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Transient Heat Conduction in Aquarium Heaters

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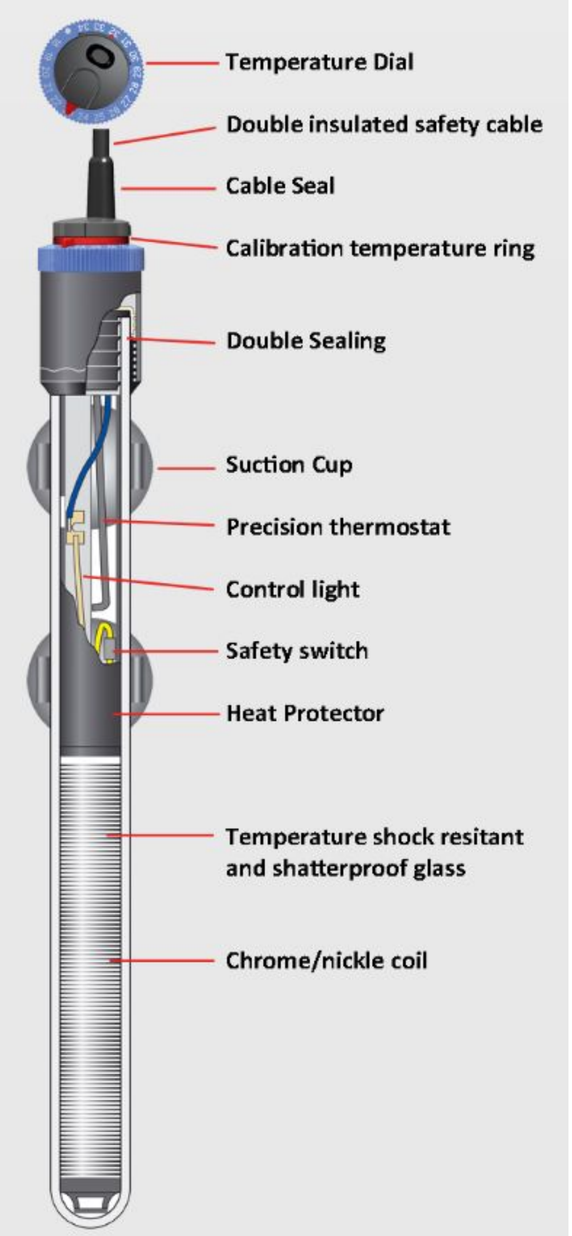
Introduction

- Aquarium heaters
  - Necessary to regulate water temperature
- The problem: Fish can burn themselves! [1]



Introduction

- Design an aquarium heater that does not reach a high surface temperature
  - Most studies [2], [3] have been inconsistent

Introduction

- Solution: Perform an experiment to determine the surface temperature and thermal conductivity of borosilicate glass, such that it can be utilized to find a minimum glass thickness that can reduce danger to aquarium fish
- A transient model will be utilized to see if thermal properties change over the operational range of aquarium heaters and determine those values

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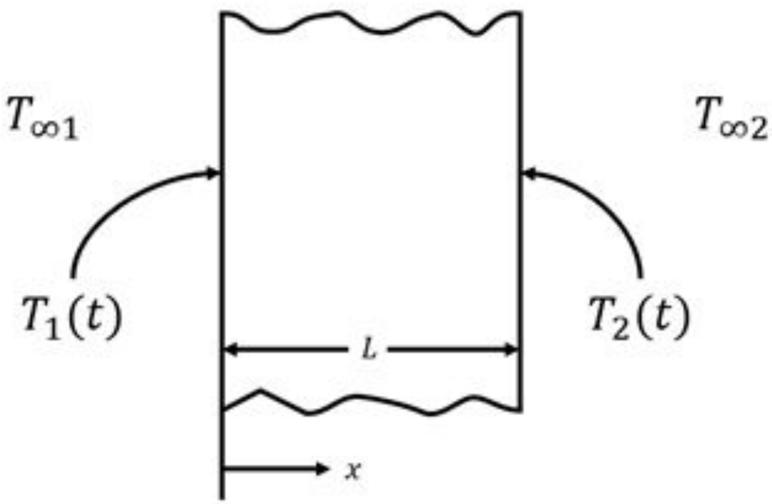
Energy Balance Model



Assumptions:

- Linear variation of T across wall
- Constant Ambient Temperature at $T_{\infty 1}$
- Zero Slip Condition at T1

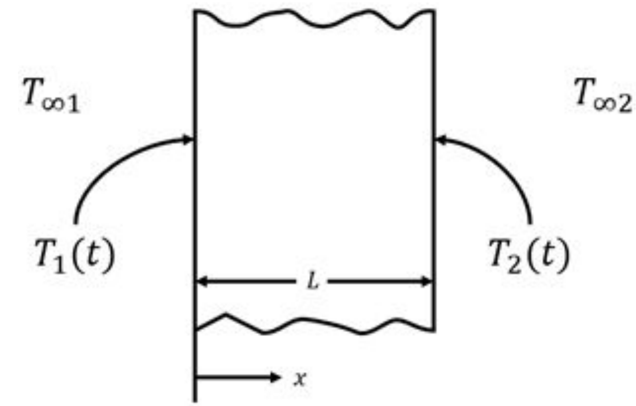
Energy Balance [4]:

$$E(t) = \frac{mc_p}{2}\left(T_2(t) - T_1(t)\right)$$

Differentiate:

$$\frac{\partial E}{\partial t} = \frac{mc_p}{2}\frac{\partial T_2}{\partial t} = \frac{\rho A_s L c_p}{2}\frac{\partial T_2}{\partial t}$$

Applying Boundary Conditions



Boundary 1: Conduction [4]

$$\dot{Q}_{cond} = \frac{kA_s}{L}(T_2(t) - T_{\infty 1})$$

Boundary 2: Convection [4]

$$\dot{Q}_{conv} = hA_s(T_2(t) - T_{\infty 2})$$

Combine boundary conditions with energy relation for a 1st Order Model:

$$\frac{kT_{\infty 1} + hLT_{\infty 2}}{k + hL} = \frac{\rho c_p L^2}{2(k + hL)}\frac{\partial T_2}{\partial t} + T_2$$

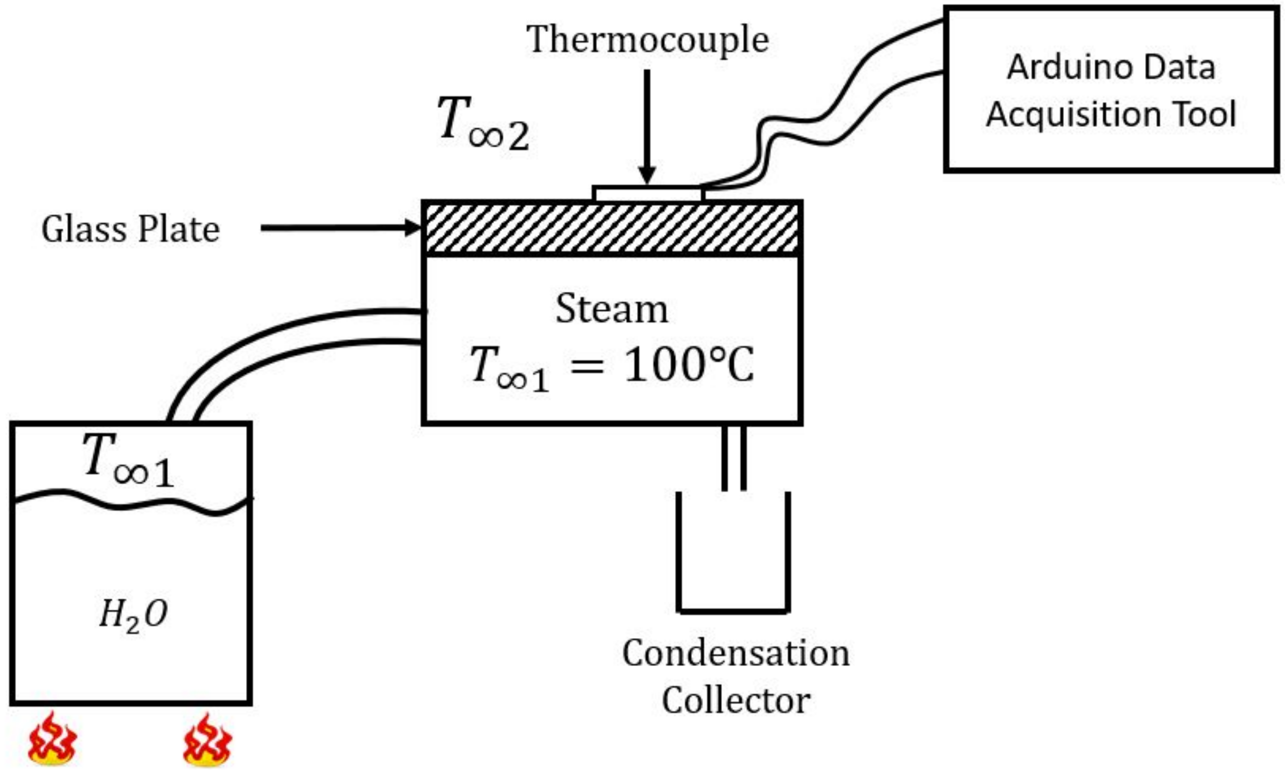
Solution:

$$T_2(t) = \frac{kT_{\infty 1} + k(T_{\infty 2} - T_{\infty 1})e^{-t/\tau} + hLT_{\infty 2}}{k + hL} \quad , \quad \tau = \frac{\rho c_p L^2}{2(k + hL)}$$

Experimental Setup/Procedure

Materials:

- Steam Chamber
- Hot Plate
- Arduino
- MAX6675
- Type K surface thermocouple



Experiment Conditions

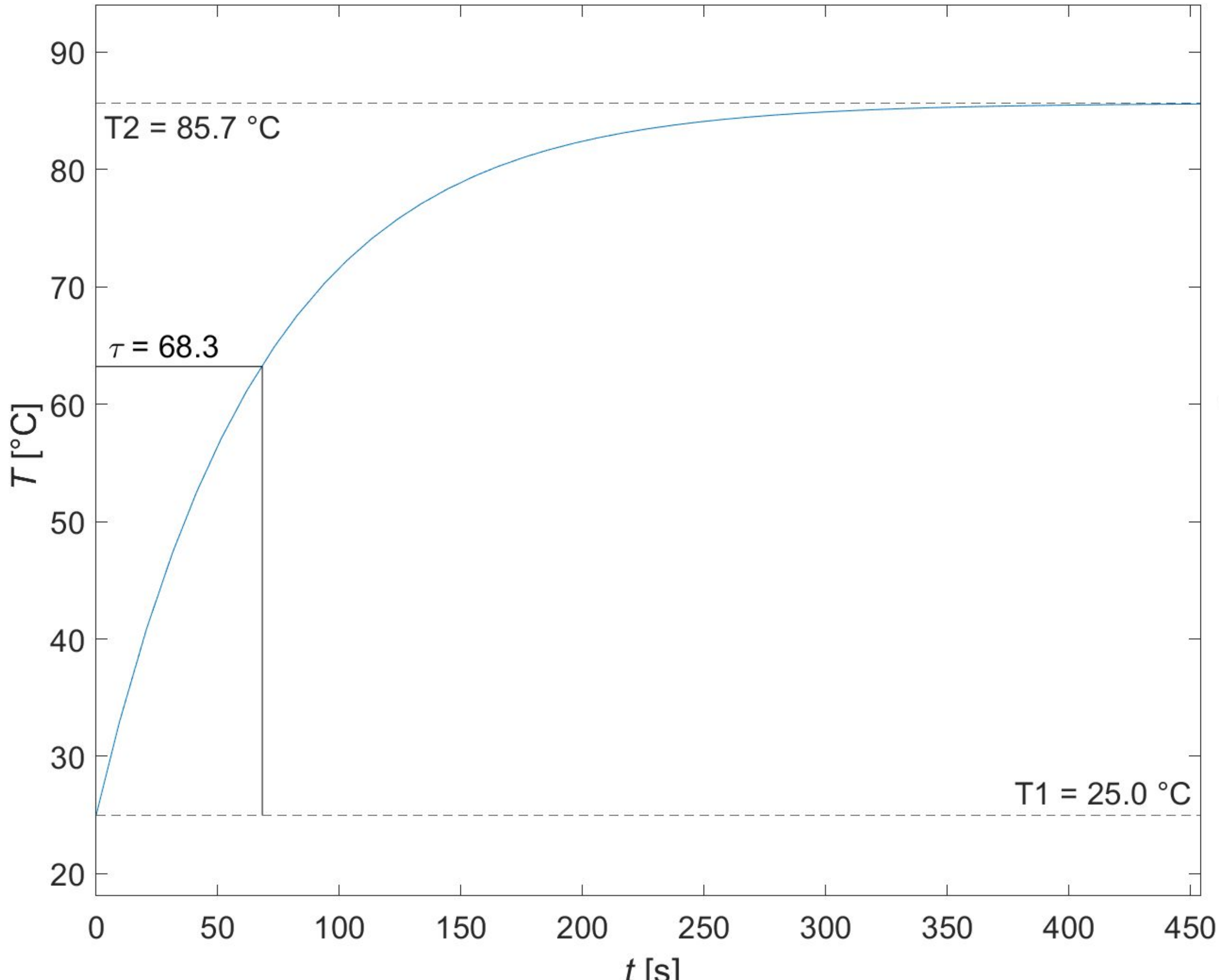
Table 1: Measurement Devices and Their Uncertainties [5]

Device	Uncertainty
MAX6675	± 0.25℃
Digital Caliper	± 0.1 mm
Arduino	± 0.0001 sec

Table 2: Constant Values assumed for simulation from [4]

Quantity	Value	Projected Uncertainty
L [cm]	1	± 0.01
h [W/m^2-K]	26	± 0.5
ϱ [kg/m^3]	2225	± 0.5
C_p [J/kg]	835	± 0.5
k [W/m-K]	1.1	± 0.05
$T_{\infty 2}$ [°C]	25	± 0.25

Expectations



$$T_2(\tau) = 0.63\Delta T$$

$$\tau = \frac{\rho c_p L^2}{2(k + hL)}$$

Conclusion

- Once the thermal conductivity is found, the model developed can be used to determine the minimum thickness of the borosilicate glass

$$L = \frac{kA_s}{\dot{Q}_{cond}}(T_2(t) - T_{\infty 1})$$

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References

1. C. W. Emmens, Keeping and Breeding Aquarium Fishes, Academic Press, 1953
2. Bauccio, M. (Ed.). (1994). ASM Engineered Materials Reference Book (2nd ed.). ASM International.
3. Bouras, N., Madjoubi, M. A., Kolli, M., Benterki, S., & Hamidouche, M. (2009). Thermal and Mechanical Characterization of Borosilicate Glass. Physics Procedia, 2(3), 1135-1140. 10.1016/j.phpro.2009.11.074
4. Y. A. Cengel and A. J. Ghajar, Heat and Mass Transfer, Fundamentals & Applications, 5 ed., McGraw-Hill Education, 2015.
5. AME 341 Faculty, AME 341b Lecture Notes and Lab Manual, Los Angeles, 2021.
6.