

Pressure-Enhanced Close-Contact Melting in Phase-Change Materials: An Investigation of Butter as a Thermal Management Solution

Guangxi Lucas Sun

*Chinese International School, Hong Kong SAR, China
lucas.gx.sun@gmail.com*

Abstract. Phase-change materials (PCMs) are a viable alternative for thermal management and thermal energy storage systems because of their potential to store large amounts of energy in the form of latent heat. This study investigates the pressure-enhanced close-contact melting phenomenon observed in everyday materials such as butter, where applied pressure significantly accelerates the melting process. To experimentally validate this concept and to better understand the underlying physical mechanism, a dedicated test setup was designed and developed. The results confirm that the PCM can reach a quasi-steady temperature plateau under applied pressure and suggest that, under the specific experimental and COMSOL benchmark conditions used in this study, pressure-enhanced close-contact melting exhibits an order-of-magnitude shorter apparent melting timescale than the traditional PCM configuration simulated in COMSOL. Moreover, the heat-source temperature is robustly correlated with the applied pressure. To investigate the correlation among material properties, heat flux, applied pressure, and steady-state temperature, a comprehensive physical model is derived using Fourier's law of one-dimensional conduction, the Navier–Stokes equations, and energy-conservation laws. The analysis demonstrates that pressure-enhanced close-contact melting not only accelerates the phase transition of butter but also stabilizes the heat-source temperature over a finite quasi-steady melting period.

Keywords: Phase change material, close-contact melting, heat transfer, latent heat, heat conduction

1. Introduction

The initial motivation for this research emerged from observing an unexpected phenomenon during food preparation. When butter was applied against a heated surface under pressure, it melted significantly faster than usual. This observation suggested that mechanical pressure could potentially accelerate phase transitions, presenting a novel mechanism that might improve PCM performance.

Despite their widespread adoption, traditional thermal management solutions face increasing challenges. As modern hardware improves, its heat density increases correspondingly, requiring increasingly complex active cooling systems [1-3]. This complexity leads to high costs in

manufacturing, installation, and maintenance. Thus, passive and reliable solutions are increasingly important for enabling higher-performance systems.

Phase-change materials (PCMs) are a promising approach for passive thermal management [4]. For common materials, the latent heat significantly exceeds the sensible heat [5]. PCMs take advantage of this property by utilizing phase transitions as the primary energy storage mechanism. Additionally, when applied to thermal management applications, the rate of device temperature rise decreases as the PCM absorbs heat. A typical application for PCM cooling is a thermal buffer that can flatten the transient high thermal load from the device, automatically regulating thermal conditions [6].

However, current PCM applications are constrained by key physical limitations. Most PCMs have a low thermal conductivity, resulting in poor heat transfer rate [4, 7]. As the melt front moves away from the heat source, thermal resistance increases, degrading performance throughout the melting process. Conventional solutions use fins, heat pipes, or nanoparticle additives, which significantly increase costs, introduce failure modes, and impose design constraints that limit scalability [5].

Existing studies exhibit two key limitations. First, investigations of PCM systems focus primarily on synthetic materials [8, 9] rather than organic alternatives, which possess a different set of tradeoffs. Second, most research focuses on passive solutions [10] without exploring active alternatives. This creates a significant research gap, as no studies have investigated pressure-enhanced melting in organic PCMs, despite the potential for such systems to overcome traditional thermal conductivity limitations through continuous melt front renewal.

This research addresses these gaps by investigating pressure-enhanced close-contact melting in butter as a model organic PCM, developing theoretical understanding of the physical mechanisms behind this process, and validating performance through experimental measurement. Specific goals include experimentally quantifying the relationship between steady-state behavior, applied pressure, and heat flux, developing a physics-based model to explain the resulting behavior, and comparing thermal transfer efficiency with traditional PCM methods through both experimental validation and numerical simulation.

2. Experimental methodology

To quantify pressure-enhanced melting behavior, a controllable apparatus was developed to measure the steady-state temperature response under varying pressure and heat flux conditions.

2.1. Material properties

The butter sample is cut to dimensions of 5.5 cm × 5.5 cm × 3 cm (width × length × height), providing a cross-sectional area of 30.25 cm² that matches the heating plate area. Additional thermodynamic properties are obtained from both the internet and existing literature.

$$T_{melt} = 32^{\circ}C$$

$$k = 0.2 \text{ W}/(\text{m} \cdot \text{K}) \quad [11]$$

$$\rho_s = 0.911 \text{ g}/\text{cm}^3 \quad [12]$$

$$C_{ps} = 2.04 \text{ kJ}/(\text{kg} \cdot \text{K}) \quad [13]$$

$$u_l = 42 \text{ cP (at } 43^\circ\text{C)}, \quad u_l = 20 \text{ cP (at } 65^\circ\text{C)} \quad [14, 15]$$

$$h_{latent} = 71 \text{ J/g} \quad [16]$$

2.2. Experimental apparatus

The complete apparatus design (Figure 1a) and implementation (Figure 1b) are shown in Figure 1. The system consists of four primary components: a pressure application system, a heating system, a measurement system, and a containment system.

Pressure Application: The pressure system utilizes a piston with cross-sectional area matching the butter sample to ensure uniform loading. Calibrated steel weights (100 g $\pm$ 0.1 g each) are stacked on the piston, applying controlled pressures from 0 to 3000 Pa in 327 Pa increments.

Heating System: An insulated heating plate provides controlled thermal input at power levels of 28 W, 55 W, and 150 W, which correspond to heat fluxes of 0.93 W/cm², 1.83 W/cm², and 5 W/cm² respectively.

Measurement System: A Type-T thermocouple ($\pm 1^\circ\text{C}$) mounted on the heating surface measures source temperature, with data recorded at 10 Hz using a digital data logger ($\pm 0.1^\circ\text{C}$ accuracy). Video documentation captures the melting process for qualitative analysis of melt-front progression and flow behavior.

Containment: Vertical guide rails prevent lateral movement while allowing molten butter drainage, ensuring continuous melt front renewal.

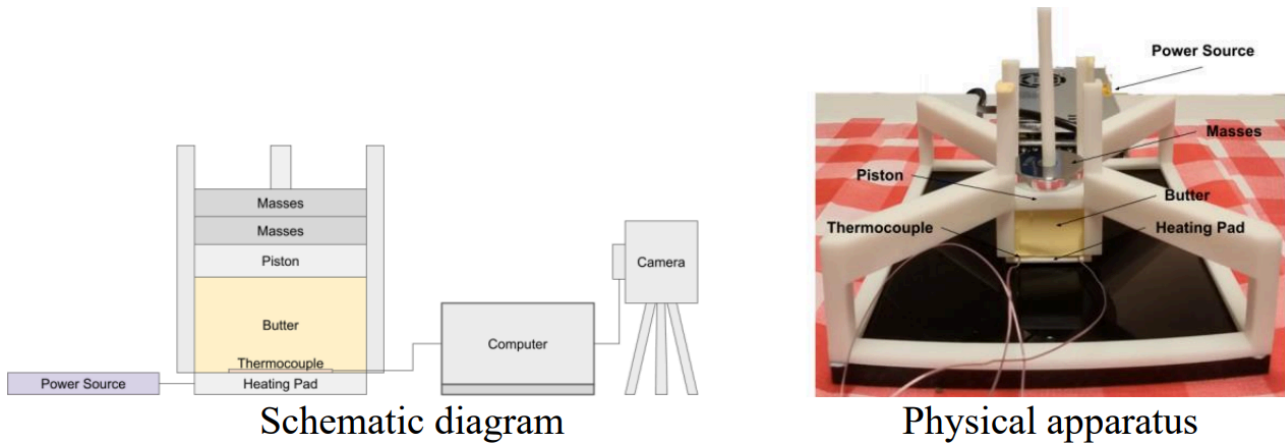


Figure 1. Experimental setup showing (a) schematic design and (b) constructed apparatus

2.3. Experimental procedure

Each test follows a standardized protocol: (1) position the butter sample on the heating plate with complete surface contact, (2) apply the specified pressure via weights, (3) allow thermal equilibration ($\pm 1^\circ\text{C}$ stability for 30 seconds), (4) initiate heating with continuous temperature recording, and (5) conclude the test when the quasi-steady temperature plateau ends or the sample is fully consumed.

2.4. Test matrix

The test conditions investigated are shown in Table 1.

Table 1. Test matrix

Heat Flux \ Pressure	327 Pa	980 Pa	1630 Pa	2940 Pa
0.93 W/cm ²		√		
1.83 W/cm ²		√		
5 W/cm ²	√	√	√	√

3. Results

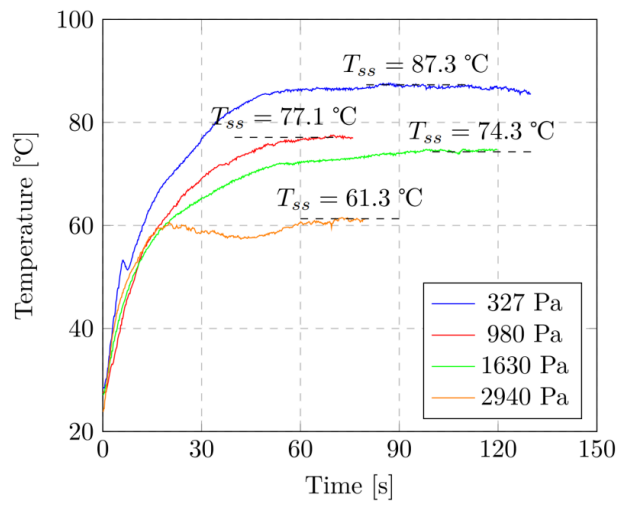


Figure 2. Temperature vs. time with varying pressures (constant 5 W/cm² heat flux)

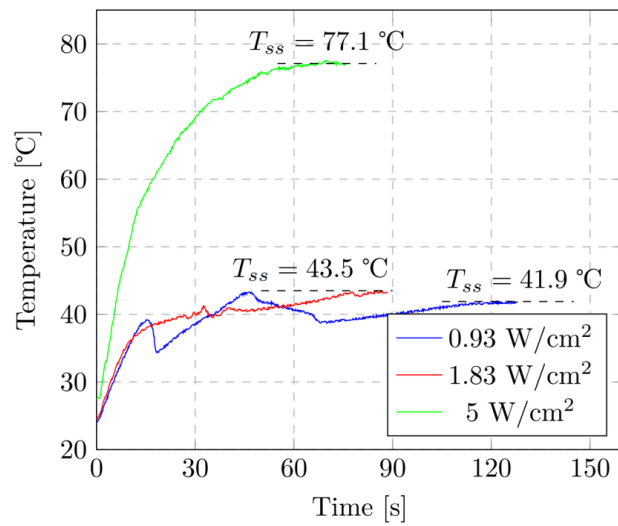


Figure 3. Temperature vs. time with varying heat fluxes (constant 980 Pa pressure)

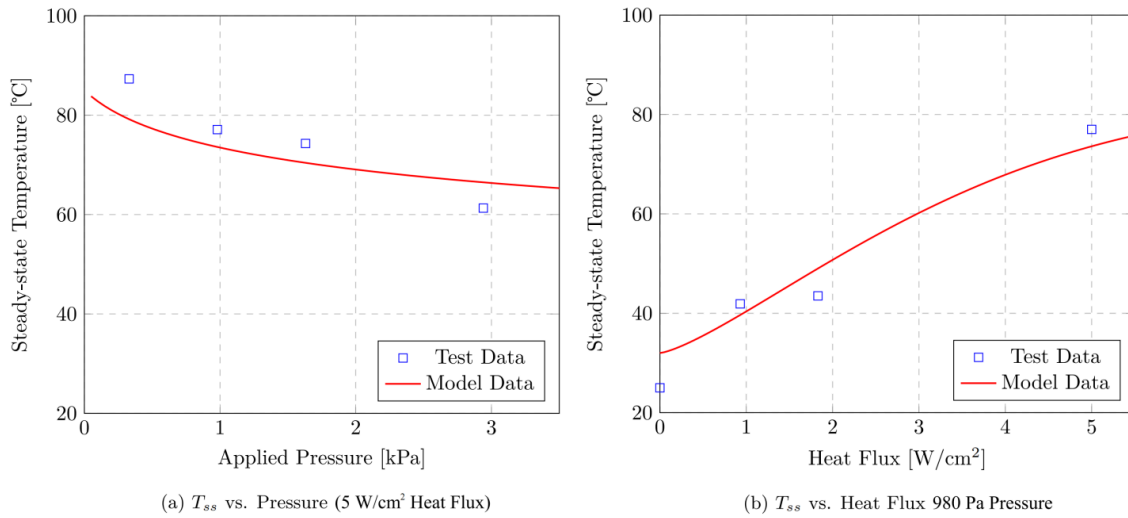


Figure 4. Steady-state temperature (T_{ss}) vs. (a) applied pressure and (b) heat flux

Tests were conducted for all combinations shown in Section 2.4. During the data collection process, it was qualitatively observed that the butter's melting speed increased when more pressure was applied. Unexpectedly, in every test, the surface temperature initially rose rapidly, but the rate of increase slowly decreased until a steady-state plateau was reached. Figures 2 and 3 show the temperature vs. time curves for various pressures and heat fluxes. Using the formula for pressure, the 100 g load corresponds to 327 Pa in the present setup, and the 900 g load to 2940 Pa, with the intermediate masses following the same linear relation.

The steady-state temperature (T_{ss}) was obtained by averaging the y-values in the plateau area, and these steady-state temperatures are plotted as functions of the pressure and heat flux in Figure 4. Figure 4a shows that a higher pressure correlates to a lower steady-state temperature, demonstrating the efficacy of pressurizing the PCM in lowering heat-source temperature. Physically, the elevated pressure squeezes the molten butter out faster, and thus thins the liquid film separating the heated surface from the solid PCM. With a thinner film, the thermal resistance drops, so heat is transferred more efficiently (as predicted by Fourier's law, Equation 18).

Figure 4b shows that a higher heat flux correlates to a higher steady-state temperature. The slope of the trend line is quite low, showing that the constant 300 g pressure helps limit temperature even at higher heat fluxes, compared with traditional PCMs that may not even reach a quasi-steady temperature plateau at similar heat fluxes. This upward trend is consistent with one-dimensional conduction. Because all supplied energy is absorbed by the butter, an increase in the heat flux must be balanced by a proportional increase in the temperature difference across the melt layer. As long as the molten-film thickness remains roughly constant, Fourier's law (Equation 18) predicts that the heat-source temperature must climb accordingly.

The observed relationships among the steady-state temperature, the pressure and the heat flux seem to be robust, raising the important question of whether these trends can be predicted using a physical-mathematical model.

4. Physical model derivation

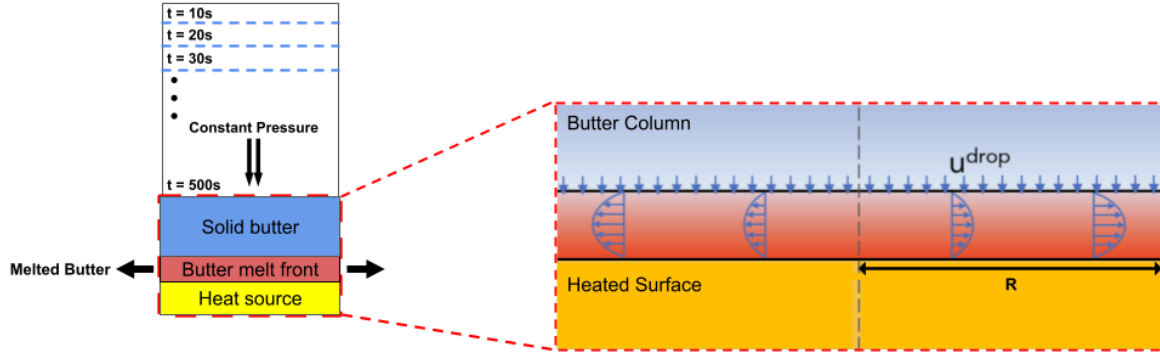


Figure 5. Diagram visualizing the developed mathematical model for pressurized PCMs

The experimental observations are now cast into a concise physical–mathematical framework.

Figure 5 depicts the idealized domain: a molten layer of thickness δ beneath a cylindrical PCM sample of effective radius R . Cylindrical coordinates (r, θ, z) are used, with $z = 0$ at the heated surface and z positive upward. Even though melting continuously replenishes the liquid layer, the slow time-scale renders the hydrodynamics identical to the classical squeeze-flow problem. The liquid is assumed incompressible, axisymmetric, and thin ($\delta \ll R$).

The starting point is the simplified equation for conservation of mass, also known as the continuity equation in cylindrical coordinates:

$$\frac{1}{r} \frac{\partial}{\partial r} (ru_r) + \frac{\partial u_z}{\partial z} = 0 \quad (1)$$

The momentum equations in the z and θ directions reduce to trivial identities. The only nontrivial balance is in the radial direction, which simplifies to:

$$-\frac{\partial p}{\partial r} + \mu_l \frac{\partial^2 u_r}{\partial z^2} = 0 \quad (2)$$

The applied boundary conditions are as follows:

$$\begin{aligned} u_r(r, 0) &= 0, & u_r(r, \delta) &= 0, \\ u_z(r, 0) &= 0, & u_z(r, \delta) &= -u, \\ u_r(0, z) &= 0. \end{aligned} \quad (3)$$

where u is the speed of the PCM column moving towards the heater surface, as shown in Figure 5.

As $\frac{\partial p}{\partial r} = \frac{dp}{dr}$, the r -momentum equation can be integrated with respect to z :

$$u_r(r, z) = \frac{1}{2\mu_l} \frac{dP}{dr} z(z - \delta) \quad (4)$$

Substituting Equation 4 for u_r in the simplified mass conservation equation Equation 1, and integrating along z twice, the following is obtained:

$$u = -\frac{\delta^3}{12\mu_l} \frac{1}{r} \frac{d}{dr} \left(r \frac{dP}{dr} \right) \quad (5)$$

Integrating twice along r , the following is obtained:

$$P(r) = \frac{3\mu_l u}{\delta^3} (R^2 - r^2) + P_0 \quad (6)$$

where P_0 is the atmospheric pressure. The mean gauge pressure is thus:

$$P = \frac{3R^2\mu_l u}{2\delta^3} \quad (7)$$

This matches the classic squeeze-flow result. By mass conservation, the melting speed u relates to the melt rate $\dot{m}$ as:

$$\rho_s \pi R^2 u = \dot{m} \quad (8)$$

An energy balance yields the melt rate:

$$\dot{m}[L + C_{p,s}(T_m - T_i)] = \dot{Q} = \pi R^2 q'' \quad (9)$$

where L is the latent heat of fusion, $C_{p,s}$ the specific heat capacity of the solid PCM, T_m the melting temperature, T_i the initial PCM temperature, and $\dot{Q}$ the heat-flow rate. It is assumed that all of the heat goes into melting of the PCM. Then, the downward speed u of the solid PCM is:

$$u = \frac{\dot{m}}{\rho_s \pi R^2} = \frac{q''}{\rho_s [L + (T_m - T_i) c_{p,s}]} \quad (10)$$

Substituting Equation 10 into Equation 7, the applied pressure P can be expressed in terms of the heat flux q'' :

$$P = \frac{3R^2\mu_l}{2\delta^3} \cdot \frac{q''}{\rho_s [L + c_{p,s}(T_m - T_i)]} \quad (11)$$

For the square-base samples used in the experiments (side length w), the cylinder radius R is replaced with an equivalent length scale $R_{eq} = w$.

$$P \propto \frac{w^2\mu_l u}{\delta^3} \quad (12)$$

The proportionality factor is different for square samples compared with circular samples. Since the solutions for pressurized PCM flow are identical to squeeze-flow, the squeeze-flow solution for square plates is considered:

$$\frac{P\delta^3}{w^2\mu_l u} = \frac{4}{\pi^2} \sum_k \sum_l \frac{1}{kl} B_{k,l} \quad (13)$$

with

$$B_{k,l} = \frac{192}{\pi^4 kl(k^2 + l^2)} \quad k, l = 1, 3, 5 \dots \infty \quad (14)$$

The summation was calculated with decimal precision of 28 significant digits for $k, l \in \{1, 3, 5 \dots, 99999\}$. The proportionality factor was found to be 0.4217310, giving

$$P = 0.42 \frac{w^2 \mu_l u}{\delta^3} \quad (15)$$

Substituting Equation 10 into Equation 15, the following is obtained:

$$P_W = 0.42 \frac{w^2 \mu_l}{\delta^3} \cdot \frac{q''}{\rho_s [L + c_{p,s} (T_m - T_i)]} \quad (16)$$

and hence

$$\delta = \sqrt[3]{\frac{0.42 w^2 \mu_l q''}{P [\rho_s L + (T_m - T_i) \rho_s c_{p,s}]}} \quad (17)$$

Although δ can be derived from q'' , the melt layer is so thin that experimentally measuring δ to infer q'' is impractical. Instead, the steady-state temperature difference across the layer, $T_{ss} - T_m$, is related to the layer thickness via one-dimensional conduction:

$$q'' = k_l \frac{T_{ss} - T_m}{\delta} \quad (18)$$

Substituting Equation 16 into Equation 18 and rearranging, the following is obtained:

$$q'' = 1.24 [k_l (T_{ss} - T_m)]^{3/4} \left[\frac{\rho_s [L + (T_m - T_i) c_{p,s}] P}{w^2 \mu_l} \right]^{1/4} \quad (19)$$

$$T_{ss} = T_m + 0.75 k_l^{-1} (q'')^{4/3} \left[\frac{\rho_s [L + (T_m - T_i) c_{p,s}] P}{w^2 \mu_l} \right]^{-1/3} \quad (20)$$

Thus, a predictive model for pressurized PCM performance is obtained via Equation 19 and Equation 20, where any of the three variables (q'' , T_{ss} or P) can be determined if the other two variables are known.

5. Model validation

Hence, given the thermodynamic properties of a PCM, a predictive model is available that relates the three different parameters: steady-state temperature, heat flux and applied pressure. Once any two parameters are known, the remaining one can be computed.

This model is implemented in Engineering Equation Solver (EES) and used to predict the experimental results. The full EES code can be found in Appendix A. The model predictions are compared with the experimental results as shown in Figure 4, demonstrating the model's predictive capabilities and accuracy and validating the physical model.

Figure 4a plots both the model and experimental data at the same heat flux of 5 W/cm² for various applied pressures. At a lower pressure, the model is under-predicting the temperature. This apparent contradiction arises from a simplifying assumption in the model: it was presumed that the solid butter would melt into a single, uniform liquid layer separating the unmelted solid from the heat source. In reality, only a portion of the butter liquefies, and the remaining butter is softened solid butter that is expelled along with the liquid butter. Hence, both its viscosity and its thickness have been underestimated, which affects the calculations derived from Equation 17. By Fourier's

law, underestimating the liquid-layer thickness results in underestimating the thermal resistance, yielding the lower temperature results in Figure 4a at lower pressures. However, at higher applied pressures, the model overestimates the temperature, as seen in Figure 4a. This is likely a result of experimental error, as uncontrolled molten butter may overflow and cover the side of the heating surface, thus extending the contact area and further cooling the surface. Nevertheless, the maximum percentage difference between model prediction and the measured heat-surface temperature is still less than 10%, demonstrating a strong fit between the model and the test data despite these inconsistencies. Figure 4b plots the model and test data at a constant pressure of 980 Pa. In this case, the model fits the data well, and the maximum percentage difference is less than 5% when computed using absolute temperature in kelvin. The zero-heat-flux point represents a non-melting boundary condition and is not part of the melting-model validation.

6. COMSOL Multiphysics model

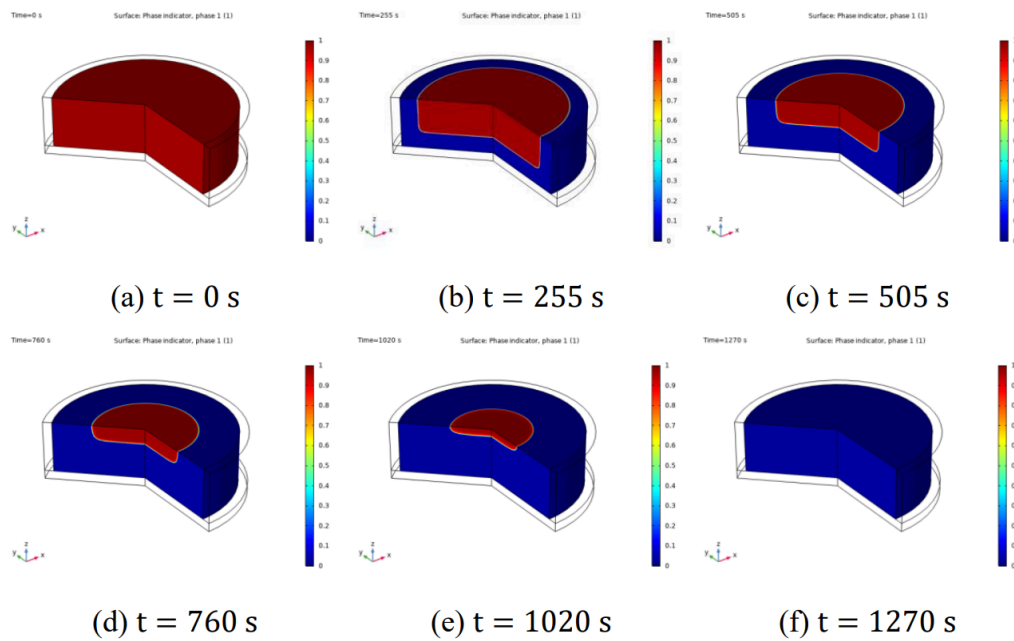


Figure 6. Phase indicator of butter using traditional PCMs in a COMSOL simulation

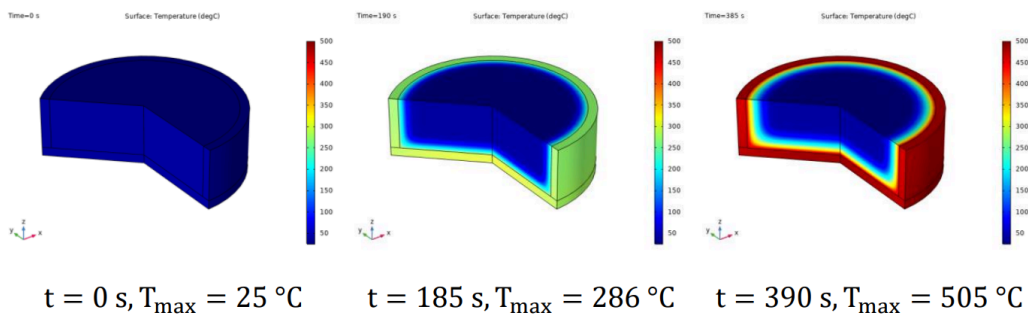


Figure 7. Temperature of butter and container using traditional PCMs in a COMSOL simulation

COMSOL Multiphysics was used to build a model representing traditional PCM methods. COMSOL includes a physical module capable of simulating phase-change materials by assuming non-linear enthalpy change during the phase-change process, where the phase-change interval is a

user-defined parameter. A phase-change interval of 5 °C was used for butter in the simulations. Other thermal properties of butter used in the simulation can be found in Section 2.1. The thermal storage system was simplified as a cylindrical aluminum container with inner radius 5 cm, inner height 3 cm, and wall thickness of 0.5 cm enclosing the butter PCM, and the initial temperature was set to 25 °C. A constant heat-flux boundary condition was applied at the bottom of the aluminum container, and natural convection was applied on the top and side container surfaces with heat-transfer coefficient $h = 5 \text{ W}/(\text{m}^2 \cdot \text{K})$.

To compare traditional PCMs with pressurized PCMs, a matching heat flux of $5 \text{ W}/\text{cm}^2$ is used in COMSOL to simulate a traditional thermal energy-storage configuration. Figure 6 shows the phase indicator of the PCM at various time steps. The phase indicator represents the phase state of the material, with 1 (red) representing a solid state and 0 representing a liquid state. As seen from the images, the butter fully melts after around 20 minutes, far exceeding the timescale of less than 1 minute required for the pressurized PCM. Furthermore, Figure 7 shows the temperature of the butter along with the maximum temperature of the thermal-storage system. As seen from the images, the heat-source temperature rises to above 500 °C within 7 minutes and does not stabilize at any point. By contrast, the pressurized PCM is able to melt within 1 minute and maintain a quasi-steady temperature plateau over the melting interval. Under the specific experimental and COMSOL benchmark conditions used in this study, the pressurized configuration exhibits an order-of-magnitude shorter apparent melting timescale than the traditional PCM case.

These observations arise from the limitations of the traditional PCM configuration used here. Conventional thermal storage systems typically use extended surface areas to enhance heat transfer, meaning there are more tubes, fins, and similar structures that incur additional material costs and occupy volumetric space for PCMs. However, when heated, the molten PCM builds up between the solid PCM and the heat source, quickly increasing the thermal resistance and reducing heat-transfer efficiency. In contrast, pressurized PCMs continuously push the liquid PCM out, thus minimizing thermal resistance. Under the present comparison conditions, the pressurized configuration not only increases the apparent melting speed by roughly an order of magnitude but also reduces reliance on added surface-area extension structures.

This differs from many previous PCM cooling approaches, which primarily functioned as thermal buffers for transient high thermal loads rather than maintaining a quasi-steady temperature plateau during continued melting. This study presents a promising way of utilizing PCMs in cooling applications that can both sustain a quasi-steady temperature response during the melting interval and deal with extreme heat fluxes.

7. Conclusion

In this paper, the pressurized melting phenomenon was investigated using butter as a model PCM. An experimental apparatus and procedure were developed to test this phenomenon, and a test matrix was constructed to systematically evaluate various parameter combinations. It was found that the heat-source temperature could be stabilized during the butter phase-change process, and that there was a robust correlation between steady-state temperature and both heat flux and pressure. A mathematical model was derived to explain the relationship and validated against the experimental data. Finally, to compare pressurized close-contact melting and a traditional PCM configuration, the latter was simulated in COMSOL, and it was found that, under the specific experimental and COMSOL benchmark conditions used in this study, the pressurized configuration exhibited an order-of-magnitude shorter apparent melting timescale.

References

- [1] Fang, Y., Liu, T., & Sun, D. (2024). Research on novel thermal management technology in the field of integrated circuits. In *2024 25th International Conference on Electronic Packaging Technology (ICEPT)* (pp. 1–6). doi: 10.1109/ICEPT63120.2024.10668500.
- [2] Lv, Y.-G., Zhang, G.-P., Wang, Q.-W., & Chu, W.-X. (2022). Thermal management technologies used for high heat flux automobiles and aircraft: A review. *Energies*, 15(21). doi: 10.3390/en15218316.
- [3] Saber, N., Richter, C. P., & Unnthorsson, R. (2025). Review of thermal management techniques for prismatic li-ion batteries. *Energies*, 18(3). doi: 10.3390/en18030492.
- [4] White, M. A., Kahwaji, S., & Noël, J. A. (2024). Recent advances in phase change materials for thermal energy storage. *Chem. Commun.*, 60, 1690–1706. doi: 10.1039/D3CC06063B.
- [5] Fikri, M. A. et al. (2023). Enhanced thermal properties of phase change materials through surfactant-functionalized graphene nanoplatelets for sustainable energy storage. *Energies*, 16(22). doi: 10.3390/en16227668.
- [6] Galazutdinova, Y., Al-Hallaj, S., Grágeda, M., & Ushak, S. (2020). Development of the inorganic composite phase change materials for passive thermal management of li-ion batteries: Material characterization. *International Journal of Energy Research*, 44(3), 2011–2022. doi: <https://doi.org/10.1002/er.5054>.
- [7] Messenger, M. A., Manglik, R. M., & Boetcher, S. K. S. (2024, March). Thermal energy storage heat exchanger design: Overcoming low thermal conductivity limitations of phase-change materials. *ASME Journal of Heat and Mass Transfer*, 146(5), 054501. <https://doi.org/10.1115/1.4064563>
- [8] Qin, M., Shen, Z., Xiong, F., Han, S., & Zou, R. (2023). Toward high-power and high-density thermal storage: Dynamic phase change materials. *ACS Energy Letters*, 8(8), 3552–3557. <https://doi.org/10.1021/acsenenergylett.3c01222>
- [9] Fu, W., Yan, X., Gurumukhi, Y., Garimella, V. S., King, W. P., & Miljkovic, N. (2022). High power and energy density dynamic phase change materials using pressure-enhanced close contact melting. *Nature Energy*, 7, 270–280. <https://doi.org/10.1038/s41560-022-00986-y>
- [10] Kozak, Y. (2022). Theoretical analysis of close-contact melting on superhydrophobic surfaces. *Journal of Fluid Mechanics*, 943, A39. <https://doi.org/10.1017/jfm.2022.458>
- [11] Foods – thermal conductivities. (n.d.). *The Engineering ToolBox*. https://www.engineeringtoolbox.com/food-thermal-conductivity-d_2177.html
- [12] Density of butter. (2012). *kg-m3.com*. <https://kg-m3.com/material/butter>
- [13] Estimate the thermal diffusivity of butter at 20 °c. (n.d.). *Bartleby*. <https://www.bartleby.com/questions-and-answers/estimate-the-thermal-diffusivity-of-butter-at-20c.-density-of-butter-911kgm3-specific-heat-2.04-kjkg/9296c814-d8ca-4883-90e2-9c3ebc9532a7>
- [14] Centipoise to pascal-second (cP → pa·s) — viscosity converter. (n.d.). *UnitConverters.net*. <https://www.unitconverters.net/viscosity-dynamic/centipoise-to-pascal-second.htm>
- [15] Chemical-compound liquid viscosity data chart. (n.d.). *PowderProcess.net*. https://powderprocess.net/Tools_html/Data_Diagrams/Chemical_Compound_Liquid_Viscosity.html
- [16] Jordan, W. P., & Helmer, W. G. (1966). Viscosity of butter and butterfat solutions. *Journal of Dairy Science*, 49(8), 997–1001. [https://doi.org/10.3168/jds.S0022-0302\(66\)88097-9](https://doi.org/10.3168/jds.S0022-0302(66)88097-9)

Appendix A Engineering Equation Solver (EES) code

$$a^3 = 0.4217 * w^2 * u * q / (\rho_s * (h_l + C_{ps} * (T_m - 25)) * P)$$

"a: thickness/height of the melt-film [m]"

"w: cross-sectional width of the square PCM [m]"

"u: liquid dynamic viscosity of the PCM [Pa*s]"

"q: heat flux of the heating pad [W/cm^2]"

"rho_s: density of the solid PCM [kg/m^3]"

"h_l: latent heat of the PCM [J/kg]"

"C_ps: heat capacity of the solid PCM [J/kg-K]"

"T_b: temperature of the PCM [C]"

"P: applied pressure [Pa]"

"T_ss is the steady-state temperature of the heated surface [C]"

"Butter PCM Properties:"

T_m = 32 [C]

w = 0.055 [m]

k = 0.2 [W/m-K]

rho_s = 911 [kg/m^3]

C_ps = 2040 [J/kg-K]

h_l = 71000 [J/kg]

"Physical Relations:"

T_b = (T_ss+T_m)/2 [C]

u = max((85-T_b)/1000, 0.001) [Pa*s] "Butter's viscosity (approx.; clamp avoids nonphysical negative values)"

q = k*(T_ss-T_m)/a "1D conduction equation"

"Input values (pressure P and heat flux q):"

$$q = 1.833 \quad [\text{W}/\text{cm}^2]$$

$$P = 980 \quad [\text{Pa}]$$