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A Preliminary Study on the Selection of Self-Heating Elements in Self-Heating Pads for Instant Tuna Packaging

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ABSTRACT

Tuna is one of the travelers' most popular instant foods due to its delicious and nutritious taste. The innovation in food technology has offered a better experience for travelers in enjoying their meals by providing a self-heating pad to reheat the instant food. However, the commercial instant tuna available in the market nowadays offers no option for reheating purposes. Therefore, this study aimed to determine the best combination of materials to be developed as a self-heating pad for reheating that instant tuna. The most suitable characteristic of the combination of materials to be incorporated in a self-heating pad is the highest final temperature, the longest duration sustained at the highest temperature, and the shorter duration to achieve the highest temperature. In this current study, there are four (4) combinations of self-heating elements were evaluated, which are calcium oxide, sodium bicarbonate, and fe(iron); calcium oxide and zinc; calcium oxide and fe(iron); calcium oxide, sodium bicarbonate, and zinc. The reaction for each combination was activated with 100 mL and 200 mL of tap water, and the temperature of each reaction was recorded. Based on the theoretical calculation, 50.72℃ is the temperature needed to reheat the tuna with 100 ml of water, and 61.30 ℃ is the temperature needed to reheat the tuna with 200 ml of water. The result of this study indicated that the combination of 40 grams of calcium oxide and 6 grams of zinc in 100 ml water exhibited the highest temperature (76 ℃) with the time sustained at the highest temperature is 2 minutes and 13 seconds, and it took about 9 minutes and 20 seconds to achieve the highest temperature. Our study showed a promising finding where the highest temperature obtained by this combination exhibited higher temperature than the theoretically calculated temperature (50.72℃) needed to reheat the tuna. Therefore, considering the overall characteristic, 40 g of Calcium oxide and 6 grams of zinc along with 100 mL was chosen as the best material to be developed further as a self-heating element for reheating instant tuna.

Keywords: *Calcium oxide, iron, instant tuna, self-heating element, self-heating pad*

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INTRODUCTION

Self-heating food packaging is active packaging that can heat the food content without external power sources. The self-heating food packaging usually consists of two items: the self-heating pad and the food itself. Commonly, the self-heating pad contains an outer layer surrounding the food, and an exothermic reaction will generate the heat. The exothermic reaction between the materials inside the self-heating pad can be activated by adding a specific amount of liquid, for example, water. Historically, this self-heating food packaging is widely used for military operations, during natural disasters, or whenever any limited sources of conventional cooking tools are unavailable. However, the purpose of self-heating food packaging is widened to recent busy consumers, leisure, during travel which suits current on-the-go lifestyles activities. Self-heating food technology has been explored and developed for over half a century. In the 1950s, research on self-heating food technology led to a satisfactory reaction mixture for heating food components incorporated in the cans, and several million of these cans was used during the war [1]. While in the United Kingdom, it was reported that self-heating could be initiated initially as war expedient and made available for public use, and the products include soups and beverages [2]. Currently, a wide variety of self-heating products are commercially available in the markets, including both food and beverages. A classroom activity also has been implemented by Oliver-Hoya et al. [3] where a self-heating beverage and Meals Ready to Eat (MRE) were used as an example of a real-life chemistry problem, for example, enthalpies of reactions and solutions, stoichiometry, and heat transfers.

Most research finding on the developments of self-heating systems are reported in the form of patents. In the earliest self-heating system development, most inventors used Magnesium-Iron alloy as the heat source. Pickard *et al.* [4] described an exothermic chemical heater in a self-heating group assembly that consists of Magnesium-Iron alloy improved its performance. At the same time, Lamensdorf [5] presented a flameless heater with self-heating technology using a powder mixture of Magnesium-Iron alloy. Various options for heat output are available, but the most reactive reaction is always the most dangerous, potentially toxic, and might produce undesirable gaseous by-products. However, the current trends in food technology offer a better option for consumers where calcium oxide (Quicklime) and water are the most suitable material or elements due to their safety, cheapness, and readily available, and the reaction produces no dangerous side effects towards our environment [6]. Kolb [7] reported an insertable thematic module for self-heating cans. This heater consists of a solid and liquid reactant, calcium oxide, incorporated with a wax-based inhibitor. A chemical mixture of potassium permanganate and calcium oxide activated by liquid reagent, glycerol, and water, is reported to heat the food effectively, safely, and in 10-15 minutes [8].

To date, instant tuna is one of the instant foods popular among people due to its delicious taste and ease of preparing breakfast daily. This is evidenced by Malaysia's percentage of tuna exports, which continues to increase from 2017 to 2019. In fact, most of the instant tuna manufactured nowadays is readily cooked and needs to be kept either in the refrigerator or left at room temperature. However, some people also prefer to eat hot tuna instead of its normal condition. However, the current instant tuna products in the market do not have self- heating-pad for reheating purposes. Therefore, this study aimed to determine the best combination of elements in a heating pad for reheating instant tuna. Implementing this preliminary study can contribute to an insightful knowledge of designing self-heating pads for instant tuna in the future.

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EXPERIMENTAL

Determination of Heat and Temperature Needed to ReheatReheat the Tuna

Generally, the basic temperature to cook instant get tuna is between 90°C to 92°C [9]. Based on the parameters in Table 1 and assuming no heat loss in the surrounding, the temperature needed to reheat the instant tuna was determined using Equations 1 and 3.

Table 1: Parameters of surrounding

Parameters	Value
Weight of water	100 and 200 g
Weight of tuna	250 g
Specific heat capacity of tuna	3180 J/kgC
Specific heat capacity of water	4182 J/kgC
Room temperature	29°C
Boiling water temperature for tuna	92°C

Based on this equation, the needed temperature to produce by heater pack is 50.72°C for 100 ml and 61.30°C for 200ml of water based on the following equations and calculations:

Heat loss by water = Heat gain by tuna — Equation 1
Heat loss by hot water = $m\,C\Delta T$ — Equation 2
Heat gain by tuna = $m\,C\Delta T$ — Equation 3

Heat loss by water = Heat gain by tuna
$(0.1)\,(4182)\,(92C-T) = (0.25)\,(3180)\,(T-29C)$
$418.2\,(92-T) = (795)\,(T-29)$
$T = 50.72°C$

Heat loss by water = Heat gain by tuna
$(0.2)\,(4182)\,(92C-T) = (0.25)\,(3180)\,(T-29C)$
$(836.4)\,(92-T) = (795)\,(T-29)$
$T = 61.30°C$

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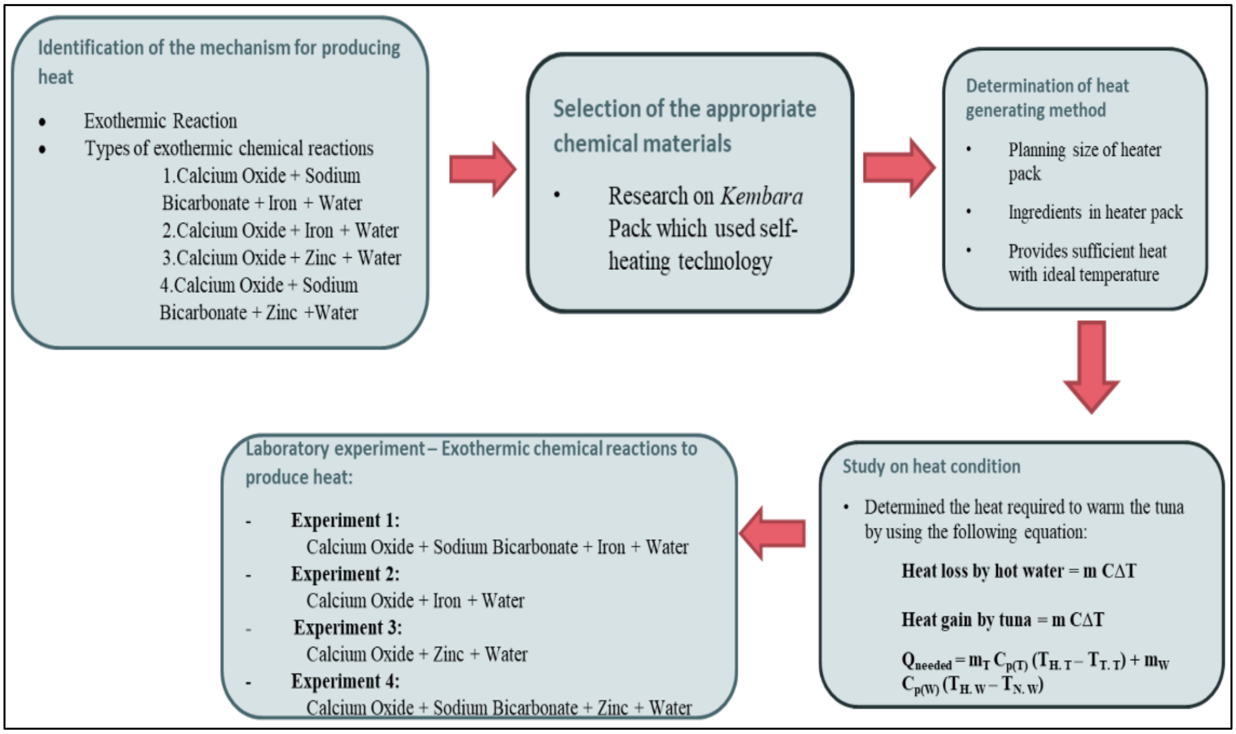

Figure 1: Process flowchart of methodologies

Production of Heat Using Exothermic Chemical Reaction

An amount of 20g of calcium oxide, 20g of sodium bicarbonate, and 2g of Fe (iron) was weighed using a digital weighing scale. Next, 100 ml of water was measured using a measuring cylinder. Then, all chemical substances were mixed with water in one beaker, and the mixture was stirred using a glass rod until it dissolved. After that, the beaker was covered with aluminum foil, and some tiny holes were poked. The thermometer was placed in the beaker, and the initial temperature was recorded. The highest temperature achieved, the duration taken to rise at the highest temperature, and the duration sustained at the highest temperature was observed and recorded. The experiments were repeated with different amounts of zinc, iron, and water based on the design of the experiment (20 g of CaO+20 g of $NaHCO_3$ + 4 g of Fe (iron), +100 mL of water). Similar steps were repeated for each sample on each combination of calcium oxide, sodium bicarbonate and zinc, calcium oxide and fe(iron), and calcium oxide and zinc.

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RESULTS AND DISCUSSION

Calcium Oxide (CaO) + Sodium Bicarbonate ($NaHCO_3$)+ Fe (iron) in 100 ml and 200ml of Water

In this research, the combination that showed the highest temperature above the needed theoretical temperature will be selected as a potent self-heating element to be developed further. Figure 2 shows the final temperature obtained for each sample in the combination of calcium oxide, sodium bicarbonate, and iron (fe) in 100 mL and 200 mL of water.

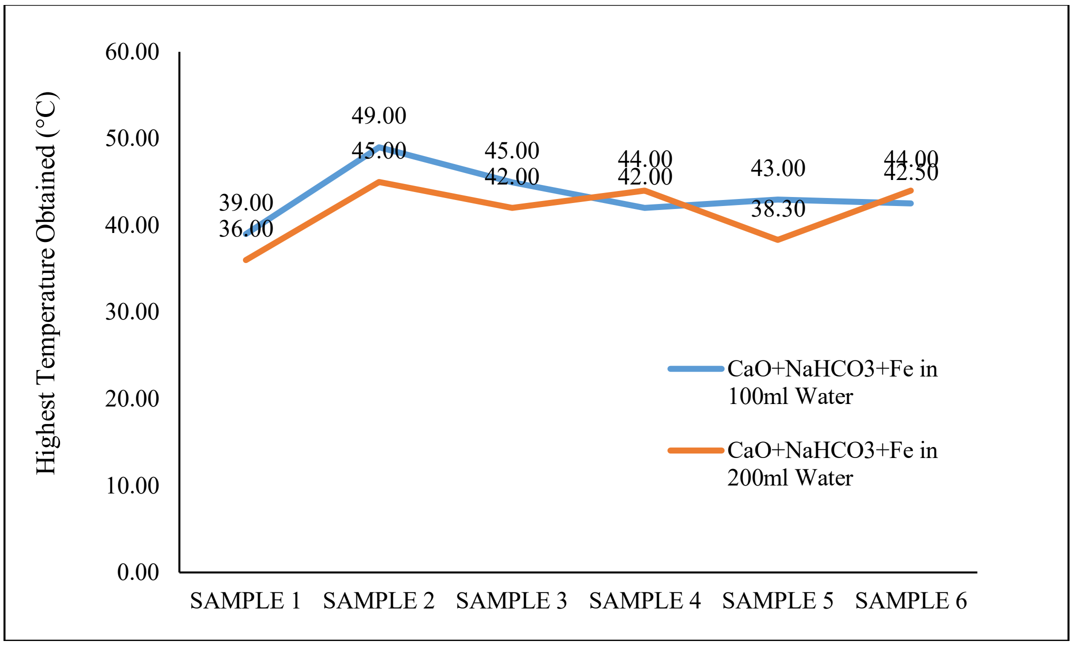

Figure 2: Final temperature obtained from the combination of each sample in the combination of CaO+ NaHCO3+Fe in 100ml and 200ml of water

From Figure 2, this combination shows the final temperature ranging from 36°C to 49 °C. Based on the calculation mentioned in the methodology, the minimum temperature needed to reheat the tuna in 100 mL and 200 mL of water is 50.72 °C and 61.3 °C, respectively. However, this combination's highest temperature (49 °C) is lower than the calculated temperature. Table 1 indicates the information on the temperature difference, duration sustained at the highest temperature, and duration taken to rise at the highest temperature for each combination.

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Table 1: The result for the combination of calcium oxide with sodium bicarbonate and iron in 100 mL and 200 mL of water

Run	CaO (g)	$NaHCO_3$ (g)	Fe (g)	Water (mL)	Initial temp. (˚C)	Final temp. (˚C)	Temp. difference (Final temp. - Initial temp.) Δ°C	Duration sustains at the highest temp. (min)	The duration is taken to rise at the highest temp. (min)
SAMPLE 1	20	20	2	100	29	39.00	18.00	4min 28 s	6min 34s
SAMPLE 2	20	20	4	100	29	49.00	19.50	3min 41s	5min 24s
SAMPLE 3	20	20	6	100	29	45.00	14.00	2min 21s	5min 32s
SAMPLE 4	20	20	8	100	29	42.00	21.00	9 min 9s	6min 3s
SAMPLE 5	20	20	10	100	29	43.00	20.50	8 min 9s	7min 11s
SAMPLE 6	20	20	12	100	29	42.50	16.50	5min 21s	13min 5s
SAMPLE 1	20	20	2	200	29	36.00	17.00	1min 45s	6min 53s
SAMPLE 2	20	20	4	200	29	45.00	17.00	2min 12s	1min 44s
SAMPLE 3	20	20	6	200	29	42.00	17.00	1min 52s	4min 41s
SAMPLE 4	20	20	8	200	29	44.00	18.50	1min 51s	3min 48s
SAMPLE 5	20	20	10	200	29	38.30	18.00	9min 55s	10min 27s
SAMPLE 6	20	20	12	200	29	44.00	19.80	2min 13s	3min 53s

Based on the research on the commercial *Kembara* self-heating pad, the recommended duration sustained at the highest temperature is approximately 7-10 minutes, and it should only take 1 to 2 min to rise to the highest temperature. From Table 1, the highest final temperature (49 °C) was exhibited by the combination of 20 g CaO along with 20 g of $NaHCO_3$ and 4g of iron (fe) activated by 100 mL of water, which took about 5 minutes and 24 sec to rise at this highest temperature and sustained for 3 minutes and 41 sec. Overall, taking into consideration the whole characteristics of lower final temperature obtained, long duration taken to rise at the highest temperature, and short duration sustained at the highest temperature, this combination (Equation 4) did not show any potential to be further developed as self-heating elements for the self-heating pad to reheat the instant tuna.

Calcium Oxide (CaO) + Sodium Bicarbonate ($NaHCO_3$) + Zinc in 100ml and 200ml of Water Equation 4

Figure 3 exhibits the obtained final temperature for each sample in the combination of calcium oxide, sodium bicarbonate, and zinc in 100ml and 200ml of water.

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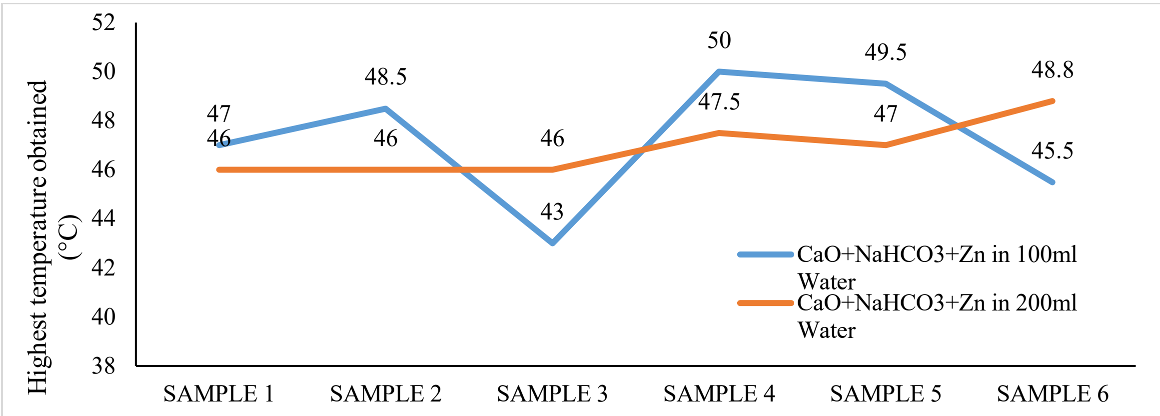

Figure 3: The obtained highest temperature in the combination of $CaO+NaHCO_3 + Zn$ in 100ml and 200ml of water

From Figure 3, this combination shows the final temperature ranging from 43°C to 50°C. From Table 2, the highest final temperature (50 °C) was exhibited by the combination of 20g CaO along with 20g of $NaHCO_3$ and 8g of zinc activated by 100 ml of water, and it could sustain for 3 minutes and 41 seconds. This combination showed a similar pattern to the previous combination of CaO, $NaHCO_3$, and fe (iron), where the highest final temperature is lower than the needed temperature to reheat the instant tuna, and other characteristics (Table 2) also did not show promising findings to be further developed as self-heating elements in the self-heating pad.

Table 2: Result for the combination of calcium oxide, sodium bicarbonate, and iron (fe) in 100 mL and 200 mL of water

Run	CaO (g)	NaHCO3 (g)	Zn (g)	Water (mL)	Initial temp. (˚C)	Final temp. (˚C)	Temp. difference (Final temp. - Initial temp.) Δ°C	Duration sustains at the highest temp. (min)
SAMPLE 1	20	20	2	100	29	47	18	3 mins 30 s
SAMPLE 2	20	20	4	100	29	48.5	19.5	5 mins 43 s
SAMPLE 3	20	20	6	100	29	43	14	4 mins 36 s
SAMPLE 4	20	20	8	100	29	50	21	3 mins 8 s
SAMPLE 5	20	20	10	100	29	49.5	20.5	4 mins 56 s
SAMPLE 6	20	20	12	100	29	45.5	16.5	3 mins 27 s
SAMPLE 1	20	20	2	200	29	46	17	1 min 48 s
SAMPLE 2	20	20	4	200	29	46	17	1 min 57 s
SAMPLE 3	20	20	6	200	29	46	17	2 mins 22 s
SAMPLE 4	20	20	8	200	29	47.5	18.5	2 mins 22 s
SAMPLE 5	20	20	10	200	29	47	18	2 mins
SAMPLE 6	20	20	12	200	29	48.8	19.8	2 mins 39 s

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Figure 4 shows the obtained final temperature for each sample in the combination of calcium oxide and iron (fe) and calcium oxide and zinc in 100 mL and 200 mL of water. The combination can be summarised as in Equation 5.

Calcium Oxide (CaO) + Iron (Fe) and Calcium Oxide + Zinc in 100 mL and 200 mL of Water   Equation 5

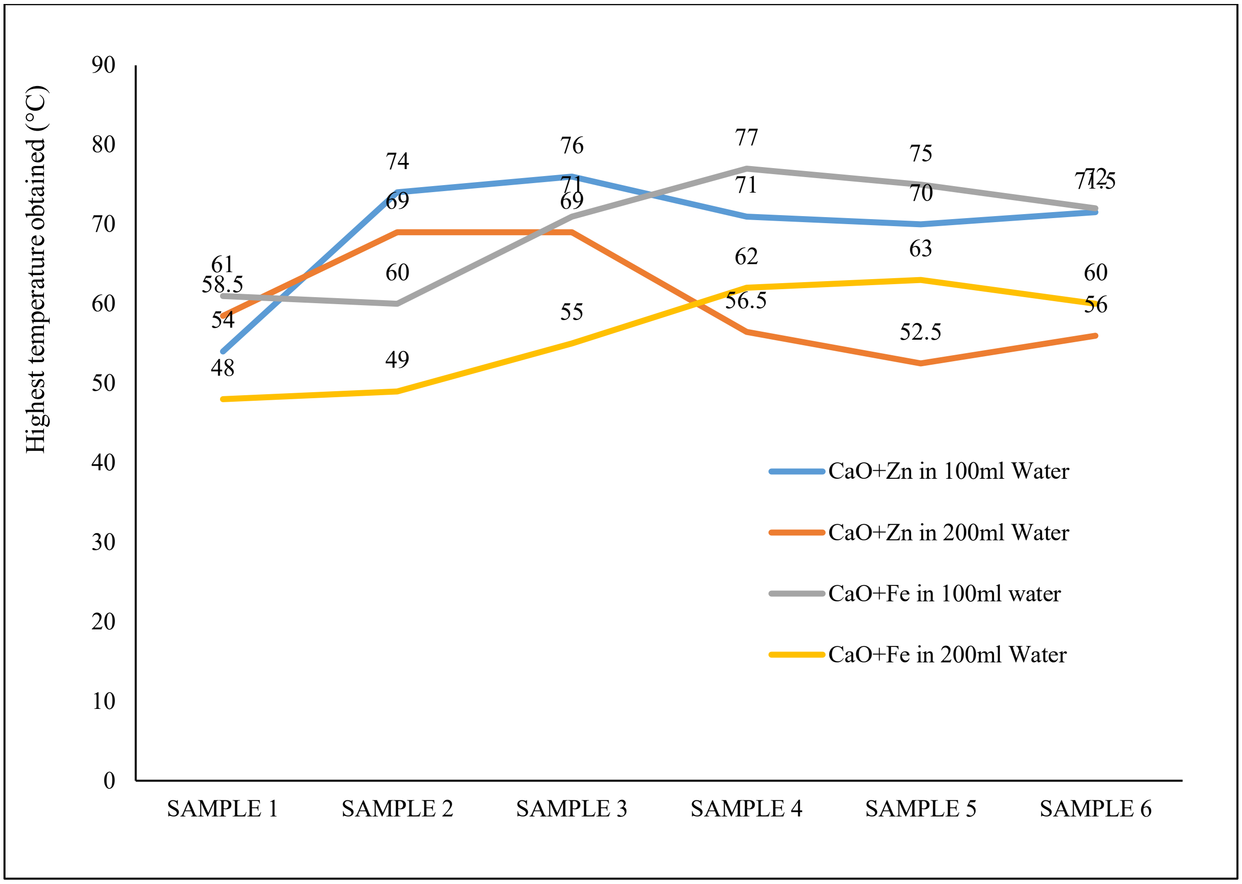

Figure 4: The obtained highest temperature from the combination of CaO+ Zn and CaO+ Fe in 100 mL and 200 mL of water

From Figure 4, the temperature obtained from these combinations ranges from 48 °C and 77 °C. The highest temperature obtained from the combination of CaO+fe is 77 °C, exhibited by sample 4, where 40 g of CaO was mixed with 8 g of Fe (iron) and was activated by 100 mL of water. While for a combination of CaO+Zinc, the highest temperature of 76 °C was shown by sample 3 with 40 g of CaO and 6 g of zinc, and the exothermic reaction was activated by adding 100 mL of water. This combination of CaO with zinc and fe (iron) has shown a promising finding where several combinations indicate the temperature above the needed calculated temperature to reheat the instant tuna.

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From Table 3, the obtained highest temperature was indicated by sample 4 with the final temperature of 77 °C; the duration sustained at the highest temperature is 2 min, and it took about 11 min and 50 sec to achieve the final temperature.

Table 3: Result for the combination of calcium oxide and iron (fe) in 100 mL and 200 mL of water

Run	CaO (g)	Fe (g)	Water (mL)	Initial temp. (˚C)	Final temp. (˚C)	Temp. difference (Final temp. - Initial temp.) Δ°C	Duration sustains at the highest temp. (min)	The duration is taken to rise at the highest temp. (min)
SAMPLE 1	40	2	100	29	61	32	2min 5s	12 min 50s
SAMPLE 2	40	4	100	29	60	31	2min 15s	14 min 24s
SAMPLE 3	40	6	100	29	71	42	1min 24s	10 min 20s
SAMPLE 4	40	8	100	29	77	48	2min	11 min 50s
SAMPLE 5	40	10	100	29	75	46	1min 28s	12 min 51s
SAMPLE 6	40	12	100	29	72	43	2min	12 min
SAMPLE 1	40	2	200	29	48	19	9min 32s	12 min 44s
SAMPLE 2	40	4	200	29	49	20	10min	15 min 35s
SAMPLE 3	40	6	200	29	55	26	6min 12s	13 min 30s
SAMPLE 4	40	8	200	29	62	33	2min 1s	6min 10s
SAMPLE 5	40	10	200	29	63	34	2min 8s	9 min 42s
SAMPLE 6	40	12	200	29	60	31	3min 56s	12 min 50s

Table 4 indicates the highest temperature achieved by sample 3 with the final temperature of 76 °C, which took approximately 9 min and 20 sec at this highest temperature. In contrast, the duration sustained at this temperature was 2 min and 13 sec. Generally, the combination that showed characteristics of the highest temperature along with the shortest duration to achieve the highest temperature and the longest duration sustained at the highest temperature will be selected as a potent combination for a further detailed study on self-heating elements for a self-heating pad. From Tables 3 and 4, sample 3 in Table 4, which consists of 40 g CaO and 6 g of zinc activated by 100 mL of water, was chosen as the best combination for the self-heating element in the self-heating pad to reheat the instant tuna. Even though this combination has shown lower temperature as compared to sample 4 in Table 3 (77 °C) in the combination of CaO and fe(iron), other characteristics of shorter duration to achieve the highest temperature and more prolonged duration sustains the highest temperature were also needed to be considered in the chosen of the best combination.

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Table 4: Results for the combination of calcium oxide and zinc in 100 mL and 200 mL of water

Run	CaO (g)	Zn (g)	Water (mL)	Initial temp. (˚C)	Final temp. (˚C)	Temp. difference (Final temp. - Initial temp.) Δ°C	Duration sustains at the highest temp. (min)	The duration is taken to rise at the highest temp.(min)
SAMPLE 1	40	2	100	29	54.00	25.00	5min 05s	13 min 14s
SAMPLE 2	40	4	100	29	74.00	45.00	1min 43s	10 min 3s
SAMPLE 3	40	6	100	29	76.00	47.00	2min 13s	9 min 20s
SAMPLE 4	40	8	100	29	71.00	42.00	2min 19s	13 min 21s
SAMPLE 5	40	10	100	29	70.00	41.00	1min 55s	14 min 41s
SAMPLE 6	40	12	100	29	71.50	42.50	1min 35s	13 min 47s
SAMPLE 1	40	2	200	29	58.50	29.50	4. min 1s	13 min 28s
SAMPLE 2	40	4	200	29	69.00	40.00	1min 12s	12 min 17s
SAMPLE 3	40	6	200	29	69.00	40.00	1min 46s	10 min 16s
SAMPLE 4	40	8	200	29	56.50	27.50	2min 28s	21 min 14s
SAMPLE 5	40	10	200	29	52.50	23.50	3min 18s	15 min 45s
SAMPLE 6	40	12	200	29	56.00	27.00	5min 41s	21 min 39s

In this current study, the reaction between calcium oxide and catalyst, which is zinc and fe(iron), and the addition of water produced an exothermic reaction. In exothermic reactions, the energy was released, and the reaction mixture's temperature also increased. In this principle, the catalysts are designed to lower the activation energy of the reaction, thus leading to the reaction's acceleration and a reduction in the time of the process. An increased amount of catalysts resulted in its higher efficiency [10]. Our finding showed that 6 g of zinc and 8 g of Fe (iron) could reduce the time of the reaction process better (shorter time to rise at the highest temperature) as compared with 12 g of zinc and Fe (iron). Our findings also suggest that the amount of the catalyst does not align with its efficiency, and this finding was supported by previous findings where they found that the catalyst type was more crucial than its amount [11].

CONCLUSION

Based on this current experiment, there are two combinations of elements (CaO and Fe (iron) and CaO and Zinc) that potentially showed the pattern that is needed temperature to reheat the tuna. The highest temperature for calcium oxide + zinc is 76 °C; meanwhile, the highest temperature for calcium oxide + iron is 77 °C. A few aspects need to be considered to choose the best combination of elements in a self-heating pad for instant tuna. The essential factors are the final temperature (above the needed temperature to reheat tuna), duration sustained at the highest temperature (within 7-10 min), and duration taken to rise at the highest temperature (within 1-2 min). Therefore, taking consideration into overall characteristics, 40 g of calcium oxide and 6 g of zinc along with 100 mL water was chosen as the best combination of material to be developed further as the self-heating elements for reheating instant tuna as it showed 76 °C as highest

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temperature and it remained for 2 min and 13 sec and took only 9 min and 20 sec to achieve this final temperature.

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AUTHOR'S CONTRIBUTION

Nur Syukriah Ab Rahman supervised the research progress, wrote, and revised the article. Fatahiya Mohamed Tap, Iswaibah Mustafa, and Aishah Derahman designed the research, conceptualized the central research idea, and provided the theoretical framework. Nur Ellyliana Mohd Razali, Tuan Muhammad Sadiq Zafran, Tuan Zainal Abidin, and Nur Syazwani Abd Rahman carried out the research in the laboratory.

CONFLICT OF INTEREST STATEMENT

The authors agree that this research was conducted without any self-benefits or commercial or financial conflicts and declare the absence of conflicting interests with the funders.

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