The Sydney Journal of Interdisciplinary Engineering ÿ
SJIE 1(2) X-X (2025) https://doi.org/XXXX/XXXX

Investigation into Safe Kitchen Utensil Design through Conductive and Convective Heat Transfer

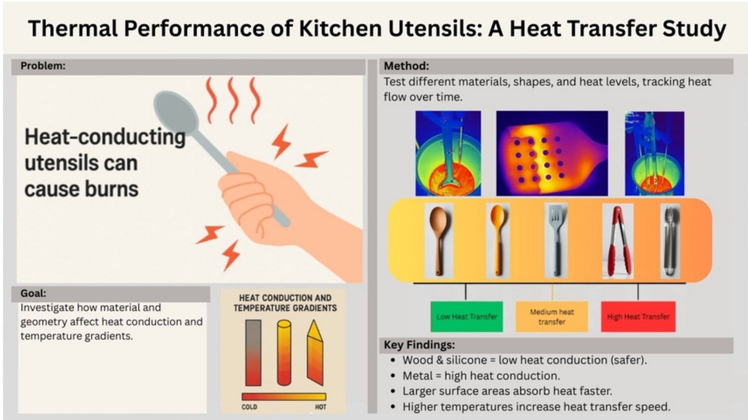
Saxon Krause[1], Lachlan Binnekamp[2], Cooper Ross[3], Anthony Nguyen[4], Jack Taylor[5], Minghao Zhang[6], Dr. Gobinath Rajarathnam[7]

[1] Chemical and Biomolecular Engineering, The University of Sydney, Sydney, Australia

E-mail: xxx@xxx.xx

Received xxxxxx
Accepted for publication xxxxxx
Published xxxxxx

Graphical Abstract



Abstract

This study investigates the thermal performance of common kitchen utensils, focusing on conduction based heat transfer, cooling rates, and insulation effectiveness. This is in order to investigate how the various properties impact the safety aspects of kitchen utensils on its users. Three experiments were conducted to assess the influence and thermal conductivity of material type, surface area, and insulation. Using a thermal imaging camera, transient temperature changes and temperature gradients were able to be recorded. Further analysis applied Fourier's Law and surface area-to-volume ratios to explain differences in heat transfer and cooling performance. Results showed how he increase in temperature increases the maximum temperature of the handle. However, made safe due to timbers exhibiting minimal heat conduction, meaning that heat does not travel up the handle presenting a hazard. Conversely, metal utensils demonstrated significantly higher heat transfer however, insulated variants reduce this significantly with the increase in surface area increases heat transfer. As a result, presenting their importance in safe utensil design. Procedural inconsistencies such as camera positioning, utensil placement, and environmental reflections were identified as key sources of error, obscuring precision and hindering repeatability. Recommendations for improved experimental setup are also discussed to increase data reliability in future studies.

Keywords: conductive heat transfer, insulation effectiveness, Fourier's Law, safety

1. Introduction

1.1 General Problem

Kitchen utensils are essential tools in the preparation and handling of food in everyday life. While their function is primarily mechanical, utensils are also expected to act as thermal barriers between the user and hot cooking environments. A failure to prevent excessive heat transfer can pose a large threat to burns, discomfort, and handling inefficiencies to the user. This is particularly relevant for utensils exposed to hot water as its high heat capacity increases the amount of energy in the system[1]. Despite design considerations often prioritising insulation or ergonomic grips, the underlying thermal safety of a utensil ultimately depends on its material conductivity and physical geometry. While anecdotal observations—such as "metal utensils get hot quickly"—are often accurate, quantitative validation through structured experimentation and known theories such as Fourier's heat transfer theory, can highlight safe material choices. This is particularly crucial for items like tongs, ladles, and spatulas, which are commonly used in high-temperature environments and are frequently made from a wide range of materials with varying thermal properties.

1.2 Previous Studies and Existing Solutions: Known Material Properties and Gaps

Previous studies on thermal conductivity have established that a material's ability to conduct heat depends on its internal structure and dominant heat carriers. In metals, such as stainless steel, electrons are the primary means of transporting thermal energy, resulting in high thermal conductivity values whereas stainless steel with 16 W/m·K[2]. These properties highlight the effectiveness of these metals as conductors but potential hazards for utensil handles unless properly insulated.

In contrast, polymeric materials like nylon and silicone rubber conduct heat through lattice vibrations (phonons)[3]. These materials are considered thermal insulators, with conductivity values ranging from 0.2 to 0.44 W/m·K, depending on molecular structure and temperature[4] Their low conductivity and flexibility explain their widespread use in cooking utensils, especially for handles and grips where reducing burns and harm is essential.

Although these thermal properties are well-documented in material science literature, most are measured under idealised lab conditions using standard test shapes, such as thin slabs or for different kitchen appliances such as pots and pans. Few studies have experimentally examined how these material properties behave in complex geometries in common kitchen utensils. For instance, factors like handle thickness, insulation layering, and contact surface area can all affect how heat travels from the heated portion of a utensil to the user's hand.

Additionally, while Fourier's Law of heat conduction provides the theoretical framework to describe this heat flow, prior research has rarely applied it directly to utensils in domestic contexts. As such, there remains a practical gap in understanding how theoretical values translate to real-world thermal safety in consumer-grade kitchenware.

1.3 Scope and Objective of the Current Study: Focusing on Conduction with Fourier's Law.

This study aims to address the outlined gaps by conducting a targeted investigation into purely conductive heat transfer within common kitchen utensils, by breaking it down to three key questions. These key research questions are:

1. How temperature affects heat conduction within the handle of the utensil.

2. What role utensil surface area and shape play in cooling rate and heat dissipation.

3. How effective insulation is in reducing heat conduction in metal utensils.

Our experiment answered these objectives by submerging utensils into controlled-temperature water baths and recording temperature changes along their handles using a thermal imaging camera. The focus on conduction allows for a direct application of Fourier's Law of Heat Conduction, which states that the rate of heat transfer through a material is proportional to the negative gradient of temperature and the thermal conductivity of the material[5]:

$$Q = -kA\frac{dT}{dx} \qquad \textbf{(1)}$$

where Q is the rate of heat transfer, k is thermal conductivity, A is the cross-sectional area, T is the temperature and x is the distance along the handle.

By using this theoretical framework, the study evaluates the relative thermal performance of materials like wood, plastic, and metal. In addition, both the impact of added insulation through silicone and utensil geometry through the role of surface area-to-volume ratios on heat dissipation during cooling can be analysed. The overarching objective is to provide recommendations based on experimental data and calculations for material and design selection in kitchen utensil manufacturing, with the goal of enhancing user safety through thermal engineering principles.

2. Methodology

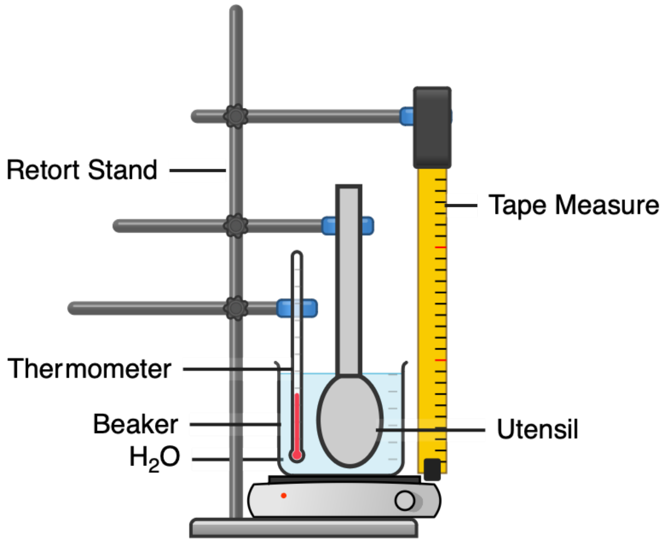


Figure 1: experimental diagram[6]

For all experiments, the experimental setup can be seen in figure 1. A 250 mL beaker was placed on a hotplate and set to specific temperatures (40°C, 60°C, or 80°C). A thermal imaging camera (InfiRay Pro 2) was used to record temperature changes in the utensils. For each measurement five readings were taken within 10-second windows around each minute to reduce random error.

Experiment 1: Effect of Temperature on Wooden Utensils

Three identical wooden spoons were submerged in water at 40°C, 60°C, and 80°C respectively. The temperature at the base and top of the handle was recorded every minute over a five-minute period.

Experiment 2: Effect of Surface Area and Shape on Heat Transfer

Two plastic kitchen utensils, one a spatula and the other a ladle, were placed into water at 80 degrees Celsius and the rate at which the temperature changed was recorded using the camera. They were then removed and placed on the bench and had heat scans taken after approximately 20 seconds of cooling to measure the effects of different surface areas and shapes on heat distribution and cooling. Similarly, during the 5 minutes both utensils were in the hot water, measurements were gathered at the end of the respective handle with the temperature being taken on each respective handle at 10±3 second intervals with 5 separate readings each time.

Experiment 3: Effect of Insulation on Heat Distribution

Two metal tongs, one made entirely of stainless steel and another with a silicone-insulated head, were submerged in 60°C water. Temperature readings were taken along the head and handle every minute for five minutes using a thermal imaging camera. The material composition of the tongs was confirmed based on product information found online; the all-metal tongs were stainless steel, while the insulated tongs consisted of stainless steel with silicone grips and tips[7&8]. Experimental heat conductivity values were calculated using equation 1.

Key Controls and Assumptions:

Utensils assumed to be homogeneous in composition, material properties (k, C_p, ρ) sourced from literature and product data, identical beakers and thermal camera setup used across all tests. No significant air drafts or environmental temperature fluctuations. Only conductive heat transfer is considered; convective effects neglected.

3. Investigation of the effect of temperature on the rate of heat transfer and distribution

3.1 Hypothesis

1. The increase in temperature will increase the steady-state temperature.

The energy transfer from the water to the spoon is given by Newton's law of convection[9] where h is the convection constant, T is the object temperature and T_∞ is the fluid temperature:

$$Q = Ah(T - T_\infty) \quad \textbf{(2)}$$

As such, when the temperature of the water increases there will be a greater temperature differential thus, increasing the rate of energy transfer. Furthermore, as given by the formula there will continue to be a transfer of energy up until the temperature of the spoon and the temperature of the water are the same. As such, since the energy is dissipated through convection from the handle and the surface area and convection constant remain constant the temperature must increase to account for the increase in energy.

2. The low thermal conductivity of the timber allows it to remain safe to use over time when exposed to direct heat.

Thermal conduction within the spoon can be modelled by equation 1. Since there is a small thermal conductivity constant of 0.1 – 0.2 the amount of energy transferred over a given distance is quite low[10]. This results in lower temperatures along the handle. However, another competing factor in reducing the temperature along the handle would be the rate at which energy is convected away from the handle[11]. Since there is only natural convection the convection constant should be small and thus, have less of an impact on the temperature gradient through the handle[12].

3.2 Results

The data that was collected all three trials indicated that the increase in temperature over time is one of a logarithmic scale (this can be seen in the appendix). As such, to confirm this relationship the natural logs of the temperature were taken and then graphed with the corresponding times. In figure 2**,** the data conforms to a linear trend affirming with a great deal of confidence that the change in temperature over time is related by a logarithmic trend with R^2 values of 0.85, 0.98, 0.96 for 40℃, 60℃ & 80℃ respectfully. This affirms the accepted and theoretical understanding of transient heat conduction. This can be seen with the lumped capacitance analysis formula for the assumption of no radiation and the convection constant remaining constant over time (equation 3) [13]. Here t is the time, V is the volume, ρ is the density and c_p is the specific heat capacity.

$$T(t) = T_\infty + (T - T_\infty)e^{-\frac{hA}{\rho c_p V}t} \quad \textbf{(3)}$$
$$T \propto e^t, t \propto \ln(T)$$

However, the relevance of this formula can be argued. This is due to first the fact that some energy will be being lost to the environment by radiation simply since there is a difference in

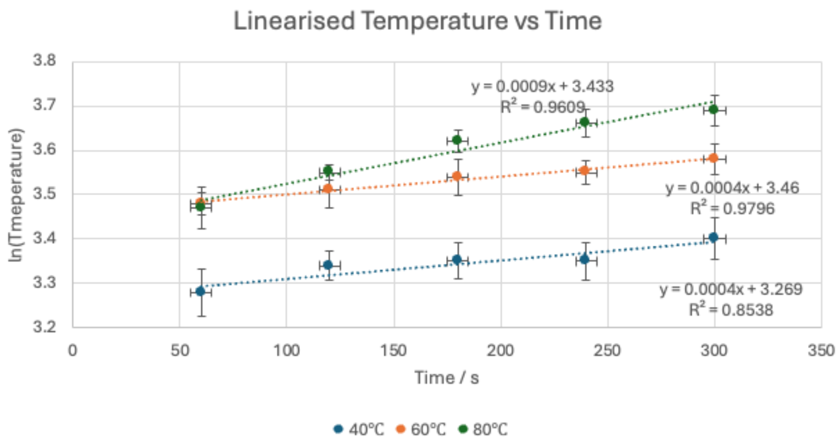


Figure 2: linearised graph of temperature with respect to time

temperatures. However, this is a somewhat reasonable assumption due to the temperature difference being small such that the energy lost will be close to negligible. Furthermore, the whole underlying assumption of general lumped capacitance is that the rate of conduction is large enough compared to the rate of convection that there is a negligible temperature gradient within the spoon. As a result, this equation is only accepted when the Biot number is less than 0.1[14]. Using the literature values for the convection constant for water we can gain a rough perspective of at least the relative order of magnitude[15]. This value, however, will be far from accurate as this is a general value not one that accounts for the wooden spoon's properties. As a result, the Biot number ranges from $4.25 \leq Bi \leq 510$ (these calculations can be found in the appendix). Hence, the assumption of lumped capacitance is not valid in this scenario and unfortunately cannot be used to model the transient temperature. However, if we compare the formula to the infinite cylinder with non-negligible temperature gradients (equation 4), we can see that the proportionality of temperature to time still holds true as the Fourier number is a function of time. As such, the data conforms with the accepted literature in forming the correct relationship between temperature and time[13].

$$T(t) = T_\infty + (T - T_\infty)\sum_{n=1}^{\infty} C_n e^{-\zeta_n^2 Fo} J_0(\zeta_n r^*)\,, Fo = \frac{\alpha t}{r_0^2} \quad \textbf{(4)}$$

$$\therefore T \propto e^t, t \propto \ln(T)$$

3.3 Discussion

The heat conduction constant can be calculated by assuming that the handle is a fin that is dissipating the energy through conduction to the atmosphere. As such, the temperature can be modelled through equation 5 where P is the fin perimeter and L is the length of the fin[16].

$$\frac{T - T_\infty}{T_b - T_\infty} = \frac{\cosh m(L-x) + \left(\frac{h}{mk}\right)\sinh m(L-x)}{\cosh mL + \left(\frac{h}{mk}\right)\sinh mL} \quad \textbf{(5)}$$

$$m^2 = \frac{hP}{kA_c}$$

Then subbing in the temperatures and taking an average (excluding outliers which were values that are either $1.5 \times IQR$ above or below the median), we can find the average heat convection constant ($h = 0.054\ Wm^{-2}K^{-1}$) [17]. Sample calculations can be seen in the appendix with the results for all the measurements. The reason for using an average is due to the variability in the convection coefficient which had a range of 0.036 excluding outliers. Although small, when compared to the average this results in $\pm 33\%$ which is not negligible. These changes in values are most likely due to drafts and changes in the velocity of air in the room in which the experiment was taking place[18]. In addition, taking an average allows us to simplify the calculation and ignore any changes in the convection constant concerning time.

The use of the fin approximation, however, comes with some assumptions, the only one that is being violated are the steady state conditions as the measurements were taken transiently[19]. However, if we ignore the bottom of the spoon and just focus on the handle the temperature gradient should be consistent. Hence, it is relatively feasible to look at it as a fin as the observational data followed the expected trend of an exponential curve.

Using the data collected a model can be made for the transient heat conduction along the spoon. T_b can be calculated using the formula for the trendlines that come from the experimental findings. This can then be modelled in 3D to see how the temperature changes along the handle with respect to time.

Evidently even when modelling into the future the temperature along the handle will never get hot enough to be dangerous to the user. This is evident with the spoon at 80°C after 20 minutes ($T = 47$°C) only going to cause damage to the basal layer of the epidermis[20]. However, this is only when touching the very bottom of the spoon. Halfway up the spoon the temperature would be only 31°C which is not enough to cause any form of damage to the skin. Furthermore, the data clearly shows the benefits of such a small heat conduction value as the temperature gradient is incredibly steep preventing the top of the handle from getting hot. This conclusion can be approximately made due to how small the convection value is such that the energy lost is not influencing the conduction curve. This makes it a highly safe utensil as it is unrealistic to have direct contact with a water at 80°C for more than 20 minutes straight and be touching it right at the hottest point.

Although there are no specific commercial cookware safety standards, typically in commercial kitchens wooden utensils

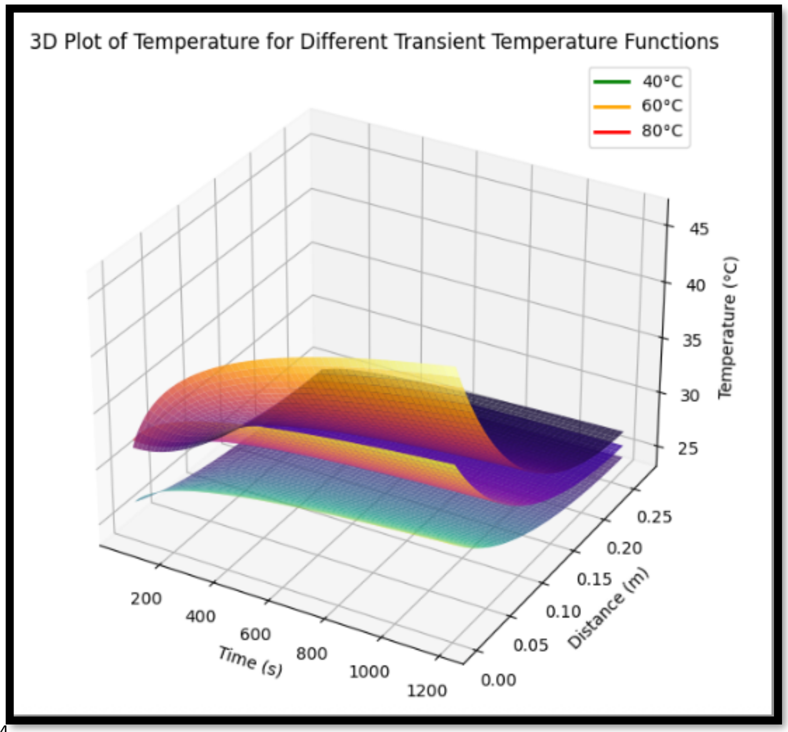


Figure 3: 3D plot of temperature, time and distance for the three different temperatures[24]

are not as common. This is due to the hygiene concerns that come with the use of timber[21]. These stem from the porous nature which allows bacteria and other pathogens to grow[22]. Since, there are extremely stringent food hygiene regulations this exacerbates the stainless-steel control over the market [23]. However, this is not to say that the findings from this experiment are worthless in a commercial environment but to say that the use of other materials with low thermal conductivities may allow for both the user to be safe and the food to maintain its hygiene. Beyond the professional environment where wooden utensils are far more common the findings conclude that they are one of the safest tools in burn prevention.

When considering other substances which can reach higher temperatures and similarly transfer heat like oil, then the temperature it will reach will be far greater increasing the energy transfer. However, oil may have a much lower convection constant ($50 - 350\ Wm^{-2}K^{-1}$) compared to water ($50 - 3000\ Wm^{-2}K^{-1}$) [16 25]. Yet again these values are most likely not correct as they are not for this specific case with timber spoons however, they serve as a comparison between their effective rates of heat transfer. As such, if taking the maximum values, it is only true when either the temperature is so high that it isn't feasible or if left in the oil for an unrealistic amount of time. However, if the convection constants are both 50 then the temperature will get considerably hotter. As such, a future area of research would be to investigate the effects of different substances.

4. Investigation into the effect of surface area and material on the rates of cooling and heat conduction

4.1.1 Hypothesis on the effects of complete insulation material on heat conduction

Both the spatula and ladle utilised in the experiment were Coles brand, however Coles does not reveal the insulation material utilised in the makeup of each product. Thus, for this experiment based on comparison to other products and the physical properties of each product compared to the properties of typical insulation plastic products to be nylon for the spatula [26] and silicone for the ladle[27]. Past academic research indicates both kitchen utensils should be good insulators of heat as each material has been found in studies to have very low heat conductivity constant with nylon ranging between 0.23-0.29W/m·k for nylon[28] and 0.2-0.44W/m·k for silicone[29], dependent on specific type of each insulating plastic utilised. These values gathered from literature reports indicate each utensil should not conduct considerable amounts of heat up the handles of each separate utensil. These values also indicate that heat conducted is expected to be found to be relatively similar amounts in each material due to similar heat conductivity constants, with silicone perhaps conducting slightly more.

4.1.2 Hypothesis on the effects of material and surface area on cooling and heat dissipation

Secondarily this experiment aimed to measure the effect of surface area, shape and material on heat distribution and cooling through taking heat scans of both the ladle and spatula 20 seconds after being removed from the hot water. Given both thermal insulating materials utilised were measured to have the same thickness it is possible to study the effects of both surface area and volume specific surface area. In general, a larger surface area leads to faster rate of cooling as a larger area allows for more contact with the cooling medium, in this case surrounding room temperature, and facilitates greater heat dissipation[30]. This would indicate the ladle head to cool much faster given the calculated surface area being $356.83cm^2$ compared to the spatula's head's calculated surface area being $177.04cm^2$. However, volume of each shape must also be considered to find a volume specific surface area(ω) as a prior study by Árpád et.at recently suggests having found ω affects Newton's law of cooling in the following way, where an increase in ω will cause an increase in cooling rate and deviation of temperature ($\Theta(\tau)$) [31].

$$\boldsymbol{\Theta(\tau) = \Theta(0) \cdot e^{-h\omega T}} \qquad \textbf{(6)}$$

This conversely indicates instead the expected outcome of the findings to be the spatula cools faster given the calculated volume specific surface area to be $10.96cm^{-1}$ compared the ladles $5.10cm^{-1}$. This also agrees with common theory that rectangular prism shaped objects generally cool faster than their spherical counterparts due to their larger surface area to volume ratio[32].

Furthermore, utilising the heat scans it will be possible to test whether the materials utilised are homogenous or if the materials are not uniform during production. Ideally homogenous plastics should have consistent heat spans that demonstrate a smooth transfer of heat during cooling with a gradual colour change being demonstrated on the heat scans[33]. However, if the materials are not homogenous, localised hot spots are more likely to be found on the heat scans.

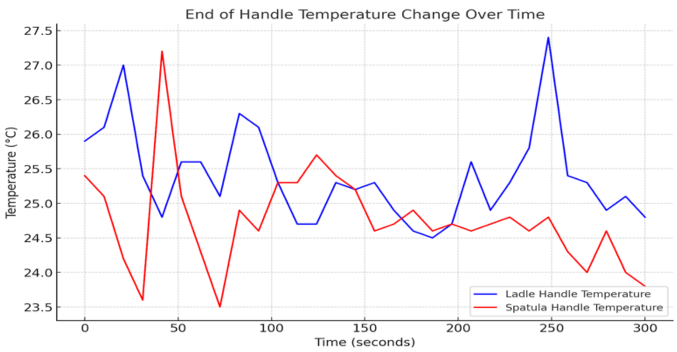


Figure 4: Line graph demonstrating the change in temperature against time at the end of the handle for both spatula and ladle

4.2 Results

4.2.1- The effects of solid insulation on heat conduction

The temperature at the end of the handle for each utensil never demonstrated a clear trend thus the data gathered can be best displayed utilising a line graph exhibiting the averages for all data points found. Averages could be taken from the 5 readings taken every 10 seconds each collection of results never exhibited major standard deviation or maximum deviation. The data collected illustrated minimal fluctuation, thus to better view variation in data the y-axis range was minimised to range between 23.5°C-27.5°C.

4.2.2 – Surface area and material heat dissipation

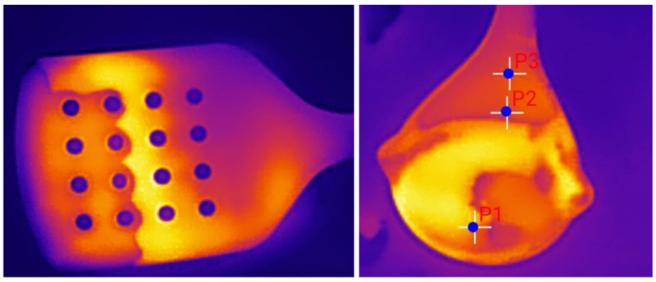


Figure 5: Heat scans taken after 20 seconds of cooling for each utensil, spatula on the left and ladle on the right.

Heat scans were taken of each utensil after 20 seconds of cooling to allow for qualitative analysis on the heat dissipation during cooling for each utensil. The spatula exhibits the central section of the utensil to be the hottest with gradual heat dissipation both the tip and back of the spatula head. The ladle also similarly demonstrates the central section of the utensil to be the hottest however its heat dissipation is slightly more irregular also with a few localised cool spots.

4.3 Discussion

4.3.1 – Solid insulation and heat conduction

The temperatures recorded at the end of both the ladle and the spatula handles evidently never displayed severe rises in temperature that could lead to them being dangerous for users. Each handle displayed initial temperature increases from room temperature of 23°C and then remained relatively stable at averages of 25.39°C for the ladle and 24.75°C for the spatula. Slight deviations in data were likely gathered from possible fluctuations within the room which lead to maximum variance from average temperature of ±1.78% for the ladle and ±1.97% for the spatula, which are relatively negligible. The gathered results support the hypothesis that each utensil should be safe for cooking at 80°C given their respective insulation materials utilised. The findings also agree to the hypothesis that silicone is a slightly better conductor of heat, hence the slightly higher average found for the lade. To further support these findings, heat flux(q) can be calculated using the Fourier law of heat conduction for a heat transfer model.

$$\boldsymbol{q} = \frac{\boldsymbol{k_x A_x (\Delta T)}}{\boldsymbol{L_x}} \qquad \textbf{(7)}$$

Through applying the above equation average heat flux values of 0.015W for the ladle and 0.018W for the spatula were found. These values reinforce the prior findings of the safety of each utensil and its insulating material given the gathered heat flux values for each are extremely small suggesting the amount of heat transferred through the handles is very minimal indicating the insulating materials, nylon and silicone are doing their jobs for each respective utensil[34].

4.3.2 - Surface area and material on heat dissipation

Through analysing the photos, it is evident for both utensils the central portion of each head is as expected the hottest part after being allowed to cool for 20 seconds. This is simply due to the fact that despite all sides seen on the heat scan being in contact with the atmosphere, the edges have more exposure to the atmosphere allowing it to release more heat[35]. As hypothesised the spatula appears to be cooling faster especially the edges which is likely due to the greater volume specific surface area on the rectangular prism shaped spatula then the hollowed out semi-ellipsoid shape of the ladle.

This can be quantitatively understood from the adapted Newton's laws of cooling equation displayed earlier where evidently slower cooling rates will be received for a smaller volume specific surface area value. The results shown here further prove the relatively recent discovery that volume specific heat capacity should be considered within Newton's laws of cooling as this proves the rate of cooling and heating not only heat transfer coefficient and materials characteristics but also volume specific surface area[31]. This would hence lead to the conclusion that when utilising utensils of a similar thickness and material but differing shapes those with higher volume specific surface areas will be safer to touch in a faster period. However as seen by each image each utensil head after 20 seconds still contains significant amounts of heat despite being made from insulating materials, thus it is highly recommended to not touch any part of a utensil that has come in contact with extreme heat for an extended period or until cooled by other systems[36].

The heat scans indicate some scale of uniformity within both utensils as neither display major localised hot spots and instead more gradual heat dissipation can be seen. However, especially within the ladle small darker spots can be seen indicating those areas to be cooling faster which could be indicating small amounts of compositional non-uniformity. This would thus lead to the conclusion of the spatula being safer to cook with then the ladle as its greater amounts of uniformity throughout its heat scan indicates the spatula heating and cooling rates are more predictable throughout then the ladle. The greater predictability of the heat dissipation within the spatula means better advice can be sought on length of cooling times before it is safe to touch the utensil in comparison to the spatula, thus making the spatula head less harmful.

5. Investigation into the effect of partial insulation on heat distribution.

5.1 Hypothesis

The aim of this experiment is to investigate the effect of insulation on heat distribution within a system. Specifically, it seeks to determine how the presence of insulating materials affects the rate of heat transfer in stainless steel tongs, compared to a pair with silicone insulation to one without. The hypothesis is that the addition of silicone insulation will reduce thermal conduction, slowing the rate of temperature change and leading to a more uniform temperature distribution over time. This is due to silicon having a lower conduction constant thus, conduction less energy and reducing the overall temperature[37].

Insulating materials reduce heat transfer by providing resistance to conductive, convective, and radiative losses. Fourier's Law of Heat Conduction states that the rate of heat transfer through a material is proportional to the temperature gradient across it and its thermal conductivity[38]. Subsequently, materials with low thermal conductivity, such as silicone or even nylon, are commonly used as insulators on kitchen utensils[38]. Prior research suggests that well-insulated systems experience slower temperature changes and exhibit greater thermal efficiency compared to non-insulated systems[40].

We expect that the insulated tongs will exhibit a significantly lower rate of heat transfer than the non-insulated tongs. This will result in a slower temperature increase in the handle region and a more uniform temperature distribution across the insulated material[41]. These expectations align with transient heat conduction models, where insulation reduces temperature gradients and slows heat transfer[42]. The practical implications, suggests that insulated tongs are safer to use for handling hot objects over extended periods.

5.2 Results

The experiment measured temperature changes in two sets of Coles brand stainless-steel tongs—one with silicone insulation on the handle[7] and one without[8]—at three locations: near the bottom closest to the water, midway up the handle, and at the top of the handle. Minimal temperature change was observed at the handle for both tongs, indicating limited heat transfer along their length. The most significant temperature changes occurred at the bottom of the tongs, as shown in Figure 1. This is due to the temperature gradients discussed in section 3 of the report. The results in Figure 1 are averages from five trials per tongs type to ensure reliability, with the corresponding data and standard deviations provided in the appendix.

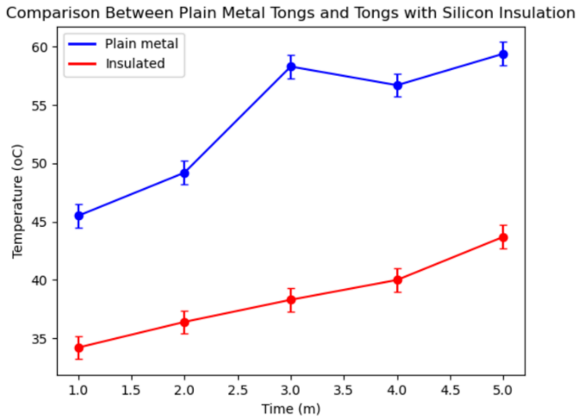


Figure 6. Temperature Change of Stainless Steel vs. -Insulated Stainless-Steel Tongs

5.3 Discussion

The results indicate that the insulated tongs conducted heat significantly less than the pure stainless-steel tongs. Based on common manufacturing standards, the stainless steel was assumed to be grade 304[43], with a thermal conductivity constant (k) of 16.2 W/m·K[44]. Its density was taken as 7930 kg/m^3, and the specific heat capacity (C_p) was identified as 490J/kg·K[45]. For the silicone insulation, the thermal conductivity constant (k) was estimated to range from 0.2 to 2.55 W/m·K, with a density of 1100 kg/m^3 and a specific heat capacity of 1050J/kg·K[37]. Since the metal core of the insulated tongs did not appear to extend deeply into the silicone tip, the submerged portion was assumed to be primarily composed of silicone.

The experimentally calculated k value for the stainless-steel tongs was 82.8 W/m·K, significantly higher than the theoretical value of 16.2 W/m·K. This discrepancy corresponds to a percentage error of 411.1% and can be attributed to multiple factors, including the simplification of the tongs' geometry. Approximating their shape as a rectangular cross-section may have led to a poor estimation of heat transfer values, as the actual geometry provides additional surface area for heat transfer not accounted for in the simplified model. Variations in temperature measurements due to shifts in the thermal imaging camera's position may have introduced minor inaccuracies.

For the insulated tongs, the experimentally determined k value was 19.93 W/m·K, which was higher than the theoretical expectation. As evident in equation 8 for the calculation of the rate of heat transfer using the total resistance formula it is evident that k calculated will be an average between the stainless steel and the silicon with respect to the surface are and thickness. (Note: all values subscript one are the constants respective to the metal and subscript two for the silicon.) However, the experimentally calculated value is outside of the range indicating that the rate of heat transfer values has been underestimated, likely due to the same limitations affecting the stainless-steel tongs.

$$q = \frac{T_\infty - T_1}{R_{total}} \quad \textbf{(8)}$$

$$R_{total} = \frac{L_1}{k_1 A_1} + \frac{L_2}{k_2 A_2} \quad \textbf{(9)}$$

While the absolute values obtained from the experiment were inaccurate compared to theoretical values, they effectively demonstrated a comparative trend. The results consistently indicated that the insulated tongs conducted heat less effectively than the pure stainless-steel tongs. This supports the hypothesis that silicone insulation reduces heat transfer and enhances thermal safety. An additional limitation in the experiment was the estimation of the submerged portion's volume. Rather than directly measuring this volume, calculations were made using dimensional approximations, which may have introduced further error. A more precise approach, such as water displacement, would have provided more accurate data and improved the reliability of the calculated k values.

Overall, the insulated utensils are far superior when it comes to the safety of its user from burns. However, it is still common to see full metal utensils rather than ones with insulated grips in industry. This is due to their cost and durability which they tend to be inferior to their full metal comparision[47]. On the contrary, silicon is far more hygienic than timber presenting no real reason for insulated grips becoming more common in the industry.

6. Conclusion

6.1.1 - The effect of temperature on heat transfer

In culmination, it is clear the temperature does in fact increase the steady state temperature of the utensil. However, as seen due to the low thermal conductivity of the timber it makes the utensil incredibly safe. This is due to it preventing thermal energy from travelling up the handle and thus, maintaining the end of the handle at practically room temperature no matter how long it is supposed to heat. This was evident with the model indicating that even at 80℃ for 20 mins the end of the handle reached a temperature of 25℃. This was similarly cooperated with the base of the handle only reaching 47℃ which was barely enough to cause harm.

6.1.2 - Investigation into the effect of surface area and material on the rates of cooling and heat conduction

To summarise, the key findings illustrated both the Coles brand spatula and ladle, which are believed to have utilised nylon and silicon respectively, to successfully maintain a safe temperature for holding whilst cooking at 80°C. Each utensil only saw slight immediate increases when placed in the water to move above room temperature and then the ends of the handles remained in between 23.5-27.5°C each. Therefore, indicating the vital role of including the conduction constant into utensil design as it limits how much energy enters the spoon.

The heat dissipation of each material exhibited the spatula to cool faster than the ladle due to its smaller volume specific surface area. This hence points towards validating Árpád et.al study recommending the addition of volume specific surface area to Newtons law of cooling. Furthermore, the slightly more irregular shape of heat dissipation in the ladle with localised cool spots, indicates the spatula was made more uniform and thus safer as its rate of cooling is more predictable.

6.1.3 - Insulation effect on heat distribution.

This experiment demonstrated that even partial insulation significantly affects rates of conduction. Thus, in utensil design it is not necessary to be made completely out of an insulated material whilst keeping the safety a priority. By reducing the rate of heat transfer, the insulation promoted a more gradual temperature change and contributed to a more uniform temperature distribution. These findings align with Fourier's Law and support the hypothesis that insulation enhances thermal efficiency by resisting conductive, convective, and radiative heat losses. The trends seen in the experimental results matching expectations, confirming that insulated materials lowered the overall temperature. While errors and external factors may have influenced the results, the overall trends were consistent with theoretical predictions.

6.2 – Summary

To conclude, this article has successfully investigated and summarised various possible sources of harm through heat conduction of an array of different kitchen utensils through a range of forms, including the effect of temperature, surface area, material and insulation. Further studies could examine how changes in liquid utilised could affect the rates of heat transfer in each investigation and further investigate the role of convection in heat transfer for kitchen utensils. Addressing potential sources of error, such as ambient temperature fluctuations, movement of the position of the thermal camera and geometric modelling assumptions, could further improve experimental reliability. Additionally, employing direct measurement techniques for submerged volume would enhance the precision of heat transfer calculations.

Acknowledgements

Thankyou to the University of Sydney for their facilities and the lab team in providing the appropriate equipment to carry out our investigation. In addition, thankyou to Gobinath

Rajarathnam and Minghao Zhang for continuous feedback during the drafting process.

References

1. Qazi, S. Chapter 7 - Solar Thermal Electricity and Solar Insolation. ScienceDirect 203–237 https://www.sciencedirect.com/science/article/abs/pii/B9780128030226000071 (2017).
2. de Naoum, K. & Schadegg, J. 316 Stainless Steel: Uses, Composition, Properties. www.xometry.com https://www.xometry.com/resources/materials/316-stainless-steel/ (2023).
3. Uher, C. Thermal Conductivity of Metals. Thermal Conductivity 21–91 (2004) doi:https://doi.org/10.1007/0-387-26017-x_2.
4. Baetens, R. High performance thermal insulation materials for buildings. Nanotechnology in Eco-Efficient Construction 188–206 (2013) doi:https://doi.org/10.1533/9780857098832.2.188.
5. Matsuno, K. & Nemoto, A. Quantum as a heat engine—the physics of intensities unique to the origins of life. Physics of Life Reviews 2, 227–250 (2005).
6. Chemix. Chemix - Draw Lab Diagrams. Simply. Chemix.org https://chemix.org (2019).
7. Coles. Cook & Dine Tongs 30cm | 1 Each. Coles https://www.coles.com.au/product/cook-and-dine-tongs-30cm-1-each-3116330?srsltid=AfmBOort0zg0761jt52r_jpW0ECnDV7_ (2025).
8. Coles. Cook & Dine Silicone Tongs | 1 Each. Coles https://www.coles.com.au/product/cook-and-dine-silicone-tongs-1-each-7071346 (2025).
9. Vollmer, M. Newton's Law of Cooling Revisited. European Journal of Physics 30, 1063–1084 (2009).
10. Pásztory, Z., Fehér, S. & Börcsök, Z. The effect of heat treatment on thermal conductivity of paulownia wood. European Journal of Wood and Wood Products 78, 205–207 (2019).
11. Swierczyna, R., Sobiski, P. & Fisher, D. Revised heat gain rates from typical commercial cooking appliances from RP-1362. ASHRAE Transactions 115, 138–161 (2009).
12. Ostrach, S. Natural Convection in Enclosures. Advances in heat transfer 161–227 (1972) doi:https://doi.org/10.1016/s0065-2717(08)70039-x.
13. P Koštial et al. Lumped Capacitance Model in Thermal Analysis of Solid Materials. Journal of physics. Conference series 588, 012006–012006 (2015).
14. Jungbauer, A. & Hahn, R. Large Scale Separations. Journal of chromatography library 561–599 (2003) doi:https://doi.org/10.1016/s0301-4770(03)80038-6.
15. Engineering Toolbox. Overall Heat Transfer Coefficient. Engineeringtoolbox.com https://www.engineeringtoolbox.com/overall-heat-transfer-coefficient-d_434.html (2019).
16. Engineers Edge. Convective Heat Transfer Coefficients Table Chart | Engineers Edge | www.engineersedge.com. Engineersedge.com https://www.engineersedge.com/heat_transfer/convective_heat_transfer_coefficients__13378.htm (2015).
17. Fundamentals of Heat and Mass Transfer. Google Books (John Wiley & Sons, 2011).
18. PennState Eberly College of Science. 3.2 - Identifying Outliers: IQR Method | STAT 200. PennState: Statistics Online Courses https://online.stat.psu.edu/stat200/lesson/3/3.2 (2024).
19. Louisiana Tech University. ME 354 - Lab 5 - Fin Experiment. Latech.edu https://www2.latech.edu/~hhegab/pages/me354/Lab5/Lab5_fin_Sp99.htm (2024).
20. Camci, M., Karakoyun, Y., Acikgoz, O. & Dalkilic, A. S. A comparative study on convective heat transfer in indoor applications. Energy and Buildings 242, 110985 (2021).
21. Martin, N. A. & Falder, S. A review of the evidence for threshold of burn injury. Burns 43, 1624–1639 (2017).
22. Toggerson, B. & Philbin, A. Uncertainty for natural logarithms. openbooks.library.umass.edu 132, (2020).
23. McDonald, E. Wood vs plastic chopping boards: which is better? delicious.com.au https://www.delicious.com.au/food-files/health/article/wood-vs-plastic-chopping-boards-which-better/i2pjec8n# (2024).
24. Food Standards Australia New Zealand Safe Food Australia. Standard 3.2.3 Food Premises and Equipment. https://www.foodstandards.gov.au/sites/default/files/publications/SiteAssets/Pages/safefoodaustralia3rd16/Standard%203.2.3%20Food%20Premises%20and%20Equipment.pdf.
25. Python Software Foundation. Welcome to Python.org. Python.org https://www.python.org (2019).
26. de Naoum, K. 7 Properties of Nylon: Everything you Need to Know. *Xometry* https://www.xometry.com/resources/materials/properties-of-nylon/ (2022).
27. Mullins, M. J., Liu, D. & Sue, H.-J. . Mechanical properties of thermosets. *Thermosets* 28–61 (2014) doi:https://doi.org/10.1533/9780857097637.1.28.
28. Xie, K., He, Y., Cai, J. & Hu, W. Thermal conductivity of Nylon 46, Nylon 66 and Nylon 610 characterized by Flash DSC measurement. *Thermochimica Acta* **683**, (2019).
29. Sahu, G., Gaba, V., Panda, S., Acharya, B. & Mahapatra, S. Thermal conductivity, thermal

diffusivity, and volumetric heat capacity of silicone elastomer nanocomposites. *High Performance Polymers* **30**, 365–374 (2017).
30. Plasquy, E., Garcia, J. M., Florido, M. C. & Sola-Guirado, R. R. Estimation of the Cooling Rate of Six Olive Cultivars Using Thermal Imaging. *Agriculture* **11**, 164–164 (2021).
31. Árpád, I. W., Kiss, J. T. & Kocsis, D. Role of the volume-specific surface area in heat transfer objects: A critical thinking-based investigation of Newton's law of cooling. *International Journal of Heat and Mass Transfer/International journal of heat and mass transfer* **227**, 125535–125535 (2024).
32. Luu, T. Impact of Surface Area and Porosity on the Cooling Performance of Evaporative Cooling Devices. (2020).
33. Chen, X., Cheng, L., Gu, J., Yuan, H. & Chen, Y. Chemical recycling of plastic wastes via homogeneous catalysis: A review. *Chemical Engineering Journal* **479**, (2023).
34. What is Heat Flux? (Thermal Flux) | SimWiki. *SimScale* https://www.simscale.com/docs/simwiki/heat-transfer-thermal-analysis/what-is-heat-flux/ (2023).
35. Posselt, B. & Pavlov, G. G. The Cooling of the Central Compact Object in Cas A from 2006 to 2020. *Astrophysical journal/The Astrophysical journal* **932**, 83–83 (2022).
36. Comcare. Kitchen appliances - Comcare, Australia. *Office Safety tool* https://www.comcare.gov.au/office-safety-tool/spaces/kitchens/kitchen-appliances (2021).
37. AZO Materials. Properties: Silicone Rubber. *AZoM.com* https://www.azom.com/properties.aspx?ArticleID=920 (2019).
38. Bahrami, M. *Steady Heat Conduction*. https://www.sfu.ca/~mbahrami/ENSC%20388/Notes/Staedy%20Conduction%20Heat%20Transfer.pdf.
39. Jingsourcing. 11 Materials of Kitchen Utensils: How to Choose the Right One? *jingsourcing* https://jingsourcing.com/p/b23-kitchen-utensils-materials/
40. Knauf. The Science of Insulation Explained | Knauf Insulation Australia. *Knauf* https://knauf.com/en-AU/knauf-insulation/competencies/expertise/energy-efficiency/tips-to-keep-warm/science-of-insulation-explained (2024).
41. Sahin, A. Z. & Kalyon, M. Maintaining uniform surface temperature along pipes by insulation. *Energy* 30, 637–647 (2004).
42. Ji, X. L., Zhang, H. H. & Han, S. Y. Transient heat conduction modeling in continuous and discontinuous anisotropic materials with the numerical manifold method. *Engineering Analysis with Boundary Elements* **155**, 518–527 (2023).
43. U.S Department of Energy. Insulation. *Energy.gov* https://www.energy.gov/energysaver/insulation.
44. de Naoum, K. & Conniff, M. Comparing 18/8, 18/10, and 18/0 Stainless Steels. *Xometry.com* https://www.xometry.com/resources/materials/18-8-vs-18-10-vs-18-0-stainless-steel/ (2024).
45. Metals Cut 4U. 304 Vs 316 Stainless Steel: Know The Real Difference. *metalscut4u.com* https://metalscut4u.com/blog/post/304-stainless-steel-vs-316-stainless-steel.html.
46. AZO Materials. Properties: Stainless Steel - Grade 304 (UNS S30400). *AZoM.com* https://www.azom.com/properties.aspx?ArticleID=965
47. *Payne, B. Exploring the Different Types of Tongs for Cooking. Misen https://misen.com/blogs/news/exploring-the-different-types-of-tongs-for-cooking (2024).*

Appendix

Table 1: 40°C change in temperature over time at the bottom of the handle

Time ± 5s	Trial 1 / ±0.1℃	Trial 2 / ±0.1℃	Trial 3 / ±0.1℃	Trial 4 / ±0.1℃	Trial 5 / ±0.1℃	Average / ℃	Error / ±	Standard Deviation	Ln(Temperature)	ln(T) Error / ±
60	25.4	27.1	27.9	25.1	27.5	26.6	1.4	1.35	3.28	0.05
120	29.1	27.3	27.8	27.7	28.6	28.1	0.9	0.780	3.34	0.03
180	28.1	27.0	29.3	28.6	29.0	28.4	1.2	0.968	3.35	0.04
240	27.3	28.9	28.3	29.7	27.8	28.4	1.2	1.01	3.35	0.04
300	29.0	30.2	28.7	31.5	30.1	29.9	1.4	1.28	3.40	0.05

Table 2: 60°C change in temperature over time at the bottom of the handle

Time ± 5s	Trial 1 / ±0.1℃	Trial 2 / ±0.1℃	Trial 3 / ±0.1℃	Trial 4 / ±0.1℃	Trial 5 / ±0.1℃	Average / ℃	Error / ±	Standard Deviation	Ln(Temperature)	ln(T) Error / ±
60	33.1	31.8	32.9	31.5	32.2	32.3	0.8	0.793	3.48	0.02
120	32.2	34.8	32.8	33.9	34.3	33.6	1.3	1.16	3.51	0.04
180	33.0	34.8	35.8	35.6	33.8	34.6	1.4	1.28	3.54	0.04
240	33.7	34.5	35.2	35.1	35.5	34.8	0.9	0.690	3.55	0.03
300	35.4	36.7	34.6	37.1	36.2	36.0	1.3	1.16	3.58	0.03

Table 3: 80°C change in temperature over time at the bottom of the handle

Time ± 5s	Trial 1 / ±0.1℃	Trial 2 / ±0.1℃	Trial 3 / ±0.1℃	Trial 4 / ±0.1℃	Trial 5 / ±0.1℃	Average / ℃	Error / ±	Standard Deviation	Ln(Temperature)	ln(T) Error / ±
60	30.7	32.7	30.9	33.7	32.5	32.1	1.5	1.27	3.47	0.05
120	34.7	34.3	35.6	34.9	35.0	34.9	0.7	0.47	3.55	0.02
180	38.0	36.5	37.6	36.1	37.8	37.2	0.9	0.846	3.62	0.03
240	37.4	39.8	39.5	38.0	39.8	38.9	1.2	1.12	3.66	0.03
300	40.1	38.1	40.6	40.8	39.9	39.9	1.4	1.07	3.69	0.03

Table 4: 40°C change in temperature over time at the bottom of the handle

Time ± 5s	Trial 1 / ±0.1℃	Trial 2 / ±0.1℃	Trial 3 / ±0.1℃	Trial 4 / ±0.1℃	Trial 5 / ±0.1℃	Average / ℃	Error / ±	Standard Deviation
60	23.0	23.9	22.8	24.1	23.7	23.5	0.7	0.650
120	23.9	23.7	24.8	25.4	25.2	24.6	0.9	0.780
180	23.2	23.9	25.1	24.6	23.2	24.0	1.0	0.829
240	24.1	23.7	25.1	24.8	24.3	24.4	0.7	0.640
300	23.2	24.1	25.2	24.9	23.1	24.1	1.1	0.900

Table 5: 60°C change in temperature over time at the bottom of the handle

Time ± 5s	Trial 1 / ±0.1℃	Trial 2 / ±0.1℃	Trial 3 / ±0.1℃	Trial 4 / ±0.1℃	Trial 5 / ±0.1℃	Average / ℃	Error / ±	Standard Deviation
60	24.9	25.2	23.8	23.6	23.5	24.2	0.9	0.793
120	24.1	23.7	24.3	24.9	24.0	24.2	0.6	0.500
180	22.9	23.5	23.9	23.1	23.1	23.3	0.5	0.440
240	24.7	25.4	25.5	24.9	25.5	25.2	0.4	0.386
300	23.2	24.4	24.5	23.8	23.6	23.9	0.7	0.600

Table 6: 80°C change in temperature over time at the bottom of the handle

Time ± 5s	Trial 1 / ±0.1℃	Trial 2 / ±0.1℃	Trial 3 / ±0.1℃	Trial 4 / ±0.1℃	Trial 5 / ±0.1℃	Average / ℃	Error / ±	Standard Deviation
60	24.1	25.1	24.9	24.0	24.9	24.6	0.6	0.510
120	25.1	25.5	26.1	26.0	25.3	25.6	0.5	0.440
180	24.6	24.3	25.7	25.1	24.8	24.9	0.7	0.534
240	25.3	24.7	24.6	25.9	25.0	25.1	0.6	0.520
300	23.9	24.3	25.0	24.8	23.5	24.3	0.8	0.620

Sample calculations for calculating the convection constant

$$\frac{T - T_\infty}{T_b - T_\infty} = \frac{\cosh m(L-x) + \left(\frac{h}{mk}\right)\sinh m(L-x)}{\cosh mL \ + \left(\frac{h}{mk}\right)\sinh mL}, m^2 = \frac{hP}{kA_c}$$

$$P = \pi D = \frac{1.7\pi}{100}, k = 0.15, A_c = \pi\left(\frac{D}{2}\right)^2 = \pi\left(\frac{1.7}{2\times 100}\right)^2, L = 0.269, T_\infty = 23℃, x = 0.269$$

$$\frac{T - 23}{T_b - 23} = \frac{\cosh m(0.269 - 0.269) + \left(\frac{h}{0.15m}\right)\sinh m(0.269 - 0.269)}{\cosh 0.269m \ + \left(\frac{h}{0.15m}\right)\sinh 0.269m}, m^2 = \frac{h\pi\left(\frac{1.7}{100}\right)}{0.15\pi\left(\frac{1.7}{2\times 100}\right)^2}$$

For the 40 degrees 60s calculation using the temperature at the top of the spoon and the temperature at the base.

$$T = 23.5, T_b = 26.6$$

$$\frac{23.5 - 23}{26.6 - 23} = \frac{1}{\cosh 0.269m \ + \left(\frac{h}{0.15m}\right)\sinh 0.269m}, m^2 = \frac{h\pi\left(\frac{1.7}{100}\right)}{0.15\pi\left(\frac{1.7}{2\times 100}\right)^2}$$

$$h = 0.061$$

Table 7: value of the respective convection constants (Note: those underlined and italicised are outliers and were not counted towards the average)

Time / s	**40℃**	**60℃**	**80℃**
60	0.061	0.064	0.051
120	*0.029*	0.071	0.039
180	0.048	*0.16*	0.063
240	0.035	0.048	0.063
300	0.055	*0.097*	*0.091*

Biot number calculations

$$L_c = 0.017$$

$$50 < h < 3000, 0.1, k < 0.2$$

$$Bi = \frac{hL_c}{k}$$

$$4.25 \le Bi \le 510$$

Uncertainty calculations for ln [15]

$$\delta ln(T) = \frac{error}{average}$$

Example calculation for 40 degrees at 60s

$$\delta ln(T) = \frac{1.4}{26.6} = \pm 0.05$$

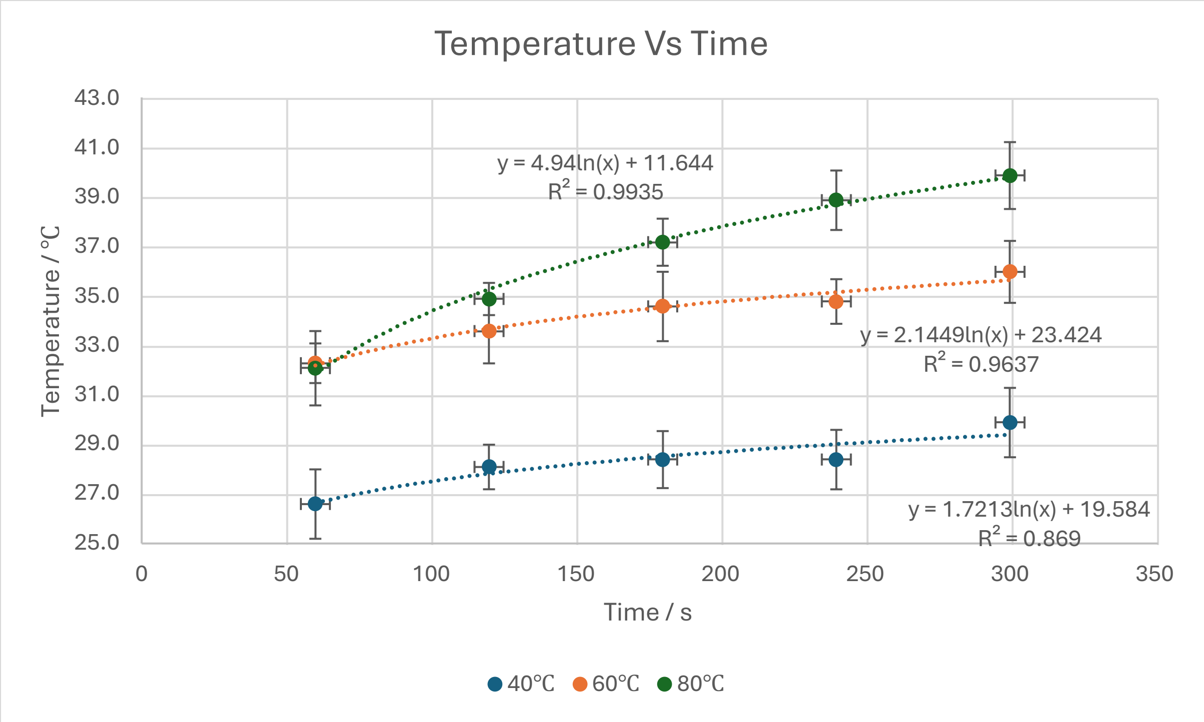


Figure 7: non linearised graph of the transient heat at the base of the handle of the wooden spoons for different temperatures of water

Table 8: Change in temperature at end of ladle handle

Time(s) ±3	Reading 1 / ±0.1℃	Reading 2 / ±0.1℃	Reading 3 / ±0.1℃	Reading 4 / ±0.1℃	Reading 5 / ±0.1℃	Mean / ℃	Error / ±	Standard deviation
0	25.9	26	26	25.9	25.7	25.9	0.15	0.012
10	26.1	26.2	26.1	26.3	25.9	26.1	0.2	0.018
20	27.3	26.9	27.2	27	26.6	27	0.35	0.06
30	25.4	25.7	25.1	25.2	25.6	25.4	0.3	0.052
40	24.5	25	25	25	24.5	24.8	0.25	0.06
50	25.9	25.8	25.6	25.8	25	25.6	0.45	0.106
60	25.4	25.7	25.4	25.9	25.7	25.6	0.25	0.038
70	25.1	25	25	25.3	25.1	25.1	0.15	0.012
80	26.3	26.3	26	26.4	26.5	26.3	0.25	0.028
90	26.2	26.2	26.4	26.2	25.6	26.1	0.4	0.074
100	25.2	25.3	25.4	25	25.6	25.3	0.3	0.04
110	24.8	24.8	24.5	24.5	24.9	24.7	0.2	0.028
120	24.6	24.6	24.7	24.7	24.9	24.7	0.15	0.012
130	25.6	25.1	25.1	25.1	25.6	25.3	0.25	0.06
140	25.3	25.1	25.2	25	25.4	25.2	0.2	0.02
150	25.1	25.1	25.4	25.1	25.9	25.3	0.4	0.098
160	24.7	24.8	25.1	24.7	25.2	24.9	0.25	0.044
170	24.8	24.4	24.9	24.6	24.4	24.6	0.25	0.042
180	24.8	24.6	24.6	24.2	24.3	24.5	0.3	0.048
190	24.6	24.5	24.6	24.5	25.4	24.7	0.45	0.118
200	25.5	25.5	25.3	25.7	25.9	25.6	0.3	0.042
210	24.9	24.8	24.9	24.7	25.2	24.9	0.25	0.028
220	25.3	25.6	25.2	25.4	25	25.3	0.3	0.04
230	25.6	25.9	25.7	25.6	26.2	25.8	0.3	0.052
240	27.5	27.1	27.6	27.1	27.7	27.4	0.3	0.064
250	25.5	25.3	25.5	25.7	25	25.4	0.35	0.056
260	25.1	25.3	25.4	25.3	25.3	25.3	0.15	0.01
270	24.7	25.2	24.9	25.1	24.6	24.9	0.3	0.052
280	25.2	25	25.3	25	25	25.1	0.15	0.016
290	25	24.8	25	24.9	24.2	24.8	0.4	0.09
300	24.9	24.8	25.1	24.9	24.3	24.8	0.4	0.072

Table 9: Change in temperature at end of spatula handle

Time (s) ±3	Reading 1 / ± 0.1℃	Reading 2 / ± 0.1℃	Reading 3 / ± 0.1℃	Reading 4 / ± 0.1℃	Reading 5 / ± 0.1℃	Mean / ℃	Error / $\pm$	Standard deviation
0	25.5	25.3	25.4	25.2	25.5	25.4	0.15	0.014
10	24.9	25.1	25	25.4	25.1	25.1	0.25	0.028
20	24.4	24.3	24.4	24	23.9	24.2	0.25	0.044
30	23.6	23.7	23.9	23.5	23.4	23.6	0.25	0.03
40	27	27	26.9	27.5	27.6	27.2	0.35	0.084
50	25.2	25.3	25	25.2	24.9	25.1	0.2	0.022
60	24	24.3	24.6	24.5	24.1	24.3	0.3	0.052
70	23.4	23.8	23.3	23.8	23.2	23.5	0.3	0.064
80	25.2	25.1	25	25.1	24.2	24.9	0.5	0.134
90	24.5	24.8	24.7	24.3	24.7	24.6	0.25	0.032
100	25.2	25.1	25.6	25.3	25.3	25.3	0.25	0.028
110	25.3	25.4	25.2	25.1	25.5	25.3	0.2	0.02
120	25.9	25.5	25.7	25.5	25.9	25.7	0.2	0.032
130	25.2	25.6	25.7	25.7	24.9	25.4	0.4	0.102
140	25.4	25.4	25.1	24.9	25.1	25.2	0.25	0.038
150	24.5	24.4	24.4	24.3	25.3	24.6	0.5	0.134
160	24.8	24.4	24.9	24.5	24.9	24.7	0.25	0.044
170	24.6	24.7	25	24.7	25.4	24.9	0.4	0.086
180	24.6	24.6	24.8	24.7	24.3	24.6	0.25	0.028
190	24.6	24.5	24.4	24.6	25.4	24.7	0.5	0.128
200	24.5	24.6	24.7	24.7	24.5	24.6	0.1	0.008
210	24.6	24.6	24.5	24.9	24.9	24.7	0.2	0.028
220	24.5	24.9	25	25	24.6	24.8	0.25	0.044
230	24.5	24.5	24.7	24.5	24.9	24.6	0.2	0.026
240	24.7	24.6	24.8	24.5	25.4	24.8	0.45	0.1
250	24.5	24	24.3	24.2	24.5	24.3	0.25	0.036
260	24	24.3	24.1	23.7	23.9	24	0.3	0.04
270	24.6	24.6	24.6	24.7	24.5	24.6	0.1	0.004
280	23.9	23.8	23.9	24.3	24.1	24	0.25	0.032
290	23.6	24	23.8	23.8	23.7	23.8	0.2	0.018
300	23.5	23.8	23.9	23.7	24.1	23.8	0.3	0.04

Surface area for spatula

Dimensions of head:

Width(w) = 8.9cm
Length(l) = 9.8cm
Thickness(t) = 0.2cm
Radius of holes(r_h) = 0.35cm

Front and Back surface area of spatula head:

$$A_f = wl = 8.9cm * 9.8cm = 87.42cm^2$$

$$A_B = A_f = 87.42cm^2$$

Surface area of side of spatula head:

$$A_s = 2wt + 2lt = 2 * 8.9cm * 0.2cm + 2 * 9.8cm * 0.2cm = 7.48cm^2$$

Area of one hole:

$$A_h = \pi r^2 = \pi 0.35^2 = 0.385cm^2$$

Surface area of inner edge of one hole

$$A_I = 2\pi rt = 2 * \pi * 0.35cm * 0.2cm = 0.44cm^2$$

Total surface area of spatula head:

$$A_{spat} = \left(A_f - 16A_h\right) + (A_B - 16A_h) + A_S + 16A_I = 177.04cm^2$$

Surface area of Ladle:

Dimensions of head:

Depth(D) = 5.9cm
Left to right radius(r_s) = 5.05cm
Front to back radius (r_l) = $5.2cm$

Outer surface area of ladle head:

$$A_O = 2\pi\left(\frac{(r_s \times r_l)^{1.6075} + (r_s \times D)^{1.6075} + (r_l \times D)^{1.6075}}{3}\right)^{\frac{1}{1.6075}} = 181.90cm^2$$

Inner surface area of ladle head:

$$A_I = 2\pi\left(\frac{((r_s - 0.2) \times (r_l - 0.2))^{1.6075} + ((r_s - 0.2) \times (D - 0.2))^{1.6075} + ((r_l - 0.2) \times (D - 0.2))^{1.6075}}{3}\right)^{\frac{1}{1.6075}} = 168.62cm^2$$

Surface area of side of ladle:

$$A_s = \Pi\pi r_l - \pi(r_s - 0.2)(r_l - 0.2) = 6.31cm^2$$

Total surface area of ladle head:

$$A_{lad} = A_O + A_I + A_S = 356.83cm^2$$

Volume of spatula head:

Volume of spatula head, not accounting for holes:

$$V_{rect} = wlt = 8.9cm \times 9.8cm \times 0.2cm = 17.44cm^3$$

Volume of one cylindrical hole:

$$V_{hole} = \pi r^2 t = \pi \times (0.35cm)^2 \times 0.2cm = 0.08cm^3$$

Total volume of spatula head:

$$V_{spat} = V_{rect} - 16V_{hole} = 16.16cm^3$$

Volume of ladle head:

Volume of a semi ellipsoid:

$$V_{full} = \frac{4}{3}\pi r_s r_l D = \frac{4}{3}\pi \times 5.05cm \times 5.2cm \times 5.9cm = 648.99cm^3$$

Volume of inner semi ellipsoid:

$$V_{inner} = \frac{4}{3}\pi(r_s - t)(r_l - t)(D - t) = \frac{4}{3}\pi \times 4.85cm \times 5cm \times 5.7cm = 579.00cm^3$$

Total volume of ladle head:

$$V_{lad} = V_{full} - V_{inner} = 69.99cm^3$$

Volume specific surface area of spatula head:

$$\omega_{spat} = \frac{A_{spat}}{V_{spat}} = \frac{177.04cm^2}{16.16cm^3} = 10.96cm^{-1}$$

Volume specific surface area of ladle head:

$$\omega_{lad} = \frac{A_{lad}}{V_{lad}} = \frac{177.04cm^2}{69.99cm^3} = 5.10cm^{-1}$$

Heat Flux calculation for ladle

$$\boldsymbol{q} = \frac{\boldsymbol{k_x A_x}(\Delta \boldsymbol{T})}{\boldsymbol{L_x}}$$

K_{lad} = 0.32W/m·k, $A_{lad} = \pi(\frac{d}{2})^2 = \pi(\frac{0.025}{2})^2 = 4.91 \times 10^{-4}m^2, L_{lad} = 0.227m$

$$\boldsymbol{q} = \frac{0.32 * 4.91 \times 10^{-4}(\Delta \boldsymbol{T})}{0.227}$$

$$q_{avg} = 0.015W$$

Heat flux calculation for spatula

$$q = \frac{k_x A_x (\Delta T)}{L_x}$$

K_{spat} = 0.26W/m·k, $A_{spat} = \pi(\frac{0.028}{2})^2 = 6.16 \times 10^{-4} m^2$, $L_{spat} = 0.273m$

$$q = \frac{0.26 * 6.16 \times 10^{-4} (\Delta T)}{0.227}$$

$$q_{avg} = 0.015W$$

Table 10: 60°C change in temperature over time at bottom of handle of stainless steel tongs

Time ± 5s	Trial 1 / ± 0.1℃	Trial 2 / ± 0.1℃	Trial 3 / ± 0.1℃	Trial 4 / ± 0.1℃	Trial 5 / ± 0.1℃	Average / °C	Error / ±	Standard deviation
60	44.2	43.6	46.1	47.5	46.1	45.5	2	1.583
120	49.3	48.1	50.1	49.5	49	49.2	1.1	0.735
180	57.9	57.4	58.1	58.9	59.2	58.3	0.9	0.738
240	54.7	56.2	56.8	58.6	57.2	56.7	2	1.425
300	58.7	58.9	60.2	59.7	59.5	59.4	0.8	0.608

Table 11: 60°C change in temperature over time at bottom of handle of insulated stainless steel tongs

Time ± 5s	Trial 1 / ± 0.1℃	Trial 2 / ± 0.1℃	Trial 3 / ± 0.1℃	Trial 4 / ± 0.1℃	Trial 5 / ± 0.1℃	Average / ± 0.1℃	Error / ±	Standard deviation
60	33	34.1	35.4	34.9	33.6	34.2	1.2	0.967
120	36.1	35.8	37.2	36.9	36	36.4	0.8	0.612
180	38.3	37.9	38.8	38.5	38	38.3	0.5	0.367
240	40.4	40.4	40.1	39.8	39.3	40	0.7	0.464
300	43.3	44.1	43.2	43.4	44.5	43.7	0.8	0.570

Insulated stainless steel tongs heat conduction constant calculations:

$$m = \rho_{Silicone} V = \rho_{Silicone} \times (L \times w \times T_h) = 1100 \frac{kg}{m^3} \times (0.02m \times 0.029m \times 0.006m) = 3.828 \times 10^{-3} kg$$

$$\frac{dT}{dt} = \frac{T_{Final} - T_{Initial}}{t} = \frac{43.7°C - 23°C}{300s} = 0.069 \frac{K}{s}$$

$$q = m \times c_{p-s} \times \frac{dT}{dt} = (3.828 \times 10^{-3} kg) \times (1050 \frac{J}{kg \cdot K}) \times (0.069 \frac{K}{s}) = 0.2773 \frac{J}{s}$$

$$\frac{dT}{dx} = \frac{T_{Final} - T_{Initial}}{d} = \frac{43.7°\boldsymbol{C}\ -\ \mathbf{23}°\boldsymbol{C}}{0.269m} = 79.95\frac{K}{m}$$

$$k = \frac{q}{A} \times \frac{dT}{dx} = \frac{0.2773\frac{J}{s}}{0.006m\ \times\ 0.029m} \times \frac{1}{79.95\frac{K}{m}} = 19.93\frac{W}{m \cdot K}$$

Stainless steel tongs heat conduction constant calculations:

$$m = \rho_{SS}V = \rho_{SS} \times (L \times w \times T_h)\ =\ 7930\frac{kg}{m^3} \times (0.02m \times 0.031m \times 0.001m)$$
$$= 4.9166 \times 10^{-3}kg$$

$$\frac{dT}{dt} = \frac{T_{Final} - T_{Initial}}{t} = \frac{59.4°\boldsymbol{C}\ -\ \mathbf{23}°\boldsymbol{C}}{300s} = 0.1213\frac{K}{s}$$

$$q = m \times c_{p-s} \times \frac{dT}{dt} = (4.9166 \times 10^{-3}kg) \times (490\frac{J}{kg \cdot K}) \times (0.1213\frac{K}{s}) = 0.292\frac{J}{s}$$

$$\frac{dT}{dx} = \frac{T_{Final} - T_{Initial}}{d} = \frac{59.4°\boldsymbol{C}\ -\ \mathbf{23}°\boldsymbol{C}}{0.32m} = 113.75\frac{K}{m}$$

$$k = \frac{q}{A} \times \frac{dT}{dx} = \frac{0.292\frac{J}{s}}{0.001m\ \times\ 0.031m} \times \frac{1}{113.75\frac{K}{m}} = 82.8\frac{W}{m \cdot K}$$

Stainless steel tongs heat conduction constant percent error calculation:

$$PE = \left|\frac{82.8\frac{W}{m \cdot K}\ -\ 16.2\frac{W}{m \cdot K}}{16.2\frac{W}{m \cdot K}}\right| \times 100\%\ =\ 411.1\%\ error$$