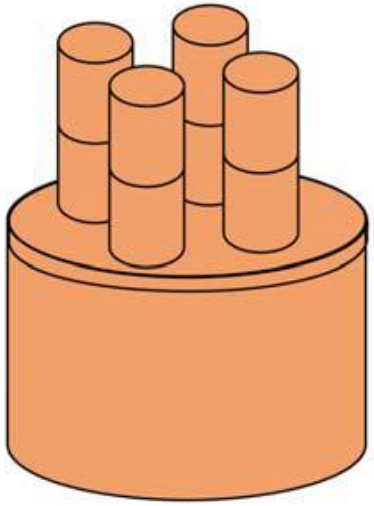
Mahidol Wittayanusorn School
Physics Science Project:

Theoretical study in efficiency of modified Zeer refrigerator

Project Advisers: Komsilp Kotmool



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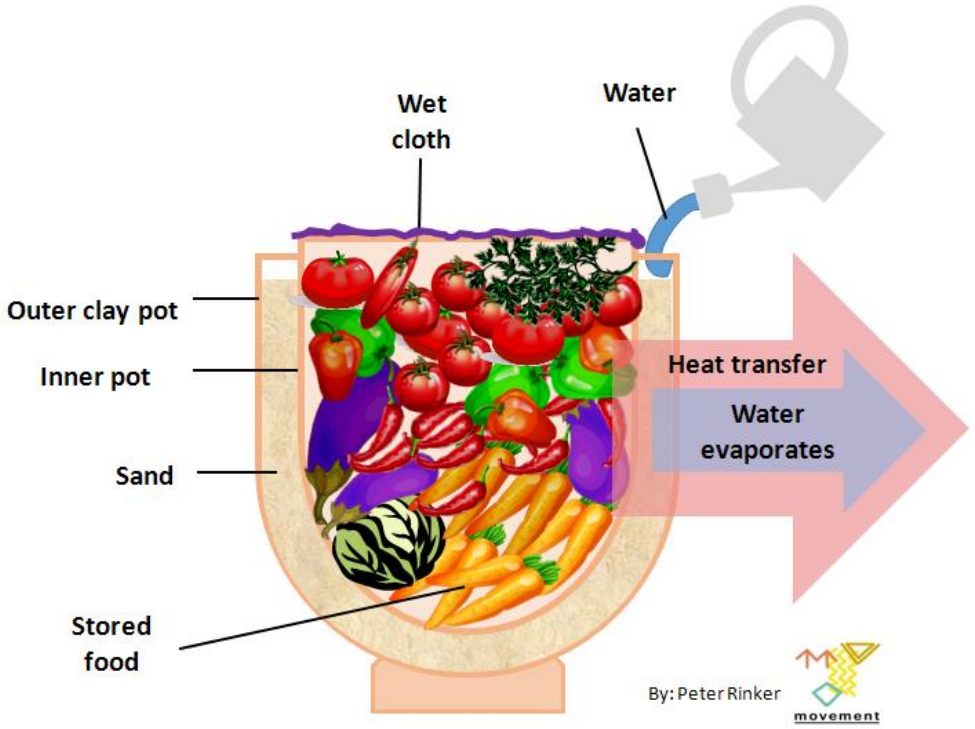
Introduction

Zeer refrigerator:

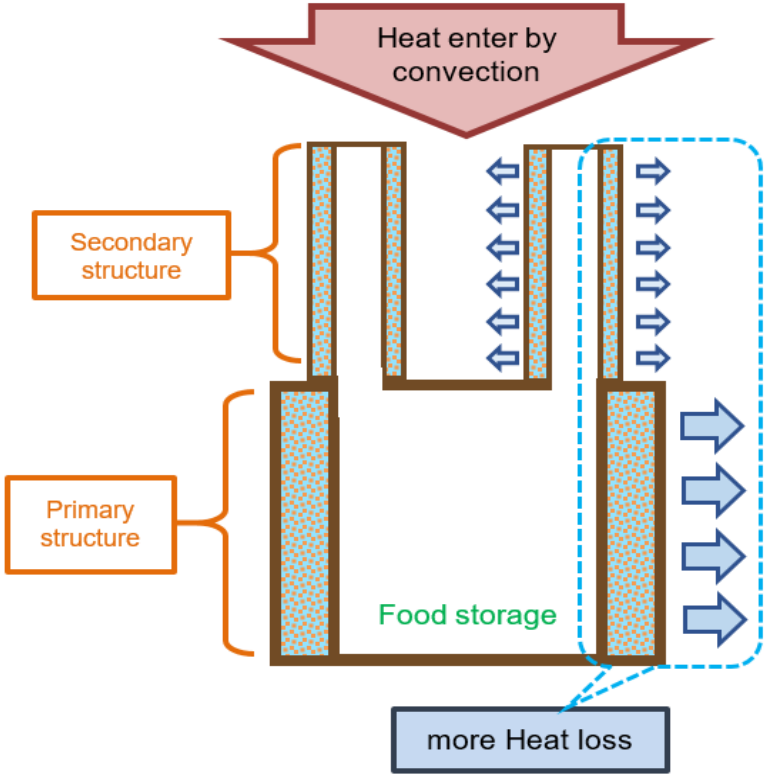
- use evaporation to cool the temperature inside.
- doesn't require electricity to operate and cost little to build.
- widely used in rural area to prolong shelf life of food.
- the amount of heat loss from Zeer refrigerator depend on outer surface area.



Introduction

Conventional Zeer refrigerator:

- Storing large amount of food with this refrigerator cause many difficulties.
- **Therefore, new design of Zeer refrigerator with higher efficiency is needed.**



Objective

- To study how dimension of Zeer refrigerator, ambient relative humidity, and ambient temperature affect efficiency of modified Zeer refrigerator.

- To compare the efficiency of modified Zeer refrigerator with efficiency of conventional Zeer refrigerator.

Procedure:

1. Understand the process in Zeer refrigerator
2. Create theoretical model
3. Specify parameters in the model
4. Calculate results (refrigerator's temperature)
5. Experiment on conventional Zeer refrigerator
6. Analyze and compare the result from the model and experiment

Procedure: Understand the process in Zeer refrigerator

Principle:

- At steady state of selected volume:

  Mass enter = Mass exit

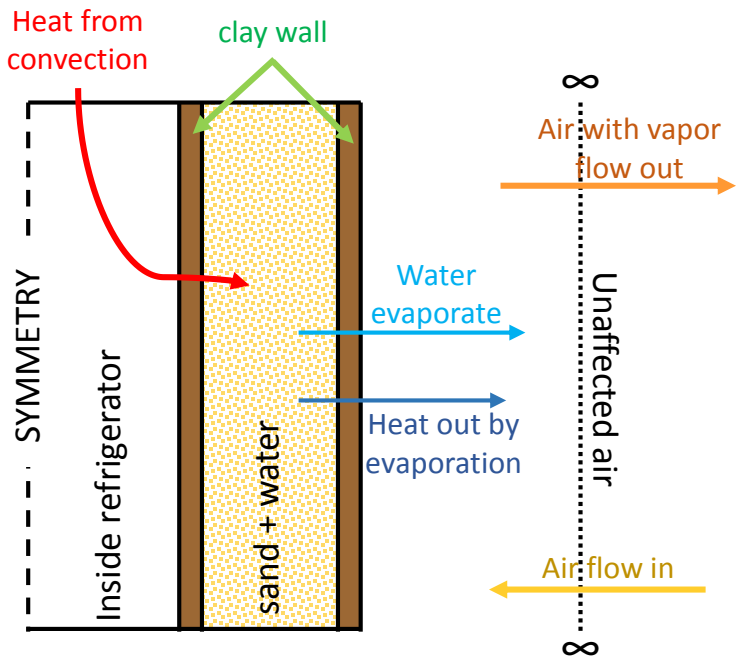
  Equation: $gA_o\omega_{v,\infty} + \dot{m}_{w,m} = (\dot{m}_{w,m} + gA_o)\omega_{v,w}$

  Heat enter = Heat exit

  Equation: $gA_o h_\infty + \dot{m}_{w,e} h_{Mw} = (\dot{m}_{w,e} + gA_o)h_w$

  $$gA_o h_\infty + \dot{m}_w h_M + \dot{Q}_{load} = \dot{Q}_L + (\dot{m}_w + gA_o)h_w$$

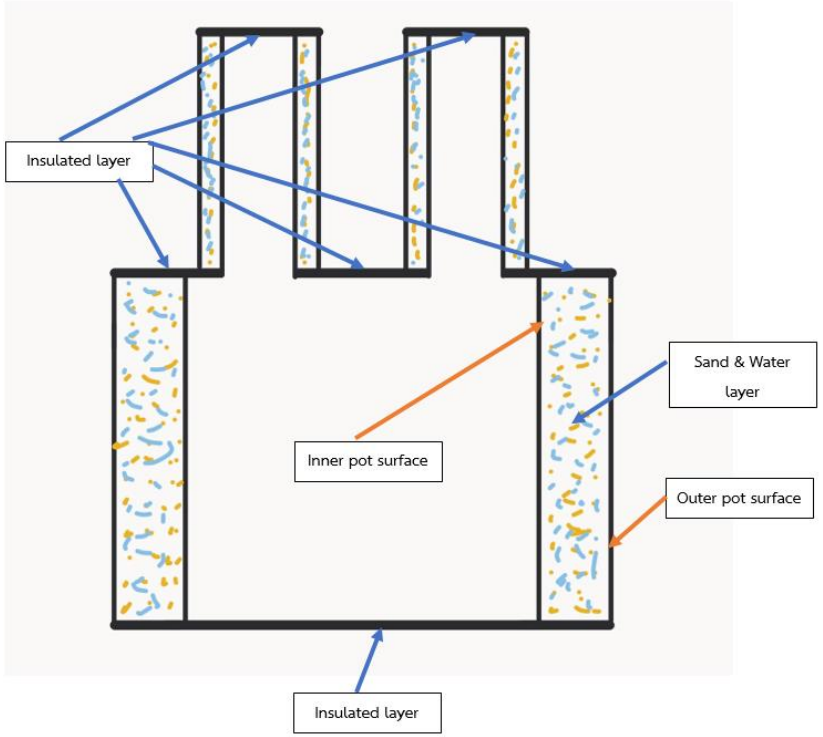
- Energy exit by evaporation
- Energy enter by convection and conduction
- Radiation can be negligible



Procedure: Specify parameters

List of parameters needed to be specified

- Dimensions: radius, height, amount of secondary structure
- Ambient condition: temperature, RH
- Properties:
  - specific heat capacity
  - latent heat of water
  - thermal conductivity



Modified Zeer refrigerator

Procedure: Create theoretical model

From principle, we acquired these equations:

- $\dot{m}_{w,m} = gA_o \times B^*$

  when $B^* = \left(\frac{0.622(1+0.05H)+(0.0189H-0.622)\omega_{v,w}}{Bi_m(0.622+0.378\omega_{v,w})}\right)$

  when $Bi_m = \frac{g}{\rho_w\left(\frac{K_p P_a}{\mu_w b_o}\right)} = \frac{g}{\rho_w K_H}$

- $\dot{m}_{w,e} = \frac{gA_o(h_\infty - h_w)}{h_{Mw} - h_w}$

Then, value of parameter which fulfill the condition $\dot{m}_{w,m} = \dot{m}_{w,e}$ is needed to be found.

Variables

- H height of refrigerator
- g convective mass transfer coefficient
- A_o side surface area of outer pot
- b_o outer pot thickness
- H height of refrigerator
- $\dot{m}_w$ evaporation rate
- ω_v mass fraction of vapor in air
- ρ_w density of water
- K_H hydraulic conductivity
- b structure's thickness
- h mass enthalpy
- B* Spalding number

Procedure: Create theoretical model

Iterative method: assumes the value of parameter until equations give the same results

- $\dot{m}_{w,m} = gA_o \times B^*$

$$\dot{m}_{w,e} = \frac{gA_o(h_\infty - h_w)}{h_{Mw} - h_w}$$

Condition: $$f = \left|\frac{\dot{m}_{w,e} - \dot{m}_{w,m}}{\dot{m}_{w,m}}\right| \times 100$$

- If $f > 10$,revise Tw
- If $f <= 10$,use current Tw for calculation & $\dot{m}_w = \dot{m}_{w,m}$

Variables

- H height of refrigerator
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Procedure: Create theoretical model & Calculate results

Equations for refrigerator's temperature calculation

conventional Zeer refrigerator

$$T_{cold} = \frac{T_w + T_\infty \cdot \frac{Qload}{A_i}\left(\frac{1}{\alpha_i} + \frac{b_i}{k_{clw}}\right)}{1 + \frac{Qload}{A_i}\left(\frac{1}{\alpha_i} + \frac{b_i}{k_{clw}}\right)}$$

modified Zeer refrigerator

$$T_{cold} = \frac{T_w + T_\infty \cdot \frac{Qload}{A_{i,pri}}\left((C_{pri} + D_{pri})\left(\frac{C_{sec}}{n} + \frac{D_{sec}}{n}\right)\right)}{C_{pri} + D_{pri} + C_{sec} + D_{sec}}$$

$$C_{pri} = \frac{1}{A_{i,pri} \cdot \alpha_{i,pri}} \qquad D_{pri} = \frac{b_{i,pri}}{A_{i,pri} \cdot k_{clw}}$$

$$C_{sec} = \frac{1}{A_{i,sec} \cdot \alpha_{i,sec}} \qquad D_{sec} = \frac{b_{i,sec}}{A_{i,sec} \cdot k_{clw}}$$

Variables

- T_∞ temperature inside refrigerator
- A_{top} surface area of top surface
- k_{clw} thermal conductivity of sand + water layer
- $\alpha_{i,pri}$ convective heat transfer coefficient
- A_{ipri} side surface area of inner pot
- $b_{i,pri}$ side surface area of inner
- $\alpha_{i,sec}$ convective heat transfer coefficient of secondary structure
- $A_{i,sec}$ side surface area of inner pot of secondary structure
- $b_{i,sec}$ side surface area of inner of secondary structure
- n number of secondary structure

Procedure: Analyze the results

Efficiency calculation

$$Efficiency(\eta) = \frac{T_\infty - T_{cold}}{T_\infty - T_{dp}}$$

Percent difference calculation

$$\text{Percent differrence} = \frac{|T_{predict} - T_{exp}|}{T_\infty - T_{dp}} \times 100\%$$

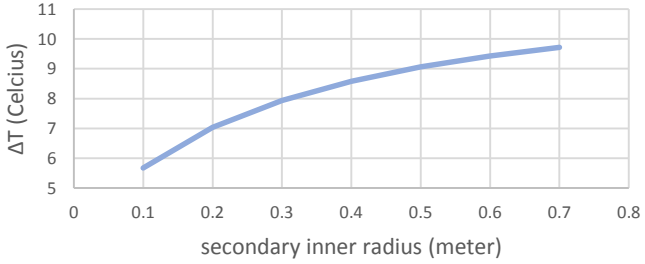
Dew point calculation

$$T_{dp} = \frac{243.12 \times \left\{ ln\left(\frac{RH}{100}\right) + \frac{17.62 \times T_\infty}{243.12 + T_\infty} \right\}}{17.62 - \left\{ ln\left(\frac{RH}{100}\right) + \frac{17.62 \times T_\infty}{243.12 + T_\infty} \right\}}$$

Result: From theoretical model

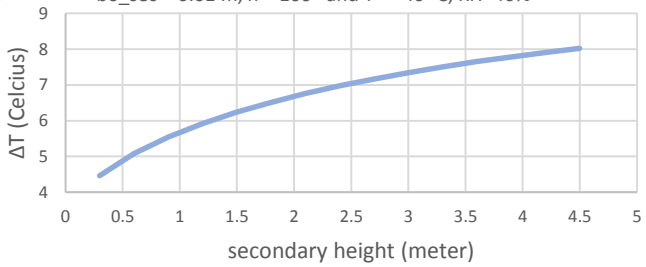
Secondary inner radius

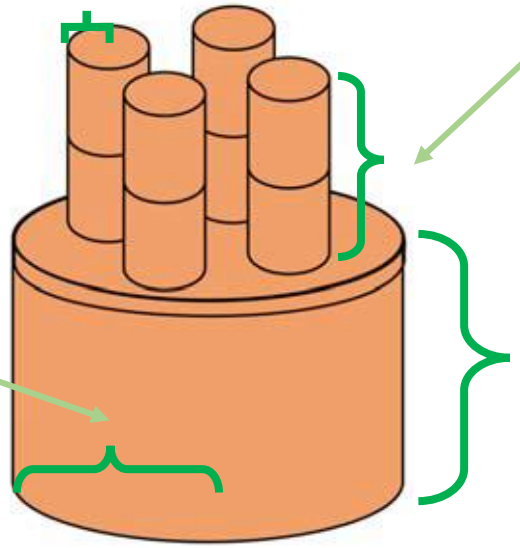
H_pri = 3 m, ri_pri = 10 m, bi_pri = bo_pri = 1 m, ro_pri-ri_pri=4 m, ro_sec-ri_sec=0.04 m, H_sec = 1 m, bi_sec = bo_sec = 0.01 m, n = 100 and T∞=40 °C, RH=40%



Secondary height

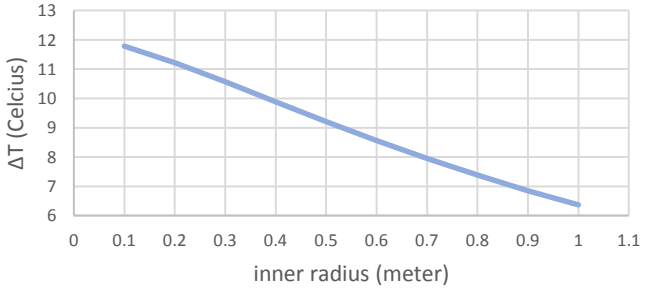
H_pri = 3 m, ri_pri = 10 m, bi_pri = bo_pri = 1 m, ro_pri-ri_pri=4 m, ro_sec-ri_sec=0.04 m, ri_sec = 0.1 m, bi_sec = bo_sec = 0.01 m, n = 100 and T∞=40 °C, RH=40%





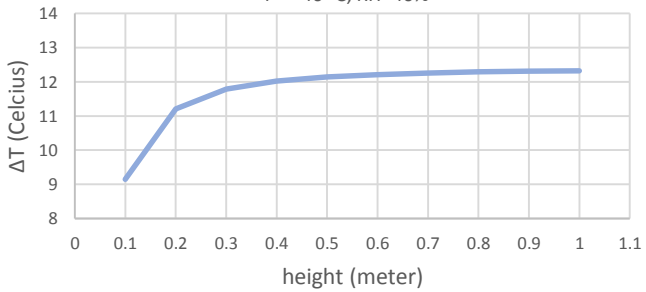
Primary inner radius

H_pri=0.3 m, bi_pri=bo_pri=0.01 m, ro_pri-ri_pri=0.04 m and T∞=40 °C, RH=40%



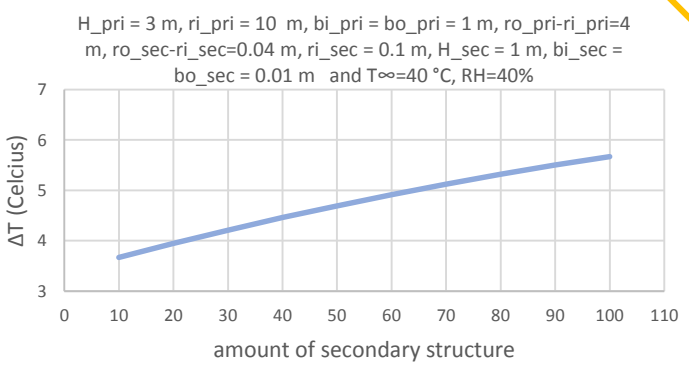
Primary height

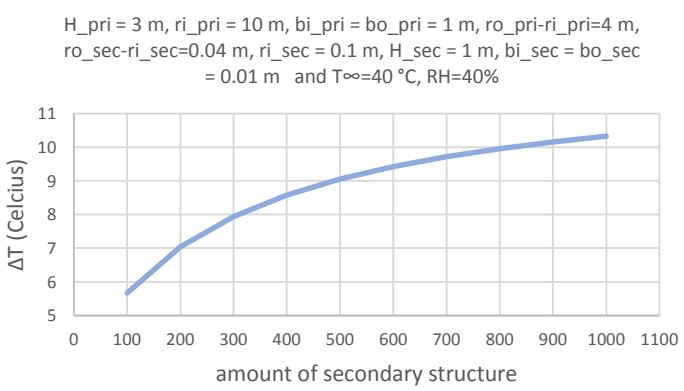
ri_pri=0.1 m, bi_pri=bo_pri=0.01 m, ro_pri-ri_pri=0.04 m and T∞=40 °C, RH=40%

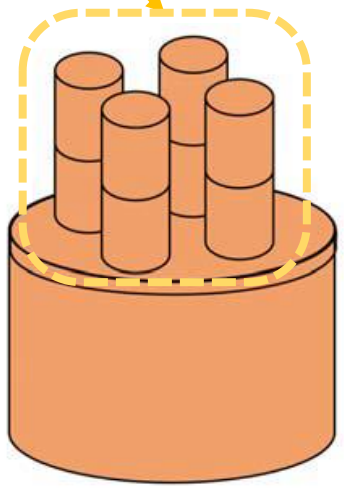


Results: From theoretical model

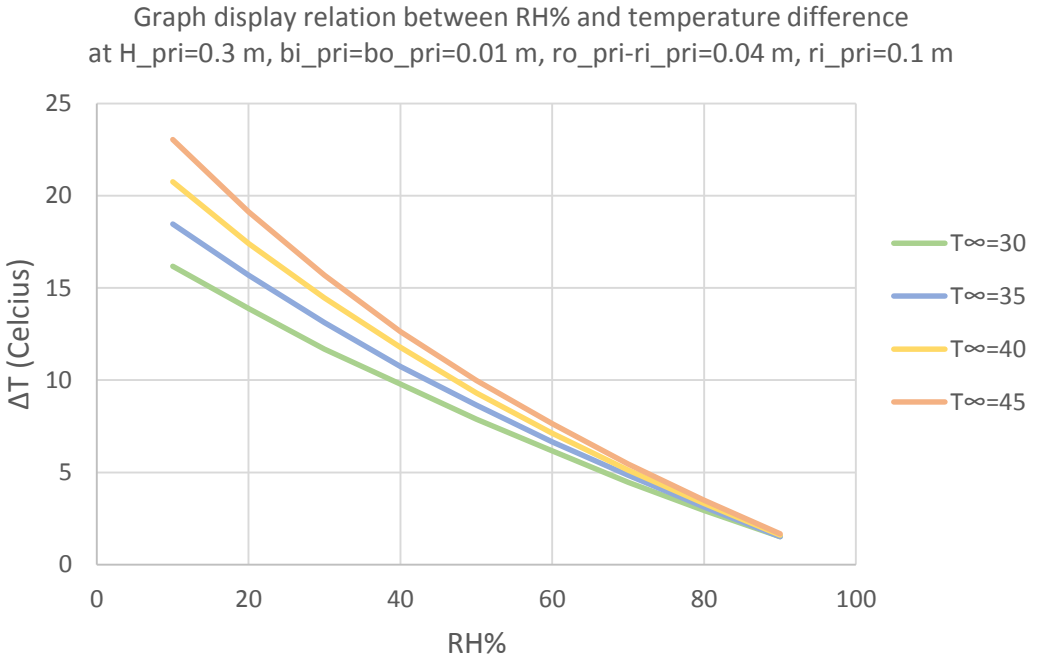
Amount of secondary structure







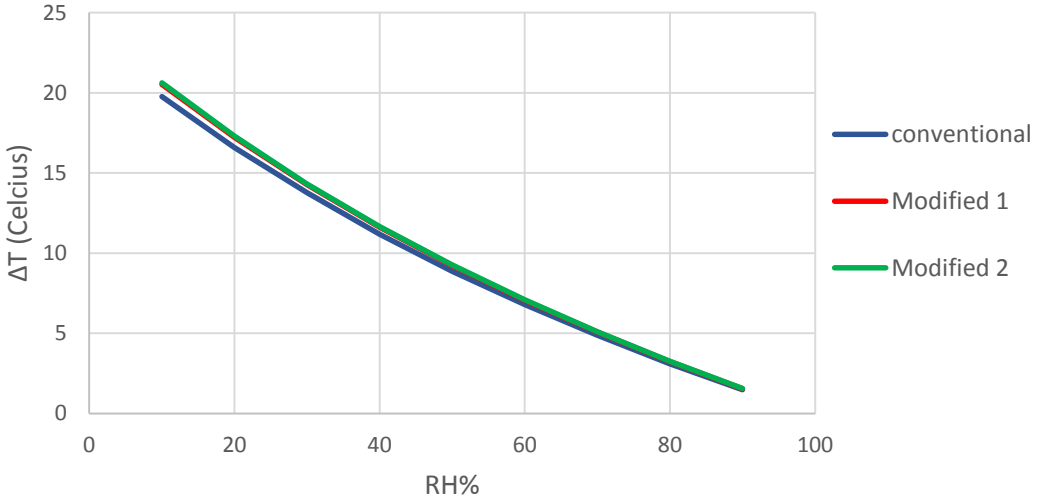
Effect of Ambient temperature and relative humidity



Result: From theoretical model

small Zeer refrigerator

Graph display relation between temperature difference and RH% at Temperature 40 degree Celcius



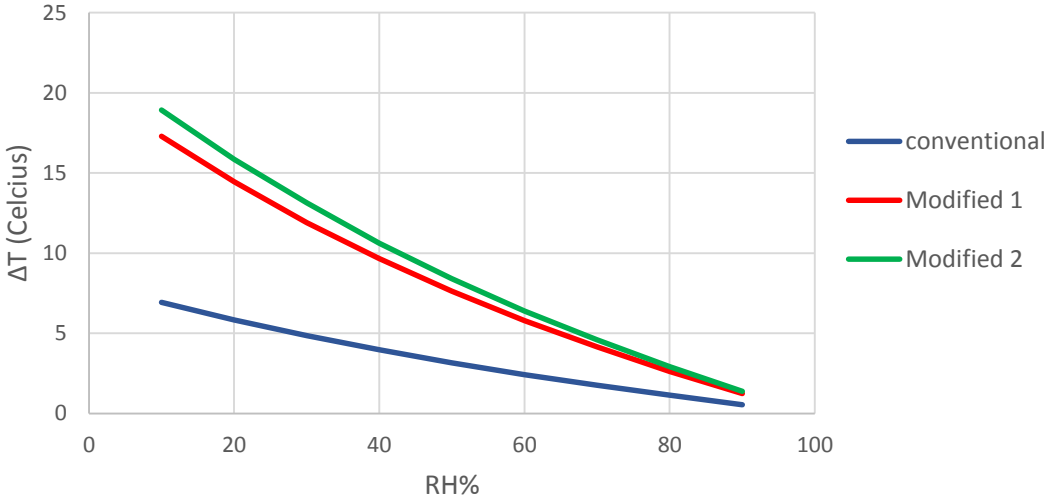
Conventional: at H_pri = 0.4 m, ri_pri = 0.3 m, bi_pri = bo_pri = 0.01 m, ro_pri-ri_pri = 0.04 m

Modified 1: at H_pri = 0.4 m, ri_pri = 0.3 m, bi_pri = bo_pri = 0.01 m, ro_pri-ri_pri = 0.04 m, ro_sec-ri _sec = 0.026 m, ri _sec = 0.064 m, H _sec = 0.3 m, bi _sec = bo _sec = 0.007 m, n = 4

Modified 2: at H_pri = 0.4 m, ri_pri = 0.3 m, bi_pri = bo_pri = 0.01 m, ro_pri-ri_pri = 0.04 m, ro_sec-ri _sec = 0.026 ri _sec = 0.019 m, H _sec = 0.3 m, bi _sec = bo _sec = 0.007, n = 16

large Zeer refrigerator

Graph display relation between temperature difference and RH% at Temperature 40 degree Celcius

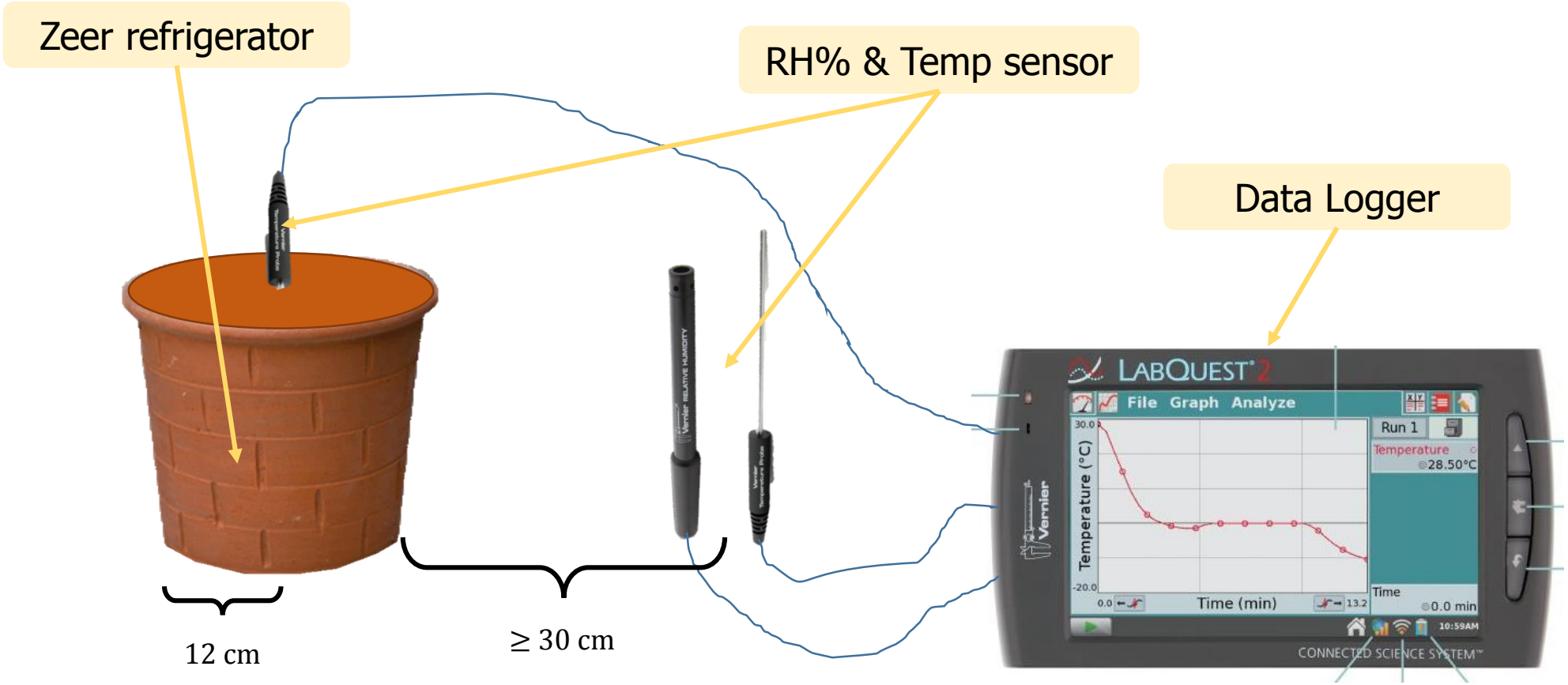


Conventional: at H_pri = 3 m, ri_pri = 10 m, bi_pri = bo_pri = 1 m, ro_pri-ri_pri = 4 m

Modified 1: at H_pri = 3 m, ri_pri = 10 m, bi_pri = bo_pri = 1 m, ro_pri-ri_pri = 4 m, ro_sec-ri _sec = 0.04 m, ri _sec = 0.5 m, H _sec = 1 m, bi _sec = bo _sec = 0.01 m, n = 100

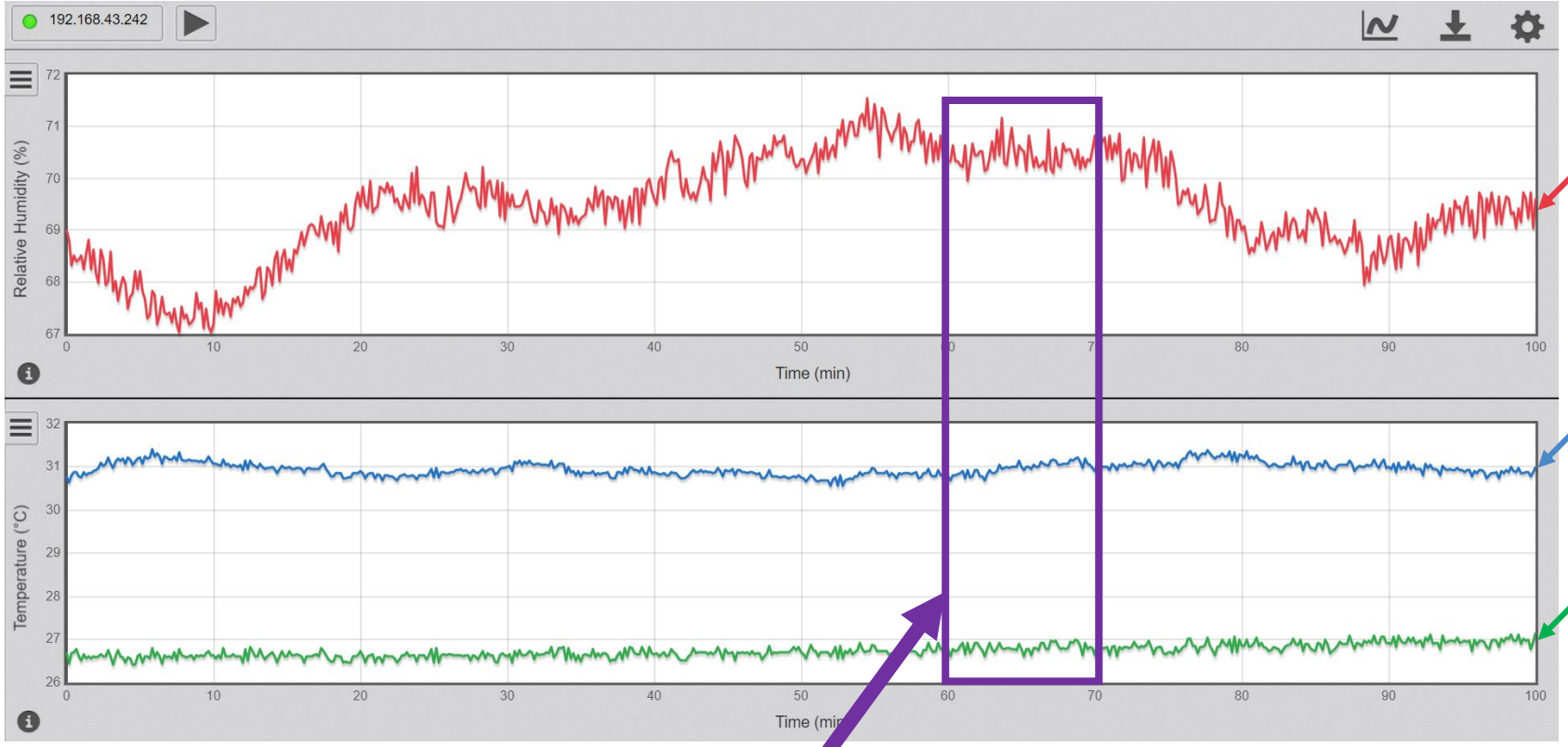
Modified 2: at H_pri = 3 m, ri_pri = 10 m, bi_pri = bo_pri = 1 m, ro_pri -ri_pri = 4 m, ro_sec –ri_sec = 0.04 m, ri_sec = 0.1 m, H_sec = 1 m, bi_sec = bo_sec = 0.01, n = 900

Procedure: Experiment on Zeer refrigerator



Procedure: Experiment on Zeer refrigerator

Procedure: Analyze the results from Data logger



Relative humidity

Ambient temperature

Temperature inside refrigerator

Temp 31, RH% 70.5

Result: From experiment

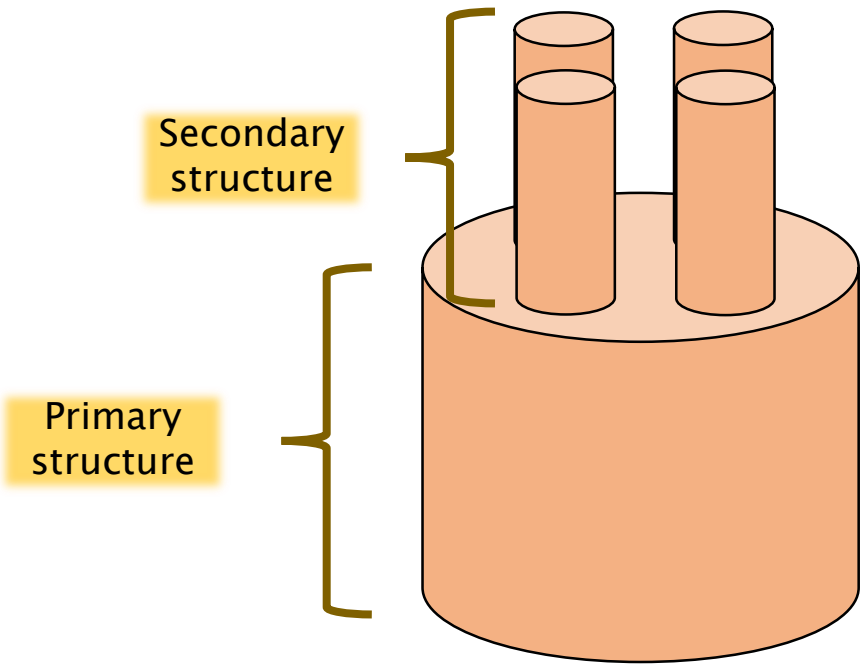
Zeer refrigerator dimension: H_pri = 0.3 m, ri_pri=0.1 m, ro_pri=0.15 m, bi_pri=bo_pri=0.01 m

Condition	Result from model (℃)	Result from experiment (℃)	Percent difference
27.3 ℃, RH% 93	26.7	26.3	66.67%
30.8 ℃, RH% 68.2	26.1	26.5	8.51%
31 ℃, RH% 70.5	26.7	26.8	2.33%
30.8 ℃, RH% 65.3	25.7	26.0	5.88%
26.8 ℃, RH% 60	22.9	22.4	12.82%
28.0 ℃, RH% 57	23.7	23.7	0.00%
30.5 ℃, RH% 50	24.9	25	1.79%
Average Percent difference			14.00%

The percent difference of the results indicates that the theoretical model should be usable and reliable.

Conclusion

- Theoretical model can be used to predict the temperature difference (of efficiency) of Zeer refrigerator accurately.
- The dimensions Zeer refrigerator has significant effect on temperature difference and its efficiency.
- Decrease of relative humidity and increase of ambient temperature cause the rise in temperature difference.
- Modified Zeer refrigerator has significantly greater efficiency and temperature difference than conventional Zeer refrigerator when the refrigerator size is large.



Future Study

Perform experiments in different ambient condition

Study the effect of refrigerator's properties on the refrigerator efficiency and temperature difference

Acknowledgement

We would like to thank Mr.Wittawas Phunmunee, Department of Physics, Mahidol Wittayanusorn School and Mr.Manon Pasomsat, Department of Social Science and Art, Mahidol Wittayanusorn School for advising and providing materials and equipments for the experiments.

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Thank you

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