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Impact of Packaging Material on Heat Retention in Ready-to-Eat Noodle Cups

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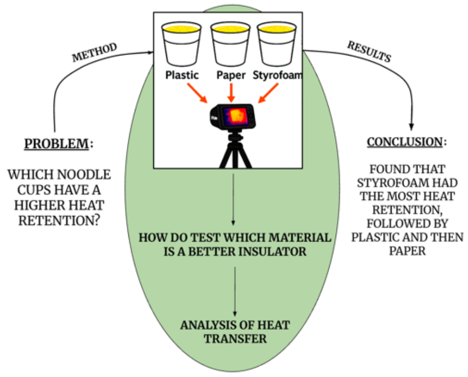
Graphical Abstract



Abstract

Thermal insulation in ready-to-eat food packaging is critical for maintaining food quality and safety. This study evaluates the heat retention performance of three common instant noodle cup materials, paper, plastic, and Styrofoam, using infrared thermal imaging across two controlled experiments: one with noodle-filled cups and another with hot water only. Temperature decay was analysed using Newton's Law of Cooling and cumulative heat loss calculations. Styrofoam consistently exhibited the best insulation, showing the lowest cooling rates and least heat loss. Plastic cups provided moderate retention, while paper allowed the fastest heat dissipation. These results highlight the strong influence of material properties, particularly thermal conductivity, on passive cooling. Despite its thermal advantages, Styrofoam, an Expanded Polystyrene (EPS), presents environmental concerns, prompting the need for sustainable alternatives. This study underscores the importance of balancing performance, cost, and environmental impact in packaging design and supports further investigation into bio-based or thermally adaptive materials for future applications.

Keywords: Heat retention, Food packaging, Instant noodles, Infrared Thermal Imaging, Newton's Law of Cooling, Insulation

1. Introduction

Efficient thermal management is a fundamental consideration in modern engineering systems, influencing the performance, safety, and energy efficiency of processes across sectors. From industrial-scale reactors to household appliances and packaging, the way heat is transferred, retained, or dissipated has broad implications for material selection, system design, and user experience[1,2]. In the context of consumer goods, particularly in the food sector, heat transfer plays a central role in safety, quality, and consumer satisfaction, especially in the context of ready-to-eat meals[3,4].

As the demand for convenience foods grows globally, so too does the importance of packaging materials that can preserve temperature for a longer duration[5,6]. This is particularly relevant for ready-to-eat meals such as instant noodles, where thermal insulation impacts the eating experience and the safe handling of the food. Instant noodles are among the most widely consumed convenience foods globally, with billions of servings consumed each year[7].

Instant noodle packaging varies widely in form and material. These meals are typically packaged in single-serve containers made of diverse materials, ranging from lightweight paper cups to plastic bowls and expanded polystyrene (styrofoam) containers. Each material possesses distinct thermal properties that influence how quickly heat is lost to the environment. While manufacturers may prioritise cost-effectiveness or aesthetic appeal, thermal performance is often overlooked. This is despite its direct impact on food temperature, cooking effectiveness, and the time window in which a meal remains palatable and safe to eat.

Packaging materials vary considerably in their thermal properties. For example, polystyrene foam is known for its low thermal conductivity and is widely used in insulated containers, while paper-based packaging offers environmental advantages but generally poorer heat retention[8,9]. Plastic containers fall somewhere in between, offering moderate insulation and structural strength[10,11]. In real-world settings, these material differences could significantly alter the rate at which heat is lost from the food to the environment.

From a Chemical Engineering perspective, understanding how material properties influence heat transfer enables more informed decisions in packaging design, particularly for products requiring thermal insulation without the use of active heating. Additionally, understanding the heat retention and treatment capabilities as a design aspect of packaging materials can guide design improvements in insulation, reduce unnecessary energy loss, and enhance consumer safety[12].

Heat transfer in this context is primarily governed by conduction through the packaging wall and convection at the fluid-air and container-air interfaces, with minor contributions from radiation. The process can be quantitatively described using Fourier's Law for Conduction and Newton's Law of Cooling for convection, where the rate of temperature change can be modelled using both the former and the latter. Hence, accounts for the geometry and material properties of the container. Furthermore, the physical properties of the contents, such as water content and heat capacity, may introduce confounding effects in real-use scenarios, which require controlled comparisons to isolate the role of the container material.

Despite the ubiquity of instant noodles, only a few studies have systematically compared the thermal performance of different food packaging materials under controlled conditions, and those studies mentioned do not specifically mention instant noodles or their optimal packaging design[13–15]. This presents a critical gap in understanding how material choices influence passive thermal management, especially in single-use packaging for instant noodles.

This study investigates how packaging material affects heat retention in ready-to-eat noodle cups by comparing three commercial products made of paper (Coles Chicken Noodles), plastic (Lian Pho Bo), and styrofoam (Fantastic Noodles). Two complementary experiments were conducted: the first measured cooling rates of the complete noodle systems, while the second used hot water alone to isolate the influence of packaging material without the confounding effects of food composition. The findings aim to inform packaging design strategies in the food industry, with broader implications for industrial performance, product quality, and sustainable material selection.

2. Methods

2.1 Experimental Setup

This study investigated the effect of packaging material on heat retention in ready-to-eat noodle cups using infrared thermal imaging. Two parallel experiments were conducted:

(1) Heat retention of noodle cups filled with noodles and hot water, and

(2) Heat retention of noodle cups filled with hot water only, isolating the influence of container material.

Three types of commercially available noodle cups were selected, representing different packaging materials:

- Coles Chicken Noodles – *Paper cup*
- Fantastic Noodles – *Styrofoam cup*
- Lian Pho Bo Rice Noodles – *Plastic bowl*

Prior to testing, cups containing noodles were weighed and adjusted to achieve consistent mass across all samples, ensuring that only the independent variable was the cup material. Water was heated to approximately 80°C using a standard electric kettle and poured into each cup at 250 mL for each cup. Lids were removed to allow natural convection, and all cups were placed on insulated laboratory benches to minimise conductive heat loss through the base.

A calibrated InfiRay Pro 2 thermal imaging camera was mounted on a makeshift tripod (Retort stand and clamp) and positioned vertically above the noodle cups to maintain a consistent viewing angle. The ambient room temperature was assumed to be approximately ~23°C throughout both experiments. A schematic overview of the procedure is provided in Figure 1**.**

2.2 Materials

- Instant noodle cups (paper, plastic, styrofoam – as above)
- Boiling water (~80 °C from electric kettle)
- InfiRay Pro 2 thermal camera (USB-C connected, calibrated)
- Retort stand and clamp (camera stabilisation & backup mounting)
- Digital scale (±0.1 g precision)
- Stopwatch (manual timing control)
- Beakers and stirring rods (for uniform water transfer)

2.3 Data Collection

After adding hot water to the noodle cups, thermal images were recorded at 5-minute intervals over a 25-minute period. Each thermal image captured the surface temperature distribution across the cup and the liquid interface. Spot temperature readings were also taken using the thermal camera's built-in measurement tool, capturing the central surface temperature of each cup. Data collection was synchronised using a stopwatch, with one operator recording times and another recording temperature readings to ensure accuracy and minimise delay.

Each measurement was repeated across five trials per cup type to account for experimental variability and support statistical analysis. All data were logged in structured spreadsheets in Microsoft Excel for subsequent processing.

2.4 Data Collection

Thermal image data were processed using the InfiRay manufacturer's software, which enabled frame-by-frame review and extraction of surface temperature data. The mean surface temperature at each time point was used to generate cooling curves (temperature vs. time) for each container type.

From these curves, the rate of heat loss was assessed visually and quantitatively. Heat transfer trends were interpreted using Newton's Law of Cooling, and container material performance was compared using the initial cooling rate. Where applicable, the convective heat transfer coefficient h was estimated assuming standard thermal models, and assessed thermal gradients across the container surfaces using visual infrared patterns.

A comparative evaluation of thermal retention performance was conducted for both experiments, isolating material influence while accounting for variability due to contents and environmental conditions.

3. Results

3.1 Temperature Measurements Over Time

Two complementary experiments were conducted. In Experiment 1, noodle cups containing both noodles and hot water were tested. In Experiment 2, the cups were filled with hot water only to isolate the effect of the packaging material alone. Temperature readings were recorded over a 25-minute period at 5-minute intervals using a calibrated thermal imaging camera. The average surface temperatures from five trials per cup type are summarised in Table 1.

Table 1. Average surface temperatures (°C) for noodle cups over 25 minutes in Experiments 1 and 2.

Temperature uncertainty: ±2 °C; time uncertainty: ±0.005 min.

EXPERIMENT 1: NOODLES AND WATER				EXPERIMENT 2: WATER WIHTOUT NOODLES		
Time (min) $\pm 0.005\ (min)$	Coles Chicken (Paper) T (°C) ± 2(°C)	Lian Pho Bo (Plastic) T (°C) ± 2(°C)	Fantastic (Styrofoam) T (°C) ± 2(°C)	Coles Chicken (Paper) T (°C) ± 2(°C)	Lian Pho Bo (Plastic) T (°C) ± 2(°C)	Fantastic (Styrofoam) T (°C) ± 2(°C)
0	80	80	80	0	80	80
5	66	69.5	72.2	5	67.2	70.8
10	56.5	62.7	67.4	10	57.9	64.1
15	49.8	56.8	63.1	15	50.6	58.3
20	45.1	51.6	59.3	20	45.2	53.4
25	41.6	47.5	55.9	25	41.1	49.4

3.2 Cooling Rate Constants

To quantify heat dissipation over time, Newton's Law of Cooling was applied (*Equation 1*):

[1] $\frac{dT}{dt} = -k\left(T - T_{amb}\right)$

Rearranging the equation we can obtain *(Equation 2):*

[2] $ln\left(T\text{-}T_{amb}\right) = \text{-}kt + C$

In order to calculate graphically the values for the cooling rate constant k, $ln\left(T - T_{ambient}\right)$ was graphed against time for both experiments, where T_{amb} = 23°C. The slope of the linear trendline represents the cooling rate constant, k as shown in Figure 1.

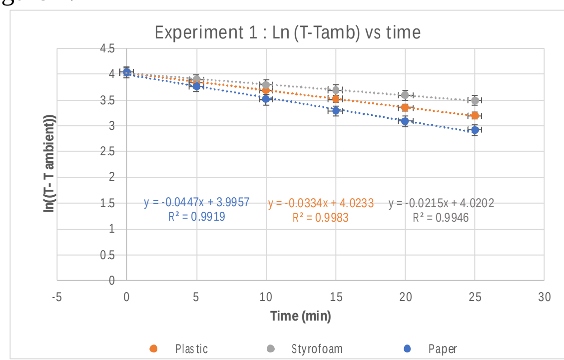


Figure 1. Cooling curves based on Newton's Law of Cooling for Experiment 1.

Logarithmic temperature differences $ln\left(T - T_{ambient}\right)$ plotted against time for three packaging materials: plastic (orange), styrofoam (grey), and paper (blue). Linear regression lines represent cooling behaviour in Experiment 1 (noodles and hot water), with slopes corresponding to the cooling constants k. Styrofoam exhibited the slowest rate of cooling, followed by plastic, with paper cooling most rapidly. Error bars represent the standard deviation from five replicates per material.

After conducting the same procedure for both Experiment 1 and 2, the following cooling constants were obtained, as shown in Table 2.

Table 2. Cooling rate constants $k\ (min^{-1})$ for paper, plastic, and Styrofoam noodle cups across Experiments 1 and 2.

EXPERIMENT N.	COLES (PAPER) $k\ (min^{-1})$ ±0.0020	Lian Pho Bo (Plastic) $k\ (min^{-1})$ ±0.0007	Fantastic (Styrofoam) $k\ (min^{-1})$ ±0.0008
1	-0.0447	-0.0334	-0.0215
2	-0.0459	-0.0306	-0.0204

Cooling constants were derived from linear regression $ln\left(T - T_{ambient}\right)$ vs. time plots, based on Newton's Law of Cooling. Experiment 1 included noodles and hot water; Experiment 2 used hot water only. Mean values are shown with standard errors: paper (±0.0020), plastic (±0.0007), styrofoam (±0.0008).

3.3 Heat Loss Quantification

Total accumulated heat loss was calculated separately through conduction and convection using the following equations ([3],[4]).

[3] $$Q_{cond} = \frac{k_{material} \cdot A \cdot \left(T - T_{amb}\right)}{D}$$

[4] $$Q_{conv} = h \cdot A \cdot \left(T - T_{amb}\right)$$

Where:

- $k_{material}$: thermal conductivity – paper (0.05), plastic (0.2), Styrofoam (0.033) $W\ /\ m \cdot K$
- h: Convective heat transfer coefficient - paper (10), plastic (12), Styrofoam (8) $W\ /\ m^2 \cdot K$
- A (Surface Area) = 0.01 m^2
- D (Diameter) = 0.002 m
- T_{amb} = 23°C

Table 3 summarises the calculated heat losses at each time point for both experiments.

Table 3. Accumulated heat loss by conduction and convection for paper, plastic, and Styrofoam noodle cups in Experiments 1 (a) and 2 (b).

(a).

EXP 1	ACCUMULATED HEAT LOSS Q (W)					
Time (min) $\pm 0.005\ (min)$	$Q_{conducted}$ (PAPER) $\pm 0.05W$	$Q_{convected}$ (PAPER) $\pm 0.02W$	$Q_{conducted}$ (Plastic) $\pm 0.2W$	$Q_{convected}$ (Plastic) $\pm 0.024W$	$Q_{conducted}$ (Styrofoam) $\pm 0.033W$	$Q_{convected}$ (Styrofoam) $0.016 \pm W$
0	14.25	5.7	57	6.84	0.57	4.56
5	25	10	103.5	12.42	1.062	8.496
10	33.375	13.35	143.2	17.184	1.506	12.048
15	40.075	16.03	177	4.056	0.401	3.208
20	45.6	18.24	205.6	7.488	0.764	6.112
25	50.25	20.1	230.1	10.428	1.093	8.744

(b).

EXP 2	ACCUMULATED HEAT LOSS Q (W)					
Time (min) $\pm 0.005\ (min)$	$Q_{conducted}$ (PAPER) $\pm 0.05W$	$Q_{convected}$ (PAPER) $0.02 \pm W$	$Q_{conducted}$ (Plastic) $\pm 0.2W$	$Q_{convected}$ (Plastic) $\pm 0.024W$	$Q_{conducted}$ (Styrofoam) $\pm 0.033W$	$Q_{convected}$ (Styrofoam) $\pm 0.016W$
0	14.25	5.7	57	6.84	9.405	6.84
5	25.3	10.12	104.8	12.576	17.8365	12.972
10	34.025	13.61	145.9	17.508	25.476	18.528
15	40.925	16.37	181.2	21.744	32.3565	23.532
20	46.475	18.59	211.6	25.392	38.5935	28.068
25	51	20.4	238	28.56	44.22	32.16

This table presents accumulated heat loss $Q\ \ (W)$ at 5-minute intervals over a 25-minute period for two conditions: Experiment 1 (a) (noodle cups with noodles and hot water, top panel) and Experiment 2 (b) (cups with hot water only, bottom panel). Heat loss was calculated separately via conduction and convection using standard thermal models and material properties. Assumed parameters include surface area $A = 0.01\ m^2$, Diameter $D = 0.002\ m$, and literature values for thermal conductivity k and convective heat transfer coefficient h. Reported uncertainties reflect propagation of error from temperature measurements and material constants.

Conductive heat loss increased linearly with time and was highest for plastic and paper containers. In contrast, Styrofoam cups exhibited markedly lower conductive losses, consistent across both noodle-containing and water-only trials seen in Figure 2.

Convective heat loss followed a similar trend, shown in Figure 3, with paper containers losing the most heat to the surrounding environment and Styrofoam the least. Plastic cups showed intermediate performance across all timepoints.

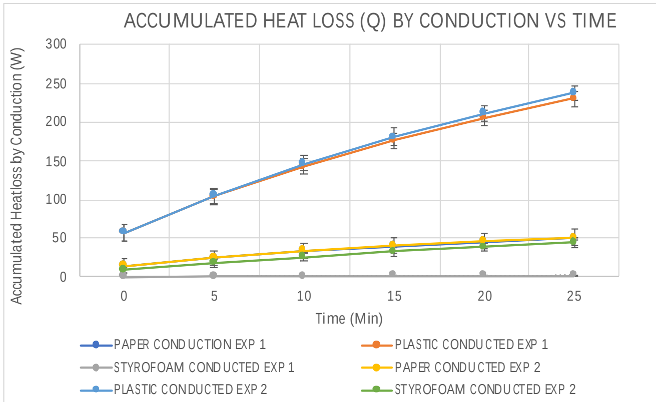


Figure 2. Accumulated heat loss by conduction over time for three packaging materials (Paper, Plastic, Styrofoam) across two experimental conditions (Experiment 1: Noodles & water, Experiment 2: Without noodles, water only).

Total conducted heat loss $Q\ (W)$ was calculated using Fourier's law for paper, plastic, and styrofoam noodle cups at 5-minute intervals. Experiment 1 (with noodles and water) and Experiment 2 (with water only) are compared. Plastic and paper cups exhibited substantially higher conductive heat loss than Styrofoam. Error bars represent uncertainty from temperature measurements and assumed material parameters.

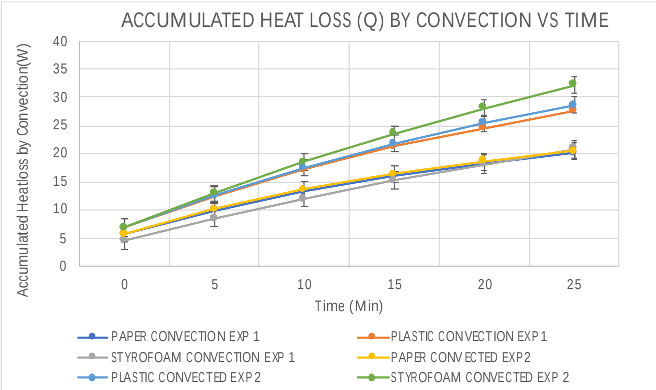


Figure 3. Accumulated heat loss by convection over time for three packaging materials (Paper, Plastic, Styrofoam) across two experimental conditions (Experiment 1: Noodles & water, Experiment 2: Without noodles, water only).

Total convective heat loss $Q\ (W)$ was calculated using Newton's law of cooling for paper, plastic, and styrofoam noodle cups at 5-minute intervals. Experiment 1 (with noodles and water) and Experiment 2 (with water only) are compared. Paper consistently showed the highest convective heat loss, while Styrofoam showed the lowest, indicating superior insulation performance. Results reflect the combined influence of surface temperature difference and estimated convective heat transfer coefficients. Error bars represent propagated uncertainty in thermal measurements and modelling assumptions.

4. Discussion

The results of both experiments confirm that packaging material plays a significant role in determining the thermal retention properties of ready-to-eat noodle cups. Across both trials, Styrofoam consistently exhibited the highest insulation performance, as evidenced by the lowest cooling rate constants and the smallest cumulative heat loss from both conduction and convection. These findings are consistent with prior literature that highlights the low thermal conductivity of expanded polystyrene (EPS), attributed to its porous microstructure and entrapped air pockets that inhibit heat transfer[16].

The exponential cooling behaviour observed in all materials, with R^2 above 0.998 for the fitted logarithmic models, seen in Figure 1, confirms the suitability of Newton's Law of Cooling for modelling temperature loss in this system. This agreement further validates the use of logarithmic regression to derive reliable cooling rate constants for comparative analysis.

In line with thermal conductivity data, plastic containers showed intermediate insulation, while paper cups exhibited the most rapid heat loss. The thermal conductivity values assumed in our calculations, 0.03 W/m·K for styrofoam, 0.2 W/m·K for plastic, and 0.05 W/m·K for paper, generally match trends reported in studies of commercial and biodegradable packaging materials[17,18]. However, it is important to note that theoretical $\boldsymbol{k}$ represents idealised or pure materials, whereas actual food containers often involve composite structures, such as laminated layers, wax coatings, or blended polymers. Real packaging may vary in wall thickness, material blends, or include multilayered structures designed to mimic biological thermoregulation, as explored in biomimetic packaging research[19]. Hence, these heterogeneities may lead to significant variation in real-world performance.

Notably, Experiment 2, which removed noodles and used only hot water, revealed greater differentiation in thermal performance among the containers. This outcome may reflect the fact that food content modifies heat transfer dynamics by absorbing thermal energy and limiting convective surface exposure. Previous infrared thermography studies support the observation that internal contents play a critical role in modulating heat retention[20].

From a Chemical & Environmental Engineering perspective, these results highlight the trade-off between thermal insulation and environmental sustainability. While Styrofoam demonstrated superior heat retention, its ecological footprint remains a pressing concern. Life cycle assessments have consistently shown that polystyrene contributes disproportionately to pollution and waste compared to biodegradable alternatives such as mycelium-based composites or molded pulp[21]. Although these greener materials continue to improve in durability and thermal stability, they still fall short of the mechanical performance achieved by petroleum-based polymers, particularly under moisture or high-temperature stress[22].

Another key consideration is food safety, particularly in relation to temperature exposure over time. Bacterial proliferation is known to peak within specific thermal windows, for example, *Escherichia coli* grows optimally between 20 °C and 45 °C, with peak replication near 37 °C[23]. Thus, the choice of packaging material has critical implications for shelf life, consumption safety, and thermal hold times. Emerging technologies such as phase change materials (PCMs) offer dynamic thermal buffering, which could help maintain temperatures outside microbial growth ranges while also enhancing thermal regulation[19].

This study, while robust in design, is subject to several limitations. First, thermal conductivity values were treated as constant, despite the fact that many materials, especially foams, exhibit temperature-dependent thermal behaviour[24]. The assumption of a fixed k-value across a cooling range from 80 °C to ~40 °C may introduce inaccuracies in estimating actual heat loss.

Additionally, instrumentation variability may have introduced measurement error. The thermal imaging cameras were calibrated prior to use, but slight inconsistencies in angle, distance, or emissivity calibration could affect surface temperature readings. Repeat trials reduced the influence of outliers, but improvements could include automated temperature logging, multi-angle imaging, or the use of embedded thermocouples to cross-validate infrared readings.

The simplified geometric and thermal modelling also assumed uniform wall thickness and heat distribution, while real containers may have variable thickness, double walls, or hidden layers. Future studies could employ CT scanning or destructive cross-sectional analysis to better characterise material structure and validate modelling assumptions.

Future work should also investigate hybrid packaging materials, including those augmented with aerogels or PCMs. Aerogel-embedded composites have been shown to provide exceptional thermal resistance at minimal weight, though they currently remain cost-prohibitive for widespread food packaging use[25]. Broader studies could also include biodegradable or recyclable materials, helping industry transition away from EPS (Styrofoam) while maintaining effective thermal performance.

Overall, the findings reinforce that packaging material choice directly influences heat retention in ready-to-eat foods. While EPS (Styrofoam) continues to deliver excellent performance in short-term insulation, it raises significant environmental and regulatory concerns. The results of this study contribute to the growing body of work aiming to find balanced solutions that optimise thermal insulation, food safety, environmental responsibility, and economic feasibility. With the emergence of novel material systems and advanced modelling techniques, future packaging innovations will be better equipped to meet these demands across the food sector.

5. Conclusion

This study demonstrated that packaging material has a significant impact on the heat retention performance of ready-to-eat noodle cups. Through two complementary experiments, one using noodle-filled containers and the other using hot water only, we showed that Styrofoam consistently exhibited the highest thermal insulation, followed by plastic, with paper showing the most rapid heat loss. These findings directly support the research aim of evaluating how material composition affects heat transfer and highlight the dominant role of packaging properties in controlling thermal behaviour during passive cooling.

The results have clear Chemical Engineering relevance, particularly for the design of thermally efficient and cost-effective food packaging. The application of Newton's Law of Cooling and fundamental conduction/convection models allowed for the quantification of cooling rates and cumulative heat loss, confirming that EPS (Styrofoam) materials retain heat longer due to their low thermal conductivity. However, the environmental burden of polystyrene packaging presents a major trade-off. This underscores a key industry challenge: balancing thermal performance with environmental sustainability, safety, and cost.

These insights have practical implications for food safety, shelf-life management, and the development of more sustainable packaging alternatives. Material innovations such as bio-foams, molded pulp, and aerogel-enhanced composites may offer viable alternatives that reduce environmental impact while maintaining adequate thermal performance. However, these emerging materials require further testing under real-use conditions to evaluate durability and cost-effectiveness.

Future research should explore temperature-dependent material properties, multilayer or composite packaging systems, and the incorporation of phase change materials for active thermal regulation. Improvements in thermal measurement techniques, such as embedded sensors or multi-surface infrared capture, could reduce experimental error and provide more detailed thermal mapping. Expanding the analysis to include biodegradable materials or dynamic loading conditions (e.g. opening/closing lids) would further enhance the applicability of findings.

In summary, this work reinforces the importance of packaging material selection in food engineering applications and provides a methodological foundation for evaluating insulation performance in consumer products. Continued interdisciplinary efforts will be essential to develop packaging solutions that meet the demands of thermal efficiency, environmental responsibility, and public health.

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Authorship statement: Elias Navarrete Cubillos served as the project coordinator, assigning roles, managing deadlines, and contributing to the Introduction, Abstract, and Conclusion while providing support for Methods, Results, and Discussion. Gabriel Gutierrez Salmeron was responsible for the Results

section and contributed to proofreading and overall editing of the Journal Article. Jordan McCammon co-authored the Discussion, alongside Samuel Stoyles, who also contributed to its development. Llewellyn Govender led the preparation of the Methods section. Sebastian Dominguez Flores (Tutor) provided task direction and project assistance, and Dr. Gobinath Rajarathnam provided conceptual direction, research and writing guiding frameworks, facilitated project resources, and direct project supervision.

Appendix

Error Calculation for k values graphical analysis:

Starting from $\Delta \boldsymbol{T}=\pm \mathbf{2}$℃ from device,

$$\Delta\, \boldsymbol{y} = \left|\frac{\boldsymbol{d}}{\boldsymbol{dT}} \boldsymbol{Ln}(\boldsymbol{T}-\boldsymbol{Tamb})\right| \cdot \Delta\, \boldsymbol{T} = \frac{1}{\boldsymbol{T}-\boldsymbol{Tamb}} \cdot \Delta\, \boldsymbol{T}$$

Where $\Delta \boldsymbol{y}=\boldsymbol{erroronln}(\boldsymbol{T}\text{-}\boldsymbol{Tamb})$,

Once we calculate the error $\Delta\, \boldsymbol{y}$ for each measurement we then have to consider the form of the best-fitting line formula: $\Delta\, \boldsymbol{y} = \boldsymbol{mx} + \boldsymbol{b}$ where the error on m would be **:**

$$\Delta\, \boldsymbol{m} = \frac{\boldsymbol{s}}{\sqrt{\sum (\boldsymbol{xi}-\bar{\boldsymbol{x}}\ )}}$$

Where s is the is the standard error of the residuals:

$$\Delta\, \boldsymbol{s} = \sqrt{\frac{1}{\boldsymbol{n}-2} \sum (\boldsymbol{yi}-\bar{\boldsymbol{y}}\ )^2}$$

This way we found out the error for all the values of K on the report

Error Calculation for heat flux conduction:

Defining C as a constant because there are guessed values,

$$\boldsymbol{q} = \boldsymbol{C} \cdot (\boldsymbol{T}-\boldsymbol{Tamb})$$

$$\Delta\, \boldsymbol{C} = \frac{\boldsymbol{k} \cdot \boldsymbol{A}}{\boldsymbol{d}}$$

$$\Delta\, \boldsymbol{q} = \left|\frac{\boldsymbol{dq}}{\boldsymbol{dT}}\right| \cdot \Delta\, \boldsymbol{T} = \left|\boldsymbol{C} \cdot \frac{\boldsymbol{d}\,(\boldsymbol{T}-\boldsymbol{Ta})}{\boldsymbol{dT}}\right| \cdot \Delta\, \boldsymbol{T} = \boldsymbol{C} \cdot \Delta\, \boldsymbol{T}$$

$$\Delta \boldsymbol{q} = \frac{\boldsymbol{k} \cdot \boldsymbol{A}}{\boldsymbol{d}} \cdot \Delta \boldsymbol{T}$$

Repeating this calculation for both experiments calculated we computed $\Delta \boldsymbol{q}$ conducted.

Error Calculation for heat flux convection:

$$\boldsymbol{q} = \boldsymbol{C} \cdot (\boldsymbol{T}-\boldsymbol{Tamb})$$

$$\Delta\, \boldsymbol{C} = \boldsymbol{h} \cdot \boldsymbol{A}$$

$$\Delta\, \boldsymbol{q} = \left|\frac{\boldsymbol{dq}}{\boldsymbol{dT}}\right| \cdot \Delta\, \boldsymbol{T} = \left|\boldsymbol{C} \cdot \frac{\boldsymbol{d}\,(\boldsymbol{T}-\boldsymbol{Ta})}{\boldsymbol{dT}}\right| \cdot \Delta\, \boldsymbol{T} = \boldsymbol{C} \cdot \Delta\, \boldsymbol{T}$$

$$\Delta \boldsymbol{q} = \boldsymbol{h} \cdot \boldsymbol{A} \cdot \Delta \boldsymbol{T}$$

Repeating this calculation for both experiments calculated we computed $\Delta \boldsymbol{q}$ convection .

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