SEMARAK ILMU
PUBLISHING
202103268166(003316878-P)

Journal of Advanced Research in Applied Mechanics

Journal homepage:
https://semarakilmu.com.my/journals/index.php/appl_mech/index
ISSN: 2289-7895

Evaluation of Heating Pad using Electrical Heating Element for Flexitank Transportation Application

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ARTICLE INFO

Article history:
Received 15 May 2024
Received in revised form 7 July 2024
Accepted 19 July 2024
Available online 30 August 2024

Keywords:
Electrical heating pad; flexitank transportation; liquid heating; heating pad; liquid transportation

ABSTRACT

Liquid transportation is accomplished in various ways, including the use of tankers and containers. Recently, most liquid shipments have utilised Flexitank as liquid containers, where steam heating is employed to melt frozen cargo liquids. However, due to limitations and disadvantages associated with steam-type heating pads, particularly in terms of the time taken to melt the liquid, researchers are exploring alternative methods for heating liquid within the Flexitank. This project aims to investigate the possibility of implementing electrical heating pads as an option for liquid heating in liquid transportation. Various types of electrical heating pads have been studied to explore their characteristics and operational capabilities. Experimental testing has been conducted on several electrical heating pads to compare their characteristics, especially in terms of the desired temperature requirement for specific liquid temperatures, and current consumption for each heating pad. This study will assist in determining the best option for implementing electrical heating pads in Flexitank. The results show a promising future for electrical heating pads in Flexitank, but further study is required to examine various heating pad arrangements in actual implementation.

1. Introduction

In the field of logistics, goods are transported using various transportation methods, namely cars, buses, trains, and ships. The choice of transportation depends on the organisation's specific needs, with delivery speed being a critical factor [1,2]. Items such as food, beverages, and liquids can be shipped using any transportation mode with cost-effective options like sea transport offering Flexitank container services [3-6].

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https://doi.org/10.37934/aram.123.1.3143

Liquid goods can be securely transported in Flexitank containers, but one challenge is the potential for liquid freezing, especially for beverages [7,8]. Consequently, using a heating pad becomes essential to uniformly reheat the liquid cargo and prevent it from cooling en route to its destination[9]. A heating pad can replace the traditional steam heating pad to streamline the process of returning the liquid to its original state.

Several challenges are associated with improving heating pads in today's logistics industry [1]. Firstly, the time it takes for a liquid to melt can extend the delivery time to the customer by up to three days. This delay is primarily caused using water vapour, which can only be employed at the point of release [10,11]. To address this issue, a new solution involves upgrading the traditional steam heating pad to an electric heating pad installed beneath the Flexitank [12].

The second challenge revolves around evaluating a heating pad system that allows liquid dilution during transportation en route to the delivery location [13-15]. To achieve this, temperature control becomes crucial, and this can be facilitated using the Blynk application to accelerate the heating process and return the liquid to its original state [11,16-19]. The purpose of implementing the electric heating pad is to swiftly reheat the cargo liquid before discharge at the designated destination.

1.1 Background of Heating Pad

In the market, there are two distinct types of Flexitank heating pads available: steam heating pads and electric heating pads. These heating pads serve as reheat devices installed beneath a Flexitank to safely warm the cargo before unloading, and they exhibit significant differences. While Figure 1 (a) shows that many companies are already offering steam heating pads, there is also a growing availability of electric heating pads.

Steam heating pads, as depicted in Figure 1 (a), come with a range of advantages, but they are effective only up to an air temperature of 100°C for restoring the cargo to a liquid state before unloading. In contrast, electric heating pads can achieve temperatures exceeding 100°C. Both types of heating pads provide a secure and efficient means of reducing product viscosity and ensuring the liquid returns to its original state at the destination, accommodating various time constraints [20,21].

(a)

(b)

Fig. 1. Heating Pad (a) Heating pad using steam [1], (b) Electrical heating pad

The electric heating pad, as depicted in Figure 1 (b), represents a significant investment for accelerating the heating of liquids within cargo compared to traditional steam heating pads [21]. Surprisingly, there is limited awareness among the public regarding the convenience and value that this device offers in terms of time efficiency. It is essential to educate the public about the numerous advantages of electric heating pads.

To begin with, electric heating pads offer several benefits. Firstly, they can be reused, which is a substantial advantage. Secondly, they provide consistent and even heating without waiting for the product to reach its destination [22]. This can significantly reduce the time required compared to using a steam heating pad. Finally, electric heating pads enable various companies to expedite the delivery of their products to customers, further enhancing their efficiency in the logistics process.

2. Methodology

This project's primary aim is to fabricate an electric heating pad with integrated IoT control capabilities. A 13A plug serves as the power source to activate the electric heating element. A 5V DC adapter is utilized to power the ESP32 NodeMCU, establishing the necessary DC supply. Upon activation of the electric heating pad and the ESP32, a MAX6675 K-type thermocouple sensor provides real-time liquid temperature readings within the pad. These readings are transmitted to the Blynk App, which is Wi-Fi-connected to the ESP32 NodeMCU.

Temperature adjustments of the item can be remotely regulated through the Blynk application interface. A visual representation of these processes is provided in Figure 2.

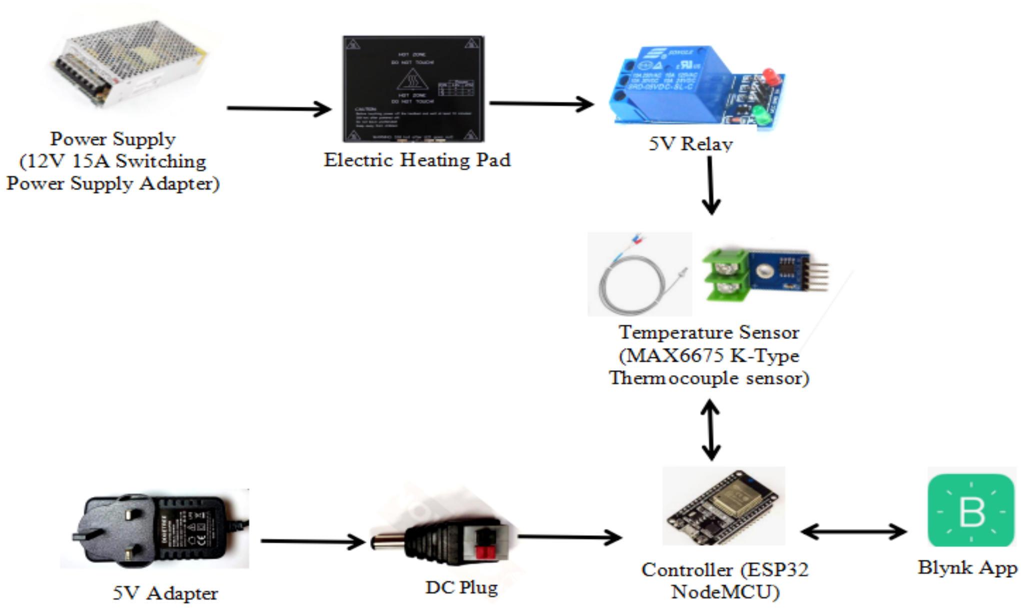


Fig. 2. Temperature control and monitoring of Electrical heating pad

2.1 Heating Pad Selection and Comparison

Various electric heating pads, as outlined in Table 1, were procured to gather comprehensive data. Each electric heating pad was selected based on several key parameters, including pricing, dimensions, voltage rating, maximum temperature capability, alignment with project objectives, and a budget allocation of approximately 50 Ringgit Malaysia.

Of noteworthy mention is electric heating pad type D, priced at 50 Ringgit Malaysia, which stands out due to its larger dimensions measuring 21.4x21.4 cm. In contrast, electric heating pad type D was chosen for its remarkable attributes, boasting a high maximum voltage rating of 220V and the ability to regulate temperatures up to 270°C. This choice was driven by the need to investigate the extent of voltage variation, as conventional electric heating pads typically operate at a 12V threshold. Additionally, this exploration aims to assess whether the Flexitank material is adversely affected when subjected to extremely high heat generated by the heating pad.

Table 1
Various type of electrical heating pad for evaluation

Type	Figure	Cost (RM)	Size [cm]	Voltage [V]	Max.temp.[◦c]	Power,P [W]
A		3.99	11.0x2.0	12	240	15
B		8.2	10.0x5.0	12	150	15
C		20.29	12.0x12.0	12	240	120
D		3.96	8.0x2.0	220	270	100
E		50	21.4x21.4	12	100	50

Electric heating pad type C draws a substantial current supply of 10 Amperes, resulting in a considerable power consumption of 120 Watts for its operation. In contrast, electric heating pad type B was specifically selected to investigate its capacity to raise temperatures from deficient levels, as it is capable of heating to temperatures from as low as -30°C. Furthermore, electric heating pad type D was chosen to assess the upper-temperature limits that can be monitored through the Blynk App without causing any detrimental effects on the state of the transported liquid cargo.

This evaluation aims to quantify the extent of heat imparted to the transported liquid by an electric heating pad, surpassing the 100°C threshold that represents the maximum temperature achievable with a conventional steam heating pad.

2.2 System Diagram and Temperature Sensor Evaluation

The temperature measurement process is facilitated by utilising the Blynk application, as visually represented in Figure 3. This application effectively showcases temperature data from the ESP32 NodeMCU, which receives input from the MAX6675 K-type thermocouple sensor strategically positioned on the electric heating pad [23]. The thermometer sensor dynamically updates temperature data, ensuring customers receive precise and real-time temperature information via the Blynk application [24].

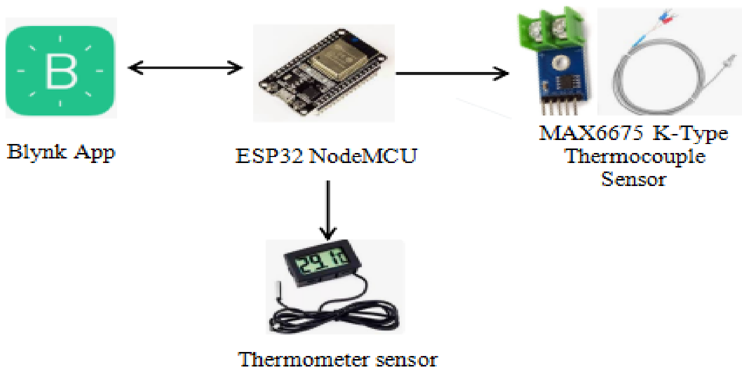


Fig. 3. Block diagram of temperature measurement device

Figure 4 provides a comprehensive system diagram for measuring and testing the heating pad. Each element within the system, including inputs, processes, and outputs, is meticulously illustrated. Input components encompass the power supply, consisting of LLDPE (Linear Low-Density Polyethylene, plastic used in Flexitank), ESP32 NodeMCU, a 5V relay, a 5V DC adapter, DC supply, and the MAX6675 K-type thermocouple sensor. The pivotal component within this system is the electric heating element, specifically the electric heating pad.

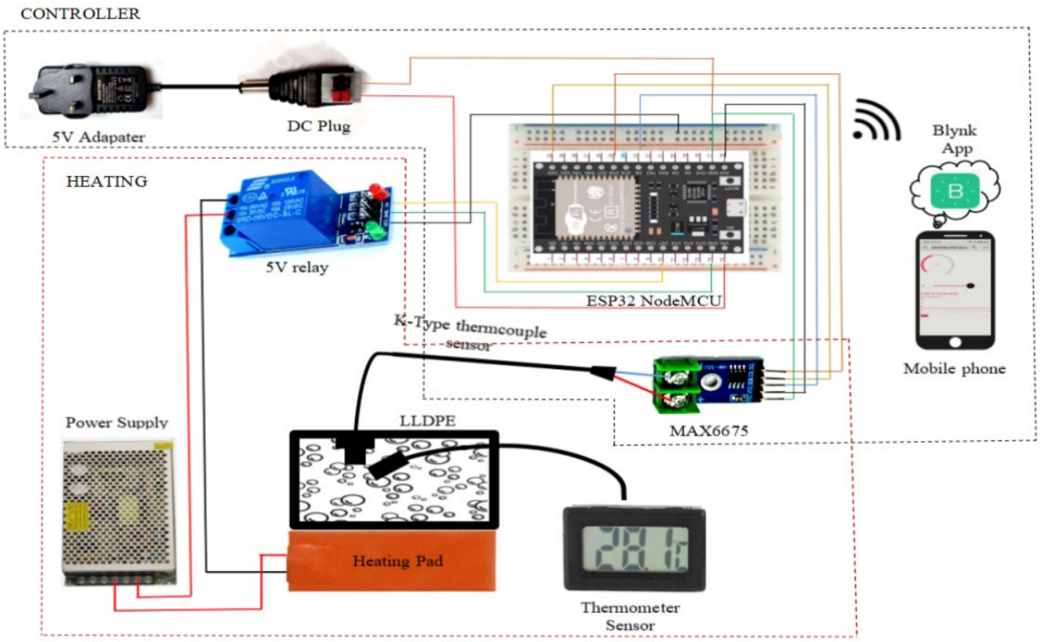
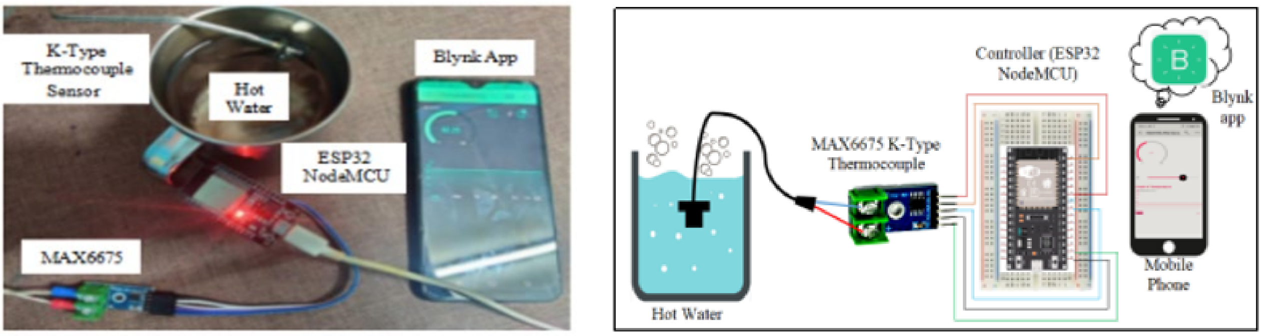


Fig. 4. Electrical heating pad system with temperature measurement device

Within this setup, the Blynk application serves as the platform for displaying temperature data obtained during the testing of LLDPE using the MAX6675 K-type thermocouple sensor. Figures 5 (a) and (b) provide illustrative insights into the temperature optimisation system. The connection between the ESP32 NodeMCU and the MAX6675 K-type thermocouple sensor is established through jumper wires. As depicted in the figures, the SO pin of the thermocouple is connected to the D19 pin, the CS pin to D23, and the SCK pin to D5 of the ESP32. Simultaneously, the sensors' VCC pin and Ground pin are meticulously connected to the corresponding 3V3 pin and Ground pin of the ESP32, ensuring precise alignment with the proper pins for seamless functionality of the monitoring system. The thermocouple sensor is powered via the VDD pin in its normal operational mode, thus guaranteeing the accurate and reliable functioning of the entire monitoring system.



(a) (b)

Fig. 5. Validation of temperature sensor device (a) actual temperature testing, (b) circuit arrangement

3. Results

This section presents the findings derived from the experimental work and the electric heating pad analysis. Initially, individual heating pads undergo comprehensive testing to elucidate their respective temperature profiles. Subsequently, a comparative study of the heating pad results is conducted and discussed to determine the optimal choice for compatibility with Flexitank applications. Finally, a refined prototype is considered a prospect for future endeavours in this domain.

3.1 Individual Performance Characteristics of Heating Pad

Five heating pads underwent rigorous testing to assess their individual characteristics comprehensively. Among these, Heating pads A (Figure 6(a)) and D (Figure 6(d)) shared a common design, both constructed from aluminium bars. However, Heating Pad A operated on a 12V voltage supply, whereas Heating Pad D required a 220V supply. Conversely, Heating pads B and C were fabricated from silicon sheets, varying primarily in size but sharing the exact 12V power requirement. Furthermore, Heating pad E resembled the type used in 3D printing beds for heating. Detailed specifications for each heating pad can be referenced in Table 1 from the preceding section.

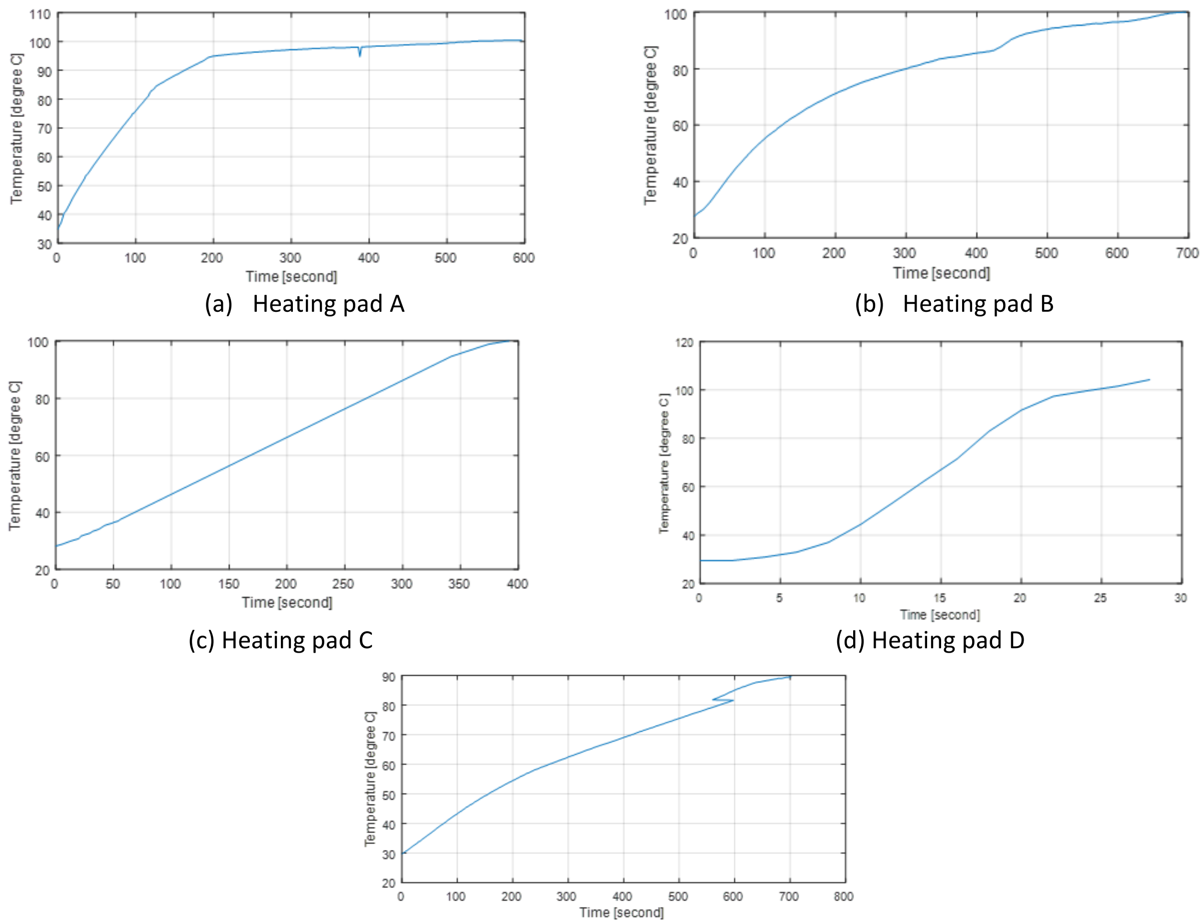


Fig. 6. Temperature characteristics and profiles for each variant of an electrical heating pad, denoted as (a) Heating pad A, (b) Heating pad B, (c) Heating pad C, (d) Heating pad D, and (e) Heating pad E, have been extracted from experimental testing.

Multiple temperature readings were taken over time for each heating pad, and the graph profiles depicted in Figure 6 represent the average temperature readings for each heating pad. Notably, Heating pad D achieved a 100°C temperature increase faster than the other heating pads. However, the prerequisite of a 220V voltage supply poses constraints on its practical implementation within the system, given that all control and primary system components operate on 5V and 12V supplies. Furthermore, the rapid temperature surge in Heating pad D may introduce challenges in control and sensing accuracy, potentially damaging the LLDPE material used in Flexitank [2,22].

Among the remaining four heating pads (Figure 6), Heating pad C exhibited promising results, steadily rising from room temperature to approximately 100°C within 375 seconds. Following closely, Heating pad A exhibited a sharp temperature increase, stabilizing at nearly 100°C after 500 seconds. Heating pads B and E both required around 700 seconds to approach the 100°C mark. The individual testing of each heating pad provided valuable insights into their respective characteristics and behaviors, facilitating the identification of suitable candidates for implementation within the heating pad system.

3.2 Comparison of Electrical Heating Pad Temperature Performance

Following the comprehensive testing and evaluation of each individual heating pad, a comparative analysis was conducted, focusing on their temperature characteristics, current consumption, and the time required for each heating pad to attain the desired temperature. Figure 10 showcases the highest recorded temperature achieved among all the electric heating pads tested. Notably, Heating pad E generated the highest temperature, reaching an impressive 105.4°C, thanks to its utilisation of a 220V power supply. In contrast, Heating pads B and C, operating at 12V and drawing 1.2A of current, achieved a peak temperature of 99.6°C. The heating pad D, the sole contender powered by a 220V supply, reached a maximum temperature of 97.4°C, making it the lowest among the tested heating pads. Heating pad F registered a maximum temperature of 99.4°C, ranking second lowest in this assessment.

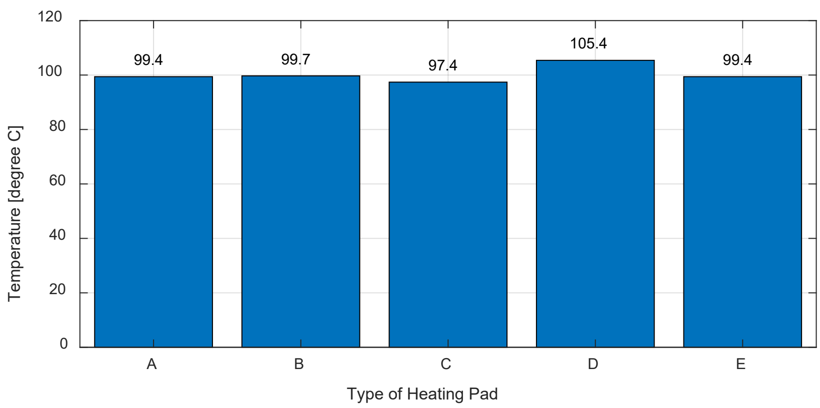


Fig. 10. Maximum achievable temperature for various heating pad

Figure 11 depicts the time each heating pad takes to reach the 100°C target temperature. Heating pad E emerged as the fastest performer, accomplishing this goal in just 28 seconds. In contrast, both Heating pads C and F required a considerably longer time, specifically 660 seconds, making them the slowest to reach the target temperature. Heating pad D completed the task in 360 seconds, while Heating pad B achieved the desired temperature in 540 seconds.

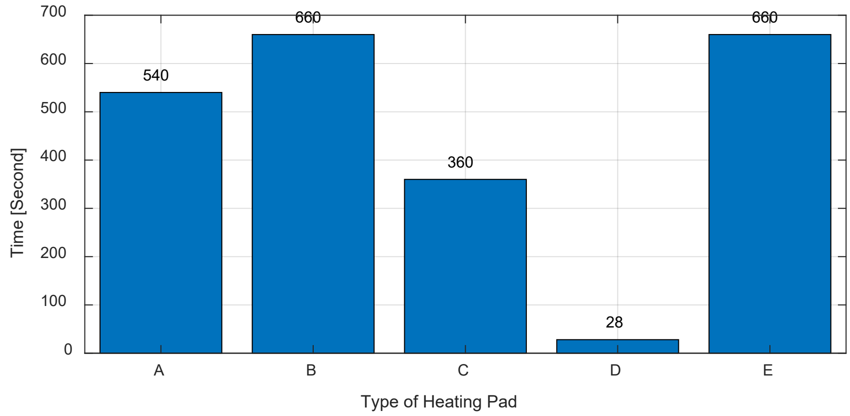


Fig. 11. Time taken for each heating pad to reach 100°C Celsius temperature

Figure 12 illustrates the current profiles for various types of heating pads, mainly focusing on the current observed under a specific liquid surface area. Heating pad D exhibited the most robust current output, making it the preferred choice, especially for compact 12x12cm square area applications. Conversely, Heating pads E and F, with dimensions of 8.0x2.0cm and 21.4x21.4cm, respectively, drew the lowest current, registering at 0.52A and 0.53A. Notably, Heating pad C displayed a current differential of 0.13A compared to Heating pad B, despite a slight difference in their dimensions (1.0x3.0cm).

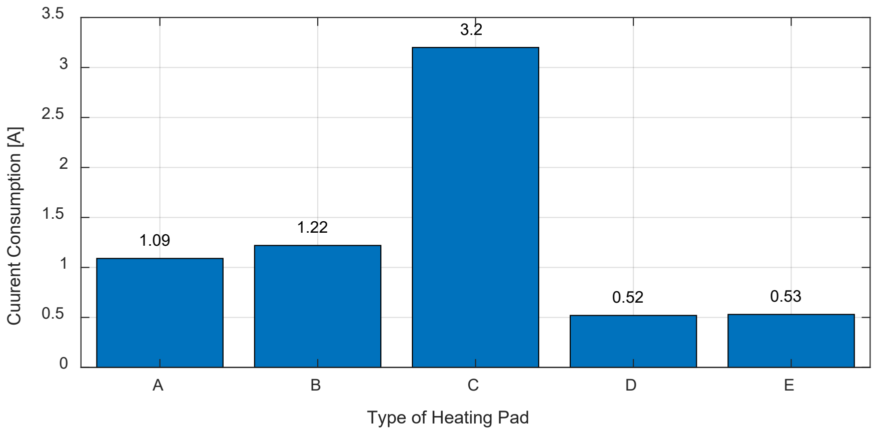


Fig. 12. Current consumption for various heating pad

3.3 Different Heating Pad Arrangement Tested with LLDPE Filled with Water

Given that the performance characteristics of each heating pad have been previously acquired to comprehend their individual traits, we can now explore various configurations of electrical heating pads to achieve larger heating surfaces suitable for Flexitank transportation. The specific types of heating pads and their arrangement options are delineated and annotated in Table 2 below.

Table 2
Setup arrangements for heating pad evaluation

Remarks	Setup Arrangement
A	Heating Pad A with Water
B	Heating Pad B with Water
E	Heating Pad E with Water
SA	Heating Pad A in Series with Water
SB	Heating Pad B in Series with Water
PA	Heating Pad A in Parallel with Water
PB	Heating Pad B in Parallel with Water

Figure 13 provides insight into the highest recorded temperature attained by each electric heating pad during testing. Remarkably, Heating pad E reached a temperature of 54.4ºC, securing the highest temperature among all, while the parallel heating pad PB closely followed with a temperature of 49.6ºC. Conversely, the parallel heating pad PA, operating in parallel configuration, attained a distinct temperature of 39.8ºC, significantly lower than its counterparts. The single heating pad B recorded the second-lowest temperature reading at 34.9ºC. Finally, the temperature readings for the single heating pad A and the heating pads SA and SB in series were identical at 33.2ºC

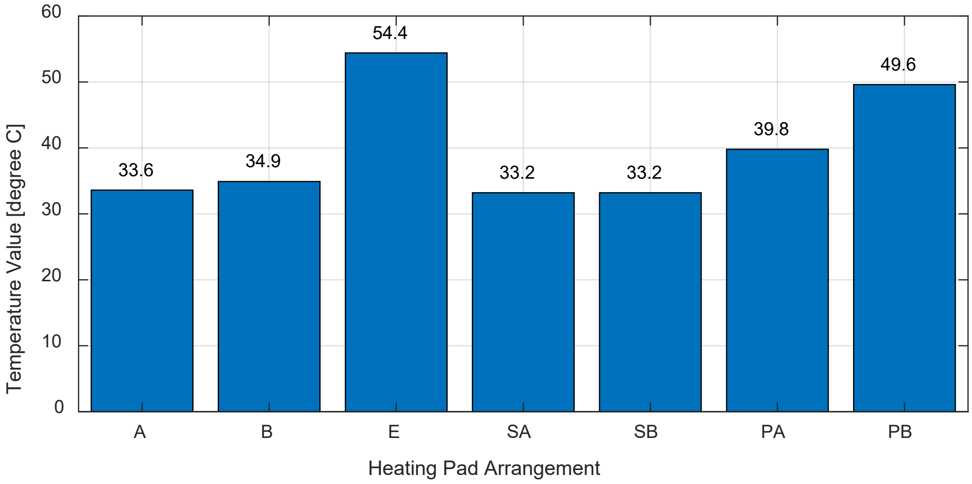


Fig. 13. Temperature value for various heating pad arrangements

Figure 14 illustrates the duration required by each heating pad to stabilize at the designated temperature during testing. The parallel heating pad PB exhibited the longest stabilization time, consuming 172 minutes to reach a temperature of 49.6ºC. In parallel configuration, the heating pad PA followed closely as the second longest, while Heating pad E required 21 minutes to reach 82.2ºC. The single heating pad A took 14 minutes to stabilize at 34.9ºC, while the shortest stabilization time of 33.6ºC was achieved by the single heating pad A. Notably, heating pad SA and SB, arranged in series, reached the same stabilization temperature of 33.2ºC but displayed differential time requirements, with heating pad SA taking 6 minutes and heating pad SB taking 11 minutes. This variation may be attributed to differences in material design (aluminum and silicon sheet) as well as size discrepancies.

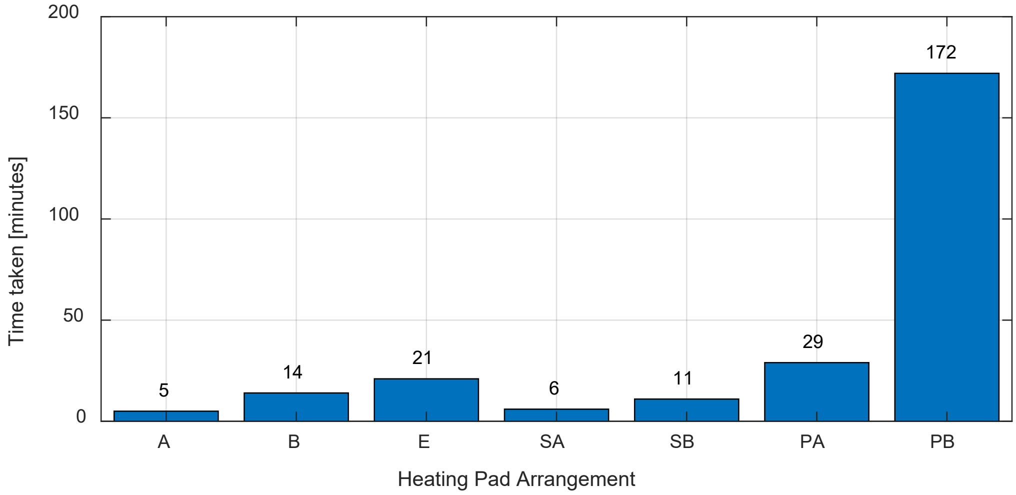


Fig. 14. Time taken for each heating pad setup to reach steady-state temperature

Figure 15 presents a graphical representation of the maximum current values (in Amperes) for various heating pad types. The current measurements are crucial for determining which heating pad exhibits the most substantial current flow across a limited surface area, especially when subjected to a packed liquid surface. Remarkably, heating pad PB demonstrated the highest current flow, solidifying its status as the most efficient heating pad, even when compared to heating pad B and SB, both of which share identical dimensions at 10.0x5.0cm. Conversely, heating pad A, sized at 11.0x2.0cm, exhibited a consistent current draw across all three tests. The heating pad PA displayed a marginal 0.01A difference compared to heating pad A and SA, registering at 1.1A, while the others maintained a current of 1.09A. Notably, Heating pad E exhibited the lowest current draw at 0.53A, despite its larger dimensions of 21.4x21.4cm

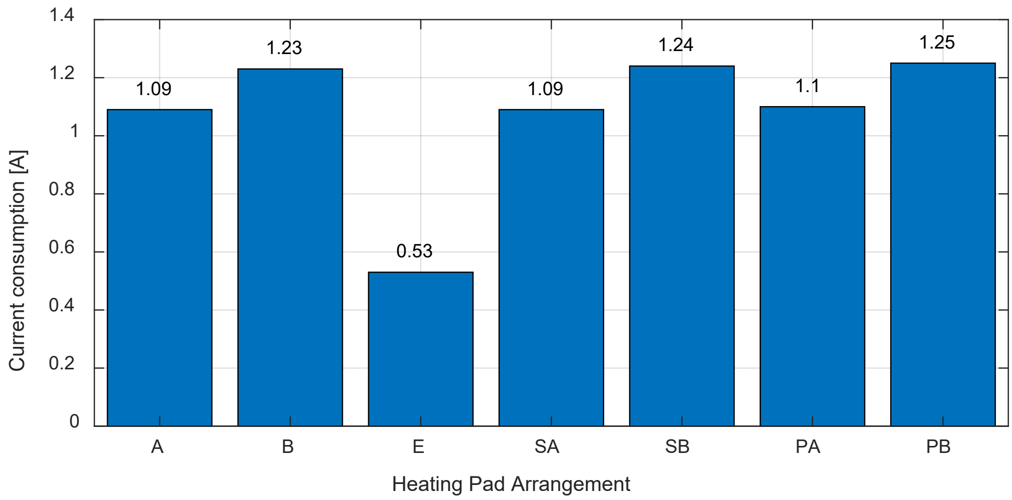


Fig. 15. Current consumption for each heating pad setup

3.4 Expected Final System Prototype

Following the comprehensive testing, characterization, and analysis of each heating pad, alongside experimental trials involving the LLDPE water bag to obtain near-realistic performance data for Flexitank testing, we have proposed the anticipated final system prototype for full-fledged implementation. The recommended system configuration involves parallel connections with both temperature and current sensors, as visually represented in Figure 16.

The proposed system incorporates an auto-cut-off temperature supply mechanism, which activates when the temperature reaches the predefined threshold, based on the type of liquid utilized within the Flexitank. This threshold can be pre-set prior to switching on the system. Additionally, the inclusion of a current sensor serves to monitor and ensure that current consumption remains within acceptable limits.

In conclusion, the proposed heating pad system can be seamlessly integrated into the Flexitank LLDPE bag, with the male socket positioned above the liquid inlet/outlet. It is worth noting that further experimental work and in-depth analysis are imperative to gain a comprehensive understanding of each variant of heating pad employed, while also assessing economic criteria to align with commercialization objectives.

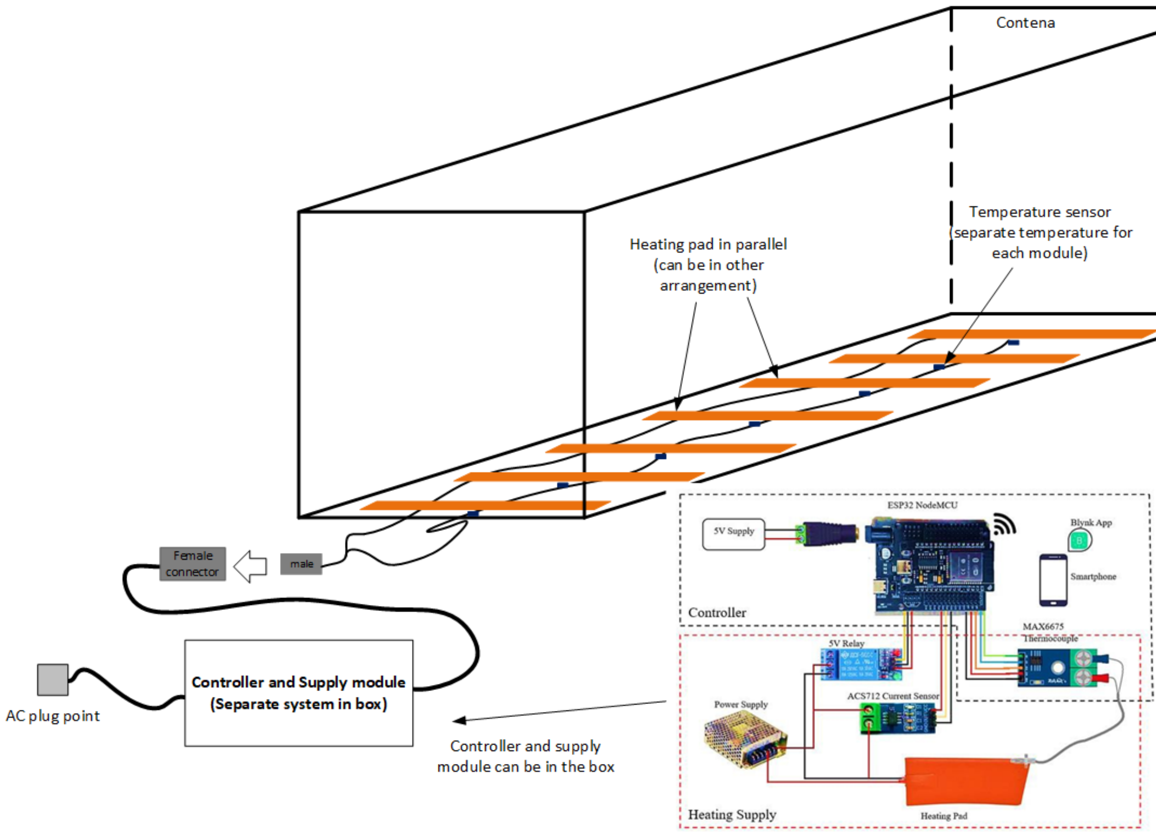


Fig. 16. Expected final setup for heating pad system for flexitank implementation

4. Conclusions

The assessment of electrical heating pad elements has been meticulously conducted, encompassing a diverse range of heating pads sourced from the market. A series of experimental tests were systematically carried out on multiple electrical heating pads to facilitate an extensive comparison of their attributes. Emphasis was placed on evaluating their suitability with respect to achieving a targeted temperature based on each liquid profiles, alongside scrutinizing the respective current consumption profiles exhibited by each heating pad.

This comprehensive investigation serves as a foundational step in the decision-making process regarding the optimal selection of electrical heating pads for integration within the Flexitank system. The conclusive findings indicate a promising trajectory for the utilization of electrical heating pads in the context of Flexitank applications. Nevertheless, a more extensive and focused exploration is warranted to explore diverse heating pad configurations for practical implementation.

Acknowledgment
This project paper is supported by Universiti Tun Hussein Onn Malaysia and MY Flexitank Industries (M) Sdn. Bhd. through Matching Grant (vot H865). The author would like to thank the Faculty of Engineering Technology, Universiti Tun Hussein Onn Malaysia, and MY Flexitank Industries (M) Sdn. Bhd for providing necessary research facility for this study.

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