using liquid salt as a heat storage material. Industrial field in low-temperature heat storage for solar PV. The obstacle to the implementation of PET is the level of technological readiness for several types of PET that is still lacking; awareness and knowledge about PET that can provide benefits to society, the public, and industry are still lacking. Investors are still reluctant to invest in large-scale projects long-term; this is due to the uncertainty of future energy system developments [13].

Research on thermal energy storage as a form of awareness of green energy is growing. Thermal energy storage units can be categorized based on thermal energy storage materials, namely sensible thermal storage, latent thermal storage, and also chemical thermal storage [14]. Thermal energy storage has categories in the operating system that are passive and active. Like basic heat transfer, passive systems utilize natural convection in their operating system, and active systems use forced convection by running the working fluid. However, it can also be with a combination of active and passive thermal storage operating systems [15], but latent heat storage materials have weaknesses, especially for organic matter such as fatty acids, i.e., during the phase change process of both melting and freezing, heat transfer is weak [17]. The phase-change material's low thermal conductivity hinders the overall rate of heat transfer [18]. On the other hand, sensitive heat storage materials also have the disadvantage of rapid energy degradation or release [19].

The discharge charge rate affects the energy storage results. The rate of temperature change has a significant impact on latent heat capacity [20]. Various experiments were conducted as an approach to improve the response time of PCM materials in filling and discharging, such as the addition of fins [21], the addition of nano-sized particles, the installation of hot pipes [22][23], porous media [24], and geometric shapes [25]. The addition of nanomaterials to PCMs can increase their melting rate, but this can also reduce their thermal energy storage capacity [26].

Increasing the rate of PCM phase change can be done by using fins and nanomaterials simultaneously, given that the low conductivity of PCM is therefore considered one of its weaknesses.

However, the use of fins is more effective in increasing the rate of phase change of PCM when compared to the use of nanomaterials in PCM [27]. The fin parameters in thermal energy storage applications have a significant effect on the discharge charge rate, as well as the fin configuration [28].

In its development, systems with natural convection mechanisms can be assisted by heat pipes to improve heat transfer efficiency [29]. Heat pipes are an efficient passive heat energy transfer device by utilizing phase changes in heat transfer [30]. Thermal storage systems that operate simultaneously consist of a discharge process sourced from the PCM and direct heat transfer from the charge [31]. The use of aluminum fins with various configurations is proposed in this study so that it is expected to increase the heat transfer rate during the filling and discharge process, so the researcher wants to determine the effect of aluminum plate fins and aluminum pipes on the performance of PCM-based thermal energy storage by conduction and convection factors and the comparison of the operating rate of PET units with aluminum plate fins compared to PET units with aluminum pipe fins, as well as exhaust temperature conditions in each thermal energy storage unit that operates simultaneously.

The researcher wanted to analyze the effect of aluminum plate fins and aluminum pipes on the performance of PCM-based PET by conduction and convection factors, then analyze the comparison of the operating rate of PET units with aluminum plate fins compared to PET units with aluminum pipe fins, and analyze exhaust temperature conditions in each PET unit operating simultaneously.

RESEARCH METHODS

Research Stages

The experiment began with a charging process from an average ambient temperature of 33°C using a 30-watt electric heater until the PCM temperature reached 90°C. Then it is continued to the discharge process using a fan installed in the *intake* hole with a wind speed of 2 m/s directed directly against the fins towards the exhaust hole until the PCM temperature returns to ambient temperature. The temperature in the exhaust duct is seen to monitor the simultaneous operation of the PET unit at filling and during discharge by the influence of the fins. Figure 1 shows a research flowchart.

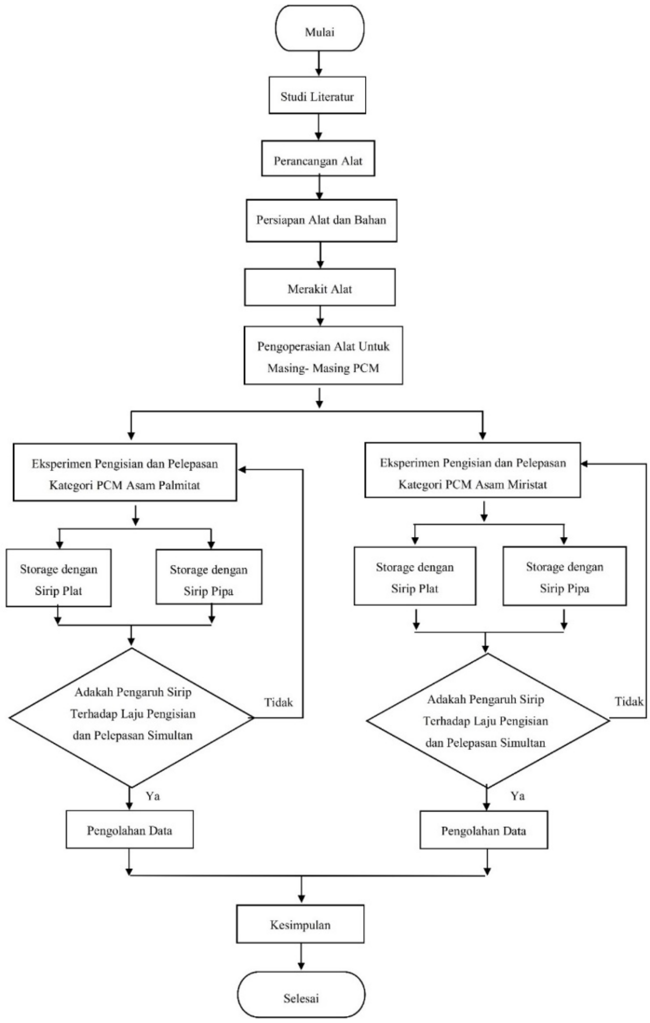

Figure 1. Research Flow Diagram

Preparation

Electric Heating Equipment Range with Temperature Sensor

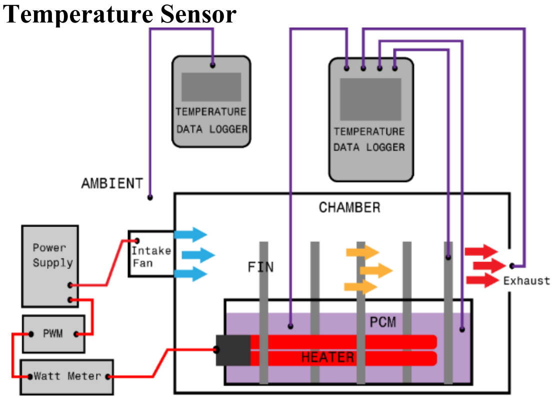

Figure 2. Experimental Equipment Range

Experimental Equipment Unit Design

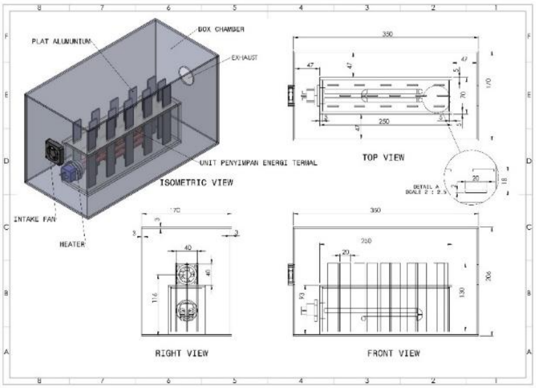

Figure 3. Working Drawings of Thermal Energy Storage Unit

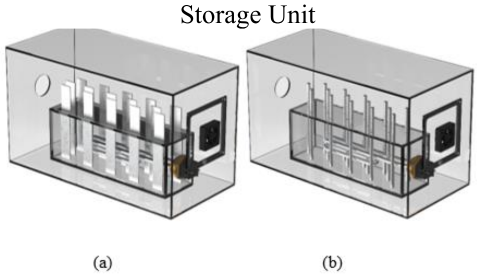

Figure 4. Latent Heat Storage Units with Fin Variations (a) Aluminum Pipes (b) Aluminum Plates

Phase Change Material

The phase change materials used in this study are in the form of palmitic acid and myristic acid.

Table 1. Phase Change Material

No.	Material	Titik lebur	Titik didih
1	Asam palmitat	62 °C	351 °C
2	Asam miristat	54 °C	333 °C

Energy Capacity Calculation

Table 2. Energy Capacity of PET Unit During Filling Process – Discharge

	Nilai Q Saat Pengisian			Nilai Q saat Pelepasan			Q Total (kJ)
Wilayah Fasa	Sensibel Padat (kJ)	Laten (kJ)	Sensibel Cair (kJ)	Sensibel Cair (kJ)	Laten (kJ)	Sensibel Padat (kJ)	
PCM Asam Palmitat	43.46	154.2	57.75	61.53	154.7	40.89	512.6
PCM Asam Miristat	28.3	144.75	64.44	68.4	141.9	25.5	473.4

Research Components

a) Power Supply
b) Electric Heater
c) Fan
d) Termometer Data Logger
e) Pulse Width Modulation
f) Watt Meter
g) Anemometer
h) Acrylic
i) Aluminum Plate
j) Aluminum Pipe
k) Asam Palmitat
l) Myrictic Acid

RESULTS AND DISCUSSION

Filling and Discharging Performance of Aluminum Plate Fin Palmitic Acid Category

All profiles of the results of the PA1 experiment were collected into a single graphic image to display the temperature comparison. The charge and discharge profile of PA1 is shown in Figure 5. PA1-T1 experienced an earlier temperature increase than PA1-T2; this was due to the location of PA1-T1, which was closer to the *heater,* but at the 84th minute the two PCM sensors, PA1-T1 and PA1-T2, were at the same temperature point at 75.7°C. In the filling process, there is also a natural release process on the fins of the aluminum plate through convection of the fins of the aluminum plate against the air in the chamber, resulting in a simultaneous filling and discharge process. This can be observed from the difference in average ambient temperature with the temperature in the exhaust, which experiences a peak temperature of 44.4°C before the discharge process.

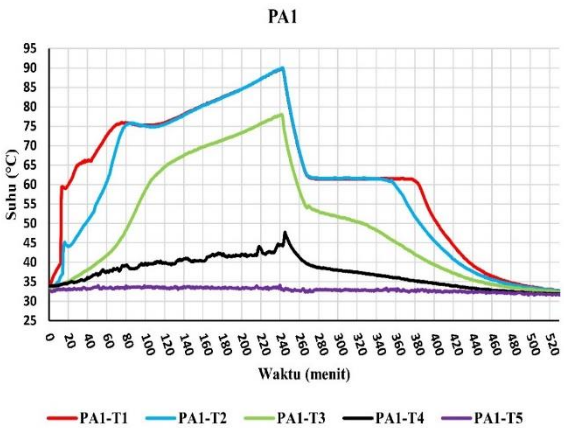

Figure 5. Increase and decrease in PA1 temperature

Filling and Discharging Performance of Aluminum Pipe Fin Palmitic Acid Category

All profiles of the results of the PA2 experiment are collected into a single graphic image to display the temperature comparison. The PA2 charge and discharge profile is shown in Figure 6.

PA2-T1 experienced an earlier temperature rise than PPPA2-T2; this was due to the location of PPPA2-T1, which was closer to the *heater,* but at the 91st minute the two PCM sensors, namely PA2-T1 and PA2-T2, were at the equivalent temperature point at 75.6 °C. Just like the previous experiment, the filling process also occurs in a natural release process on the aluminum fins through convection of the aluminum fins against the air in the *chamber*, resulting in simultaneous filling and discharging processes. This can be observed from the difference in average ambient temperature with the temperature in the *exhaust, which* experiences a peak temperature of 43.8 °C before the release process.

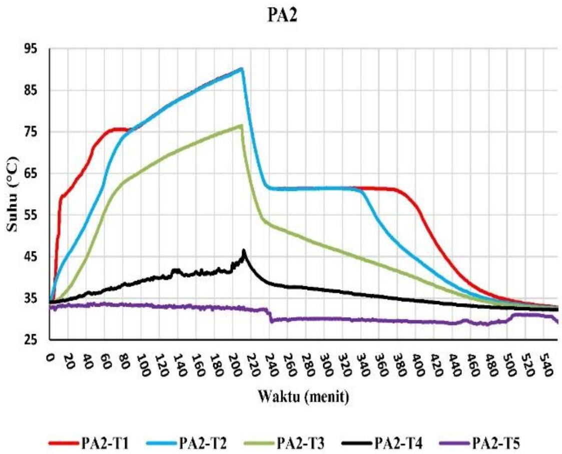

Figure 6. Increase and decrease in PA2 temperature

Filling and Discharging Performance of Aluminum Plate Fin Smyric Acid Category

All profiles of MA1 experiment results are collected into a single graph image to display the temperature comparison. The charge and discharge profile of MA1 is shown in Figure 7. MA1-T1 experienced an earlier temperature rise than MA1-T2; this was due to MA1-T1's location closer to the *heater,* but at the 48th minute, the two PCM sensors, MA1-T1 and MA1-T2, were at the same temperature point at 69.7°C.

Just like the previous experiment, the filling process also occurs in a natural release process on the fins of the aluminum plate through the convection of the fins of the aluminum plate against the air in the *chamber*, resulting in simultaneous filling and discharging processes. This can be observed from the difference in average ambient temperature with the temperature in the *exhaust,* which experiences a peak temperature of 44.3 °C.

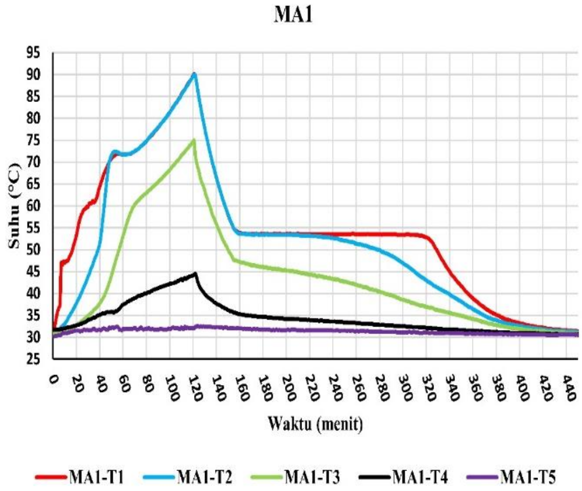

Figure 7. MA1 Temperature Increase and Decrease

Filling and Discharging Performance of Aluminum Pipe Fin Smyristic Acid Category

All profiles of the MA2 experiment results are collected into a single graphic image to display the temperature comparison. The charge and discharge profiles of MA2 are shown in Figure 8. MA2-T1 experienced an earlier temperature rise than MA2-T2; this was due to MA2-T1's location closer to the *heater,* but at the 49th minute, the two PCM sensors, MA2-T1 and MA2-T2, were at the same temperature point at 72.4°C.

Just like the previous experiment, the filling process also occurs in a natural release process on the aluminum fins through convection of the aluminum fins against the air in the *chamber,* resulting in simultaneous filling and discharging processes. This can be observed from the difference in average ambient temperature with the temperature in the *exhaust,* which experiences a peak temperature of 44.9 °C before the discharge process.

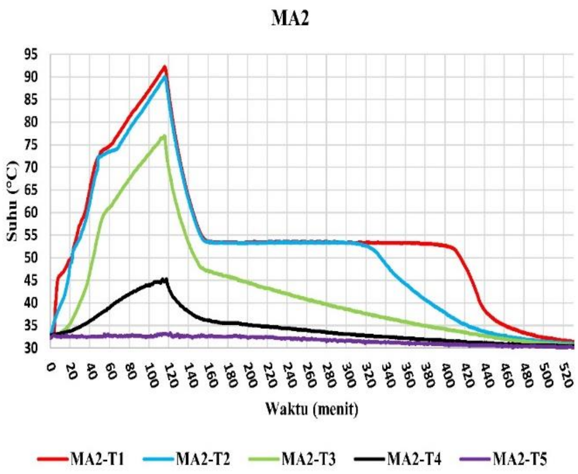

Figure 8. MA2 Temperature Increase and Decrease

Analysis of Experimental Results

Figure 9 shows a comparison of the charging and discharging duration and the total operating duration of the entire thermal energy storage unit with the data shown in Table 3. The MA2 thermal energy storage unit has the fastest charging value with a charging duration of 116 minutes, while the PA1 unit has the slowest charging duration with a charging duration of 242 minutes. In the discharge process, the PA1 unit has the fastest discharge duration with a time of 288 minutes, while the MA2 unit is the longest in discharge with a discharge duration of 374 minutes.

The MA1 unit has the fastest total charging and discharging duration with a time of 450 minutes, while the PA2 unit has the slowest total charging and discharging duration with a time of 555 minutes.

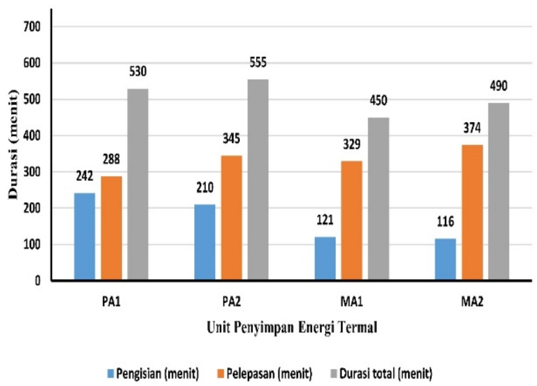

Figure 9. Comparison of PET Unit Filling and Discharging Duration

Table 3. PET Unit Filling and Discharging Duration

No.	Unit PET	Pengisian (menit)	Pelepasan (menit)	Durasi total (menit)
1	PA1	242	288	530
2	PA2	210	345	555
3	MA1	121	329	450
4	MA2	116	374	490

With the presence of fins, the PET operating system tested is simultaneous, this is characterized by an increase in the temperature of the *exhaust* in each PET unit during the filling process. The increase and decrease in *exhaust* temperature is shown in Figure 10 with the measurement data shown in Table 4.

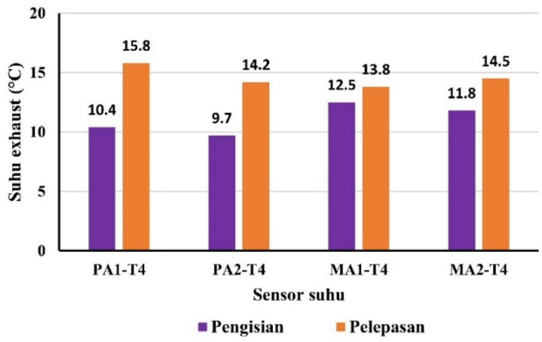

Figure 10. Increase and decrease in *Exhaust Temperature*

Exhaust *temperature measurement data* is shown in Table 4.

Table 4. Exhaust Temperature Measurement Data

Peningkatan dan penurunan suhu *exhaust*			
No.	Sensor	Pengisian (°C)	Pelepasan (°C)
1	PA1-T4	10.4	15.8
2	PA2-T4	9.7	14.2
3	MA1-T4	12.5	13.8
4	MA2-T4	11.8	14.5

CONCLUSION

Based on the results of the discussion that has been presented in this study, it can be concluded that:

1. The influence of the fins when filling: the PCM in the fin wall area melts early. This is because the temperature of the PCM has melted where a higher temperature is transmitted through the fins to the PCM that is still frozen in the lower area through the conduction process. During the discharge process, the PCM freezes early in the fin wall area; this is due to the lower fin temperature due to the transfer of convection heat during the cooling process by the wind from the fan.

2. The operating rate of PET units is faster using aluminum plate fins compared to aluminum pipe fins; is thisn be seen by the difference in total operating duration of 4.5% in PA1 and PA2 unit a difference of 8.1% in MA 1 1d MA 2 2its.

3. The presence of fins causes discharge during charging; is characterized by an increase in exhaust temperature in the charging process even without the help of wind from the *intake fan*. The temperature in the *exhaust increases by* an average1.1 °C the filling process, while the exhaust temperature discharge decreases average of 14.5 °C all PET units.

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