Phone Case Heat Dissipation Analysis

ME315 Project by:
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Introduction: Heat Dissipation in Phones

- Phones are designed with heat dissipation in mind

- Cases and covers affect the designed dissipation abilities

Objective

- To study how the addition of a phone case or skin affects the rate of heat loss from the phone via all three modes of heat transfer

- Doing so helps in understanding whether adding a case/skin benefits or hinders heat dissipation

Method: Heating the Phone

The phone was heated screen-side-up using a heat lamp until the back side measured 60 ^{o}C.

This was to make sure that every trial would have a consistent amount of thermal energy added to the system.

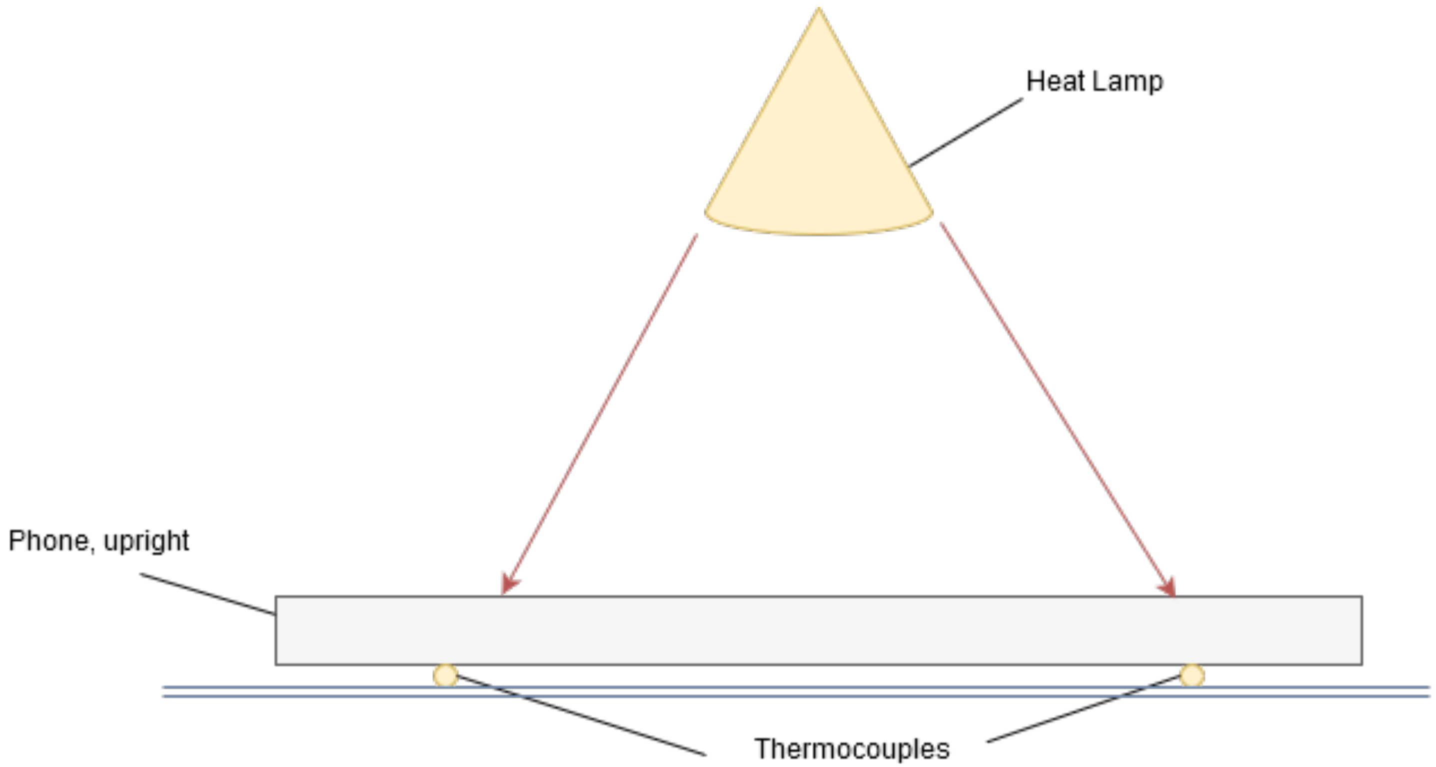
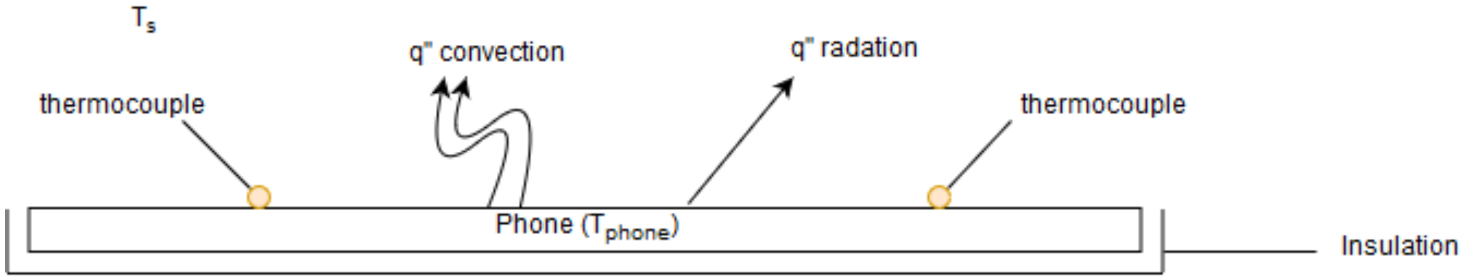


Figure: Diagram of experimental setup for heating up the phone.

Method: Monitoring Rate of Head Dissipation

- The phone was then placed screen down in the foam case, insulating it from all sides except the back.
- Thermocouples on the back of the phone monitor the temperatures at multiple points on the phone during the cooling process, until it reached steady state.

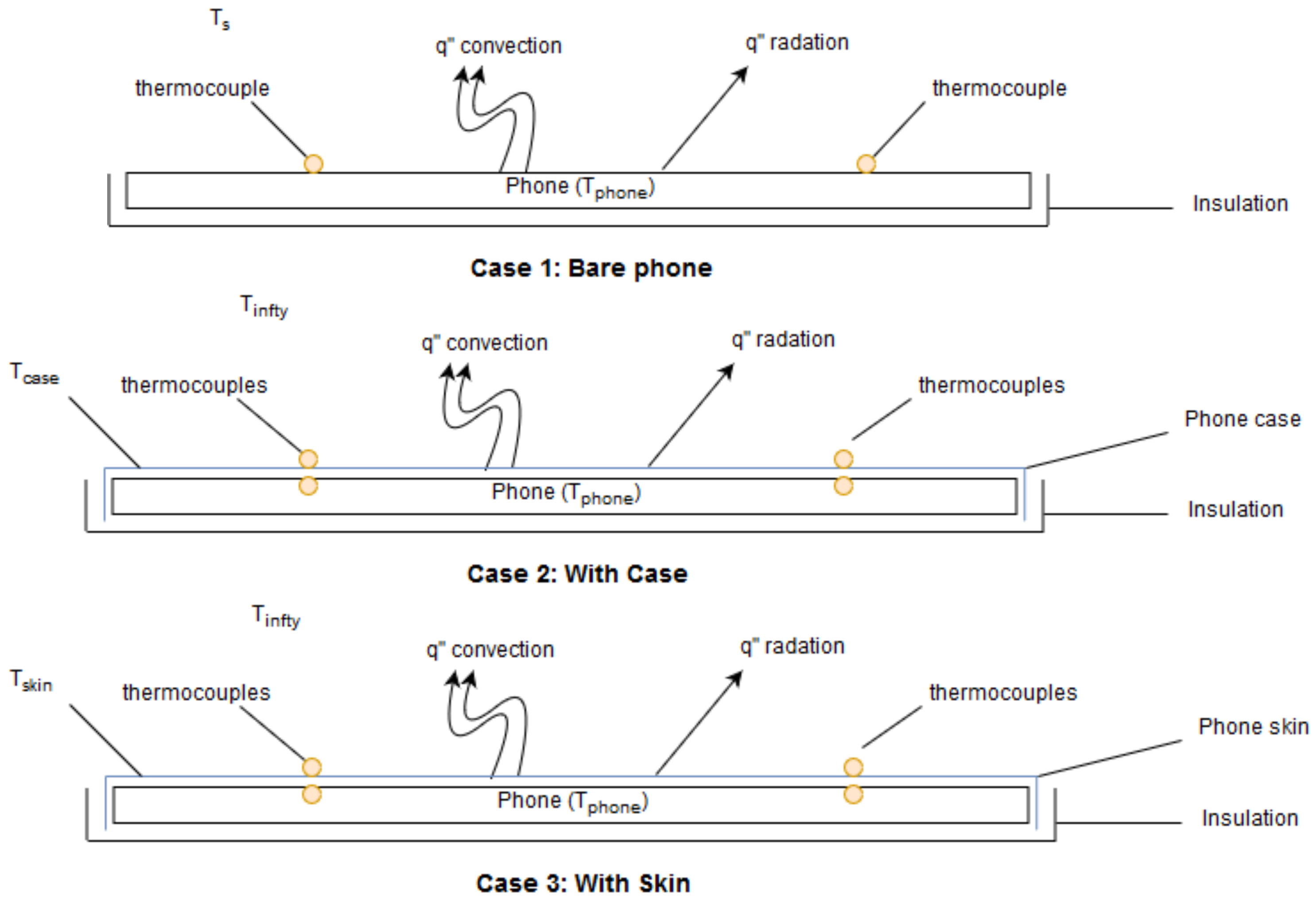


Case 1: Bare phone

Method: Three Different Cases

- The process was repeated with the following individual additions to the phone:
  - Silicon case
  - Matte black vinyl skin
- Extra thermocouples were added to the system to monitor the temperatures of the case and the skin in the separate cases.

Analysis: Schematics



Analysis: Governing Equation (Bare Phone)

$$\dot{E}_{stored} = \dot{E}_{in} - \dot{E}_{out} + \dot{E}_{generated}$$
$$V_{phone}C_{phone}\frac{dT}{dt} = -q_{conv} - \sigma\varepsilon A(T_s^4 - T_\infty^4)$$

- Assumptions
  - Insulated on sides
  - No heat generation
  - Square plate
  - Uniform temperature
  - Gray body
- Knowns
  - Heat Capacity of phone
  - Dimensions
  - Emissivity
  - Temperature data

Analysis: Governing Equation (w/Case, w/Skin)

$$\dot{E}_{stored} = \dot{E}_{in} - \dot{E}_{out} + \dot{E}_{generated}$$

$$V_{phone} C_{phone} \frac{dT}{dt} = q_{cond,exp}$$

$$V_{case} C_{case} \frac{dT}{dt} = q_{cond,exp} - q_{conv,exp} - \sigma \varepsilon A (T_s^4 - T_\infty^4)$$

$$q_{cond,th} = k_{case} A \left(T_{phone} - T_s\right)$$

- Assumptions
  - Insulated on sides
  - No heat generation
  - Square plate
  - Uniform temperatures
  - Gray body
  - 1-D Conduction
- Knowns
  - Heat Capacity of phone
  - Dimensions
  - Emissivity
  - Temperature data
  - Convective coefficient
  - Case properties

Result Validation: Calculating h and C_{phone}

- To calculate C_{phone}, Colorado University Study was used
  - Provided data of multiple phone components capacities
- Calculated the aluminum heat capacity
- Averaged everything
  - Around the same magnitude
- $C_{phone} = \sim 2 \times 10^6 \frac{J}{K \times m^3}$
- Is validated by test without case

- To calculate theoretical h, assumption of natural convection over flat plate
- $Ra = \frac{|\Delta T| g L_c^3 \rho^2 c_{p,air}}{T \mu k_{air}}$
  - Air properties known, taken at 318K
- $Nu = 0.59 Ra^{\frac{1}{4}}$
- $h = Nu \frac{k}{L}$
- Will be calculated at every temperature point and compared to experimental
- $q_{conv,th} = h A_{phone}(T_s - T_\infty)$

Analysis: Sample Calculations (Bare)

- $Area = 0.0105\, m^2$
- $Volume = 8.26E(-5)m^3$
- $C_{phone} = 2.4E(6)\frac{J}{m^3K}$
- $T_{phone} = 55°\text{C}$
- $T_\infty = 24.5°\text{C}$
- $\frac{dT}{dt} = -0.024\frac{K}{s}$
- $q_{rad} = 1.827W$
- $L_c = 0.024m$

$$-(8.26E(-5)m^3)\left(2.4E(6)\frac{J}{m^3K}\right)\left(-0.024\frac{K}{s}\right)$$
$$= q_{conv} + 1.815W$$
$$q_{conv,exp} = 2.93W$$

$$Ra = 29421.46$$
$$Nu = (0.54)Ra^{\frac{1}{4}} = 7.07$$
$$h = \frac{Nu(k_{air})}{L_c} = \frac{(7.07)\left(0.02744\frac{W}{mK}\right)}{0.024m} = 8.09\frac{W}{m^2K}$$
$$q_{conv,th} = \left(8.09\frac{W}{m^2K}\right)(0.0105\, m^2)(55°\text{C} - 24.5°\text{C})$$
$$q_{conv,th} = 2.59W$$

Analysis: Sample Calculations (w/ Case, w/Skin)

- $t = 0.002m$
- $k = 0.11\frac{W}{mK}$
- $Vol_{case} = 2.1E(-05)m^3$
- $T_{case} = 46.7°\mathrm{C}$
- $\frac{dT}{dt}_{phone} = -0.02118\frac{K}{s}$
- $\frac{dT}{dt}_{case} = -0.01525\frac{K}{s}$
- $c_{p,case} = 1350\frac{J}{kgK}$
- $\rho_{case} = 1100\frac{kg}{m^3}$
- $q_{rad} = 1.46W$

$$q_{cond,exp} = -(8.26E(-5)m^3)\left(2.4E(6)\frac{J}{m^3K}\right)\left(-0.02118\frac{K}{s}\right)$$

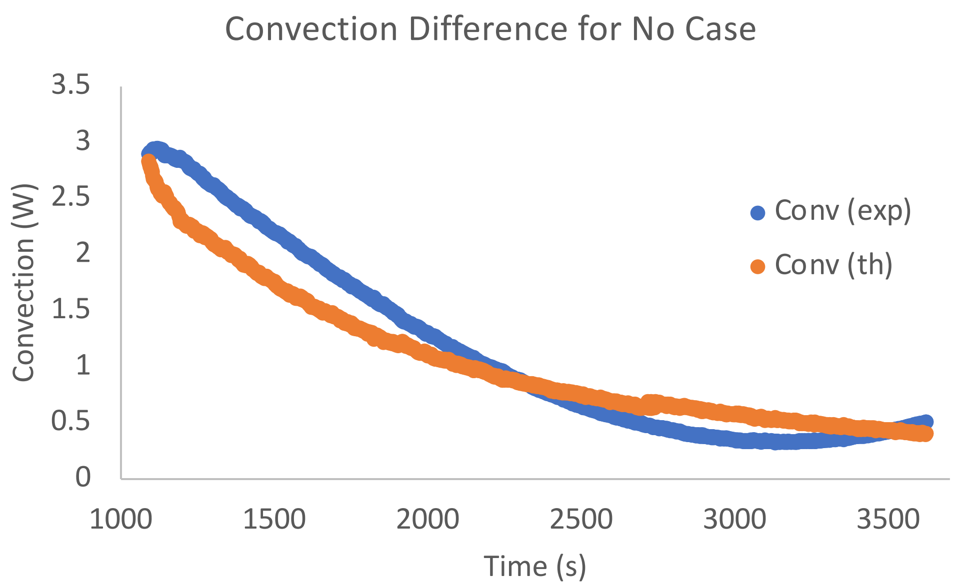
$$q_{cond,exp} = 4.2W$$

$$q_{cond,th} = \frac{\left(0.11\frac{W}{mK}\right)}{0.002m}(0.0105\,m^2)(55-46.7) = 4.81W$$

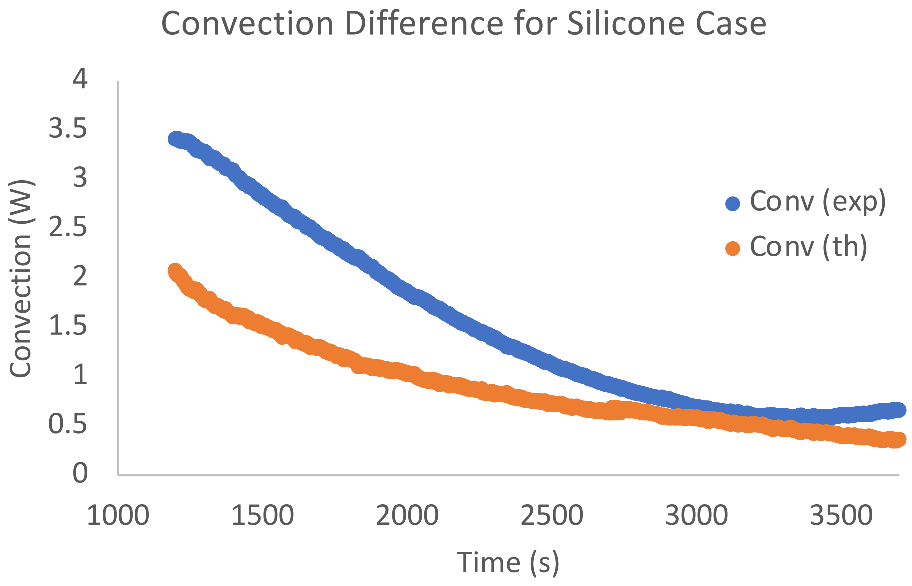
$$(2.1E(-05)m^3)\left(1350\frac{J}{kgK}\right)\left(1100\frac{kg}{m^3}\right)\left(-0.01525\frac{K}{s}\right)$$
$$= 4.2W - q_{conv,exp} - 1.46W$$

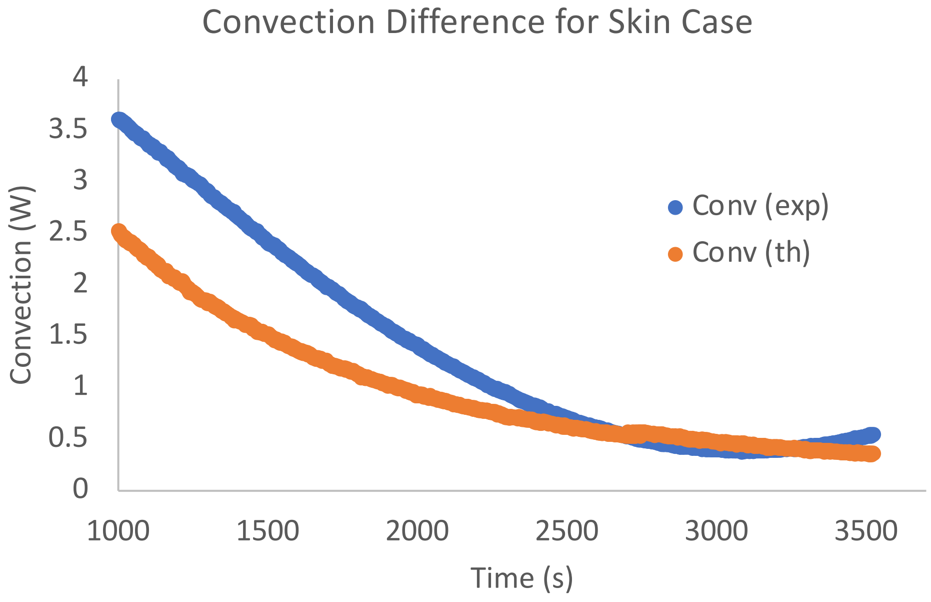
$$q_{conv,exp} = 3.21W$$
$$q_{conv,th} = 1.75W$$

Results: Convection

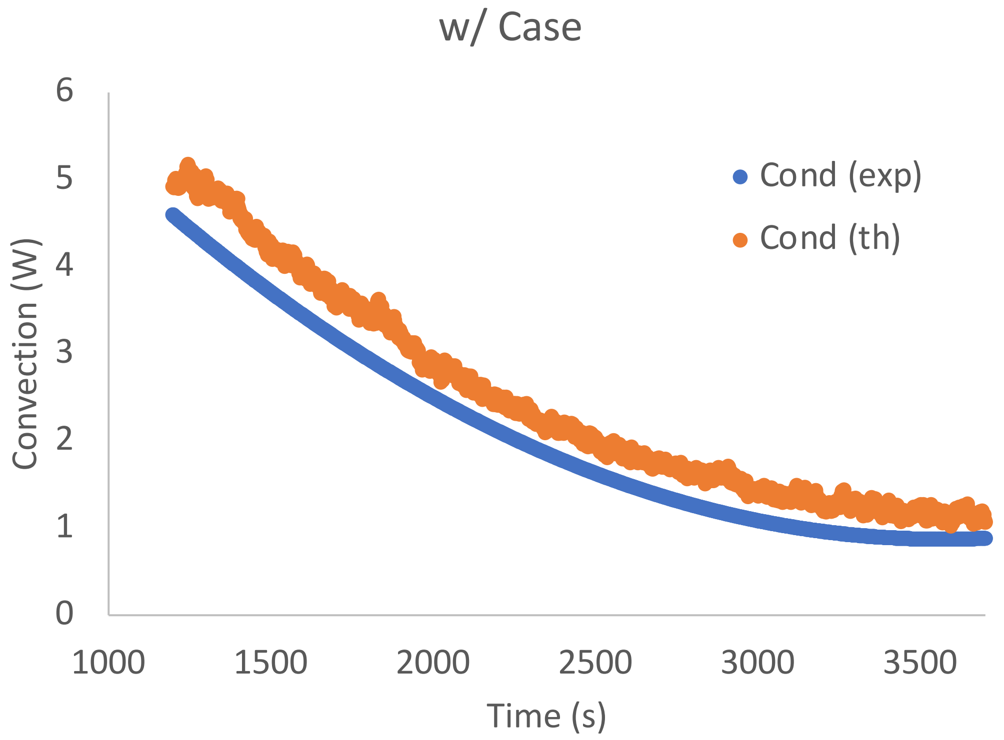


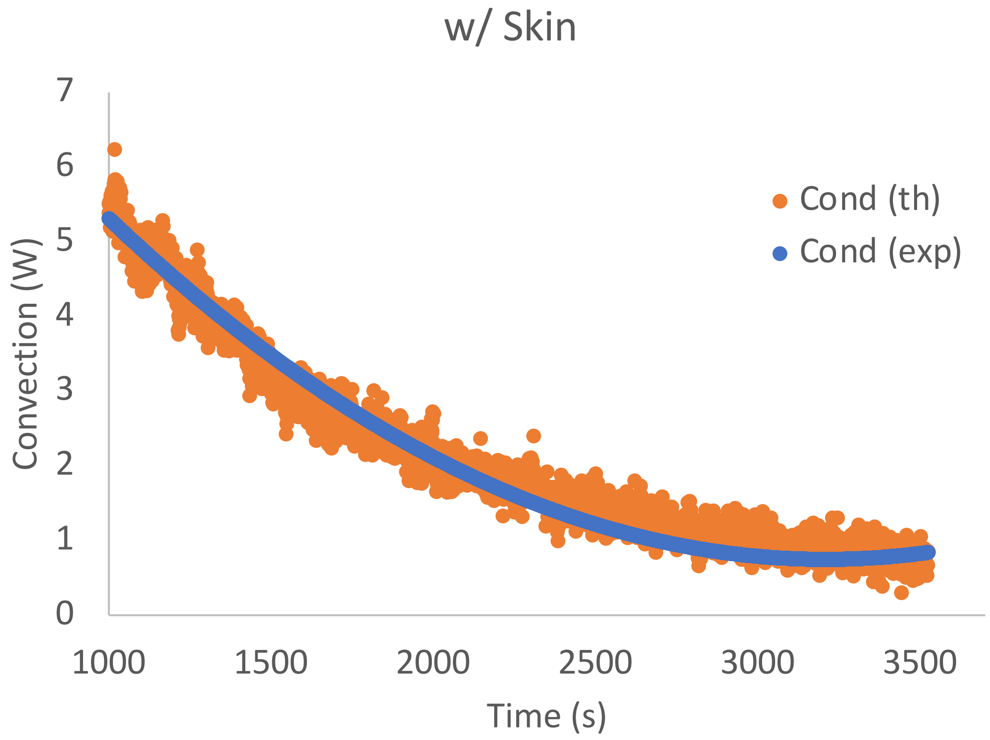
- Observable differences
- Error possibilities:
  - Properties at wrong temperatures
  - Steady State





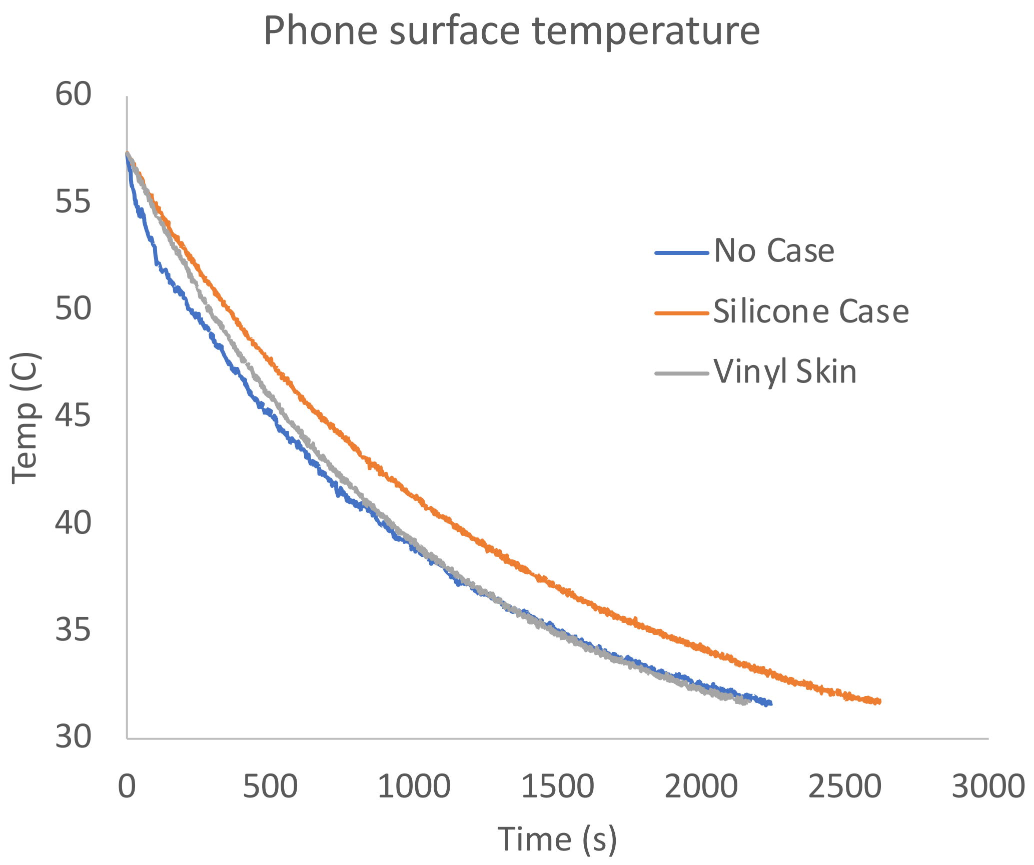
Results: Conduction

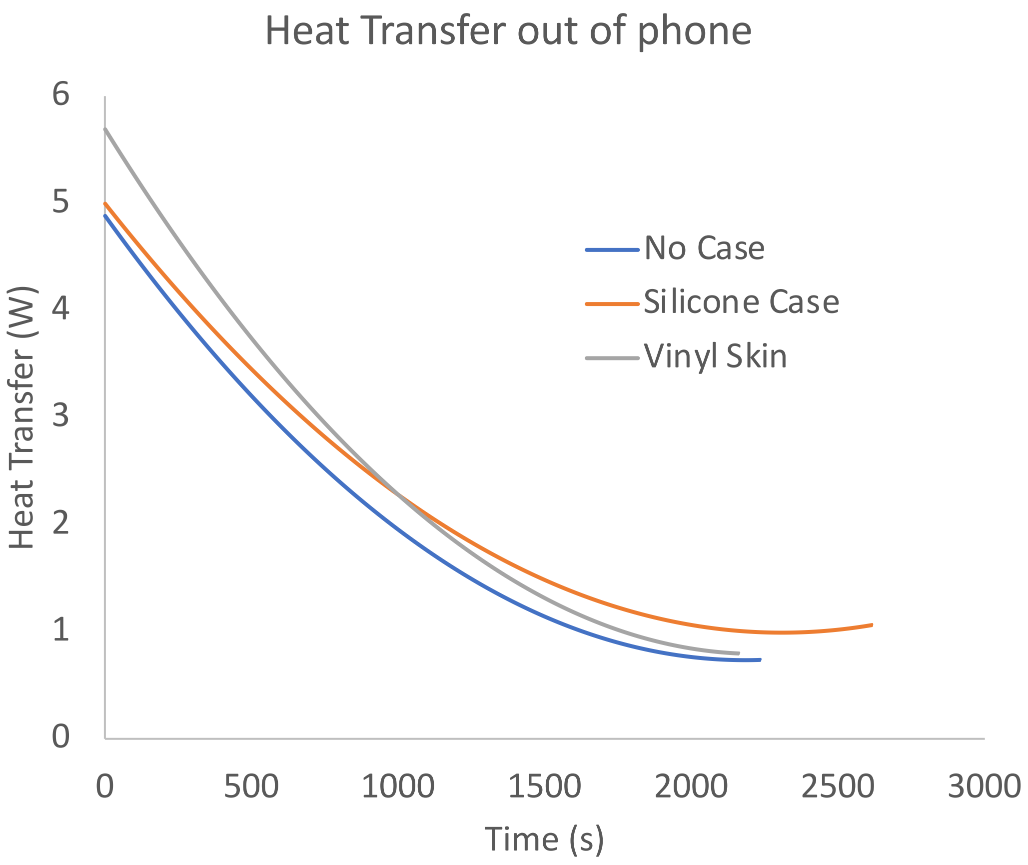




- Small differences
- Conduction matches expected results
- Possible disparities are thermal conductivity and thickness

Results: Phone Temp. and Heat Transfer vs t





Results: Overall

- Original estimate for phone heat capacity was not too far off
  - However, heat capacity directly influences results
- Theoretical plate results prove more accurate for steadier state
  - As observed on graphs, results approach at lower temperatures
- Conduction results proved accurate
  - Depending on k and t
- Silicone case definitely slows cooling of phone down
  - Took over 6 minutes to reach same temperature
  - Significant temperature differences (55°C vs 46.7°C)
- Results with skin proved faster than without a case
  - Reached same temperature a minute under phone
  - Maybe due to difference in emissivity (0.82 vs 0.94)

Uncertainty Analysis

- Absolute uncertainty of k-type thermocouple $= \pm 2.2\ °C\ or \pm\ 2.2\ K$

- At 45 ºC (318 K):
  - Relative uncertainty $= \frac{2.2\ K}{318\ K} = 0.692\%$
  - Therefore, uncertainty in $r_{rad} =\ 2.77\%$ and $r_{conv} = 2.77\%$

- Uncertainty well within 5%

Discussion

- As expected, silicone case slowed cooling of phone
  - Due to the conduction aspect and thickness
  - Does not seem damaging to the phone
  - Use material with higher thermal conductivity for heat dissipation
  - Lowering thickness lowers protection

- Skin did not have same effects since much thinner
  - Cooled down faster than phone by itself
  - Provides less protection
  - Radiation probably the cause

Sources of Error

- Phone was assumed flat plate
- Phone had a section in the back not covered by skin/case
- Thermocouples taped
- Heat Capacity approximation
- Using trend line to find dT/dt
- Thermal conductivity and thickness data
- Perfect insulation assumption
- Constant ambient temperature

Conclusion & Recommendations

- Heat capacity must be investigated further for accuracy
  - Directly impacts both convection and conduction results

- Silicone case protects better but reduces heat dissipation
- Use higher conducting materials to help
- Phone won't blow up because of it, might reduce performance

- Skin slightly helps phone cool
- Skin does not offer protection, only versus scratches
- Possibly has higher absorptivity due to color

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Q&A

References

- Slide 1 image: https://www.zteusa.com/axon-7mini
- Slide 2 image: https://www.techadvisor.co.uk/how-to/mobile-phone/phone-overheating-3647780/
- Slide 3 image: https://mobileayes.com/cases/pc-cooling-heat-dissipation-mobile-phone-case/
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