Mahidol Wittayanusorn School
Physics Science Project:

Theoretical study in efficiency of modified Zeer refrigerator

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Members

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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.
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: \( gA_o \omega_{v,\infty} + \dot{m}_{w,m} = (\dot{m}_{w,e} + gA_o)\omega_{v,w} \)
  
  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 diagram]
Procedure: Create theoretical model

From principle, we acquired these equations:

\[ \dot{m}_{w,\text{m}} = gA_0 \times B^* \]

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 \[ Bi_m = \frac{g}{\rho_w \left( \frac{\mu_{P}\mu_{l}}{\mu_{w}\mu_{l}} \right)} = \frac{g}{\rho_w K_H} \]

\[ \dot{m}_{w,\text{e}} = \frac{gA_0 (h_{\omega} - h_w)}{h_{M_w} - h_w} \]

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

**Variables**
- \( H \): height of refrigerator
- \( g \): convective mass transfer coefficient
- \( A_0 \): side surface area of outer pot
- \( b_0 \): outer pot thickness
- \( H \): height of refrigerator
- \( \dot{m}_{w} \): evaporation rate
- \( \omega_{v} \): mass fraction of vapor in air
- \( \rho_{w} \): 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:
- If \( f > 10 \), revise \( T_w \)
- If \( f \leq 10 \), use current \( T_w \) for calculation & \( \dot{m}_w = \dot{m}_{w,m} \)

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
- \( \omega_v \): mass fraction of vapor in air
- \( \rho_w \): density of water
- \( K_H \): hydraulic conductivity
- \( b \): structure’s thickness
- \( h \): mass enthalpy
- \( B^* \): Spalding number
Procedure: Create theoretical model & Calculate results

Equations for refrigerator’s temperature calculation

conventional Zeer refrigerator

\[
T_{\text{cold}} = \frac{T_w + T_\infty \cdot \frac{Q_{\text{load}}}{A_i} \left( \frac{1}{\alpha_i} + \frac{b_i}{k_{\text{clw}}} \right)}{1 + \frac{Q_{\text{load}}}{A_i} \left( \frac{1}{\alpha_i} + \frac{b_i}{k_{\text{clw}}} \right)}
\]

modified Zeer refrigerator

\[
T_{\text{cold}} = \frac{T_w + T_\infty \cdot \frac{Q_{\text{load}}}{A_{i,pri}} \left( (C_{pri} + D_{pri}) \frac{C_{sec} + D_{sec}}{n} \right)}{C_{pri} + D_{pri} + C_{sec} + D_{sec}}
\]

\[
C_{pri} = \frac{1}{A_{i,pri} \cdot \alpha_{i,pri}} \quad D_{pri} = \frac{b_{i,pri}}{A_{i,pri} \cdot k_{\text{clw}}}
\]

\[
C_{sec} = \frac{1}{A_{i,sec} \cdot \alpha_{i,sec}} \quad D_{sec} = \frac{b_{i,sec}}{A_{i,sec} \cdot k_{\text{clw}}}
\]

Variables
- \( T_\infty \): temperature inside refrigerator
- \( A_{\text{top}} \): surface area of top surface
- \( k_{\text{clw}} \): thermal conductivity of sand + water layer
- \( \alpha_{i,pri} \): convective heat transfer coefficient
- \( A_{i,pri} \): 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

Introduction | Objective | Procedure | Result | Conclusion | Future Study
Procedure: Analyze the results

Efficiency calculation

\[ \text{Efficiency}(\eta) = \frac{T_\infty - T_{\text{cold}}}{T_\infty - T_{dp}} \]

Percent difference calculation

\[ \text{Percent difference} = \frac{|T_{predict} - T_{exp}|}{T_\infty - T_{dp}} \times 100\% \]

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**

\( H_{pri} = 3 \text{ m}, ri_{pri} = 10 \text{ m}, bi_{pri} = bo_{pri} = 1 \text{ m}, ro_{pri} - ri_{pri} = 4 \text{ m}, ro_{sec} - ri_{sec} = 0.04 \text{ m}, H_{sec} = 1 \text{ m}, bi_{sec} = bo_{sec} = 0.01 \text{ m}, n = 100 \text{ and } T_{\infty} = 40^\circ \text{ C}, RH=40\% \)

**Primary inner radius**

\( H_{pri} = 0.3 \text{ m}, bi_{pri} = bo_{pri} = 0.01 \text{ m}, ro_{pri} - ri_{pri} = 0.04 \text{ m} \text{ and } T_{\infty} = 40^\circ \text{ C}, RH=40\% \)

**Secondary height**

\( H_{pri} = 3 \text{ m}, ri_{pri} = 10 \text{ m}, bi_{pri} = bo_{pri} = 1 \text{ m}, ro_{pri} - ri_{pri} = 4 \text{ m}, ro_{sec} - ri_{sec} = 0.04 \text{ m}, ri_{sec} = 0.1 \text{ m}, bi_{sec} = bo_{sec} = 0.01 \text{ m}, n = 100 \text{ and } T_{\infty} = 40^\circ \text{ C}, RH=40\% \)

**Primary height**

\( ri_{pri} = 0.1 \text{ m}, bi_{pri} = bo_{pri} = 0.01 \text{ m}, ro_{pri} - ri_{pri} = 0.04 \text{ m} \text{ and } T_{\infty} = 40^\circ \text{ C}, RH=40\% \)
Results: From theoretical model

- **Introduction**
  - Graph display relation between RH% and temperature difference at $H_{pri}=0.3$ m, $bi_{pri}=bo_{pri}=0.01$ m, $ro_{pri}-ri_{pri}=0.04$ m, $ri_{pri}=0.1$ m

- **Objective**
  - Effect of Ambient temperature and relative humidity

- **Procedure**
  - Amount of secondary structure

- **Result**
  - Effect of Ambient temperature and relative humidity

- **Conclusion**

- **Future Study**
Result: From theoretical model

small Zeer refrigerator

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

large Zeer refrigerator

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

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

Modified 1:
- 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:
- 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

Zeer refrigerator

RH% & Temp sensor

Data Logger

12 cm

≥ 30 cm
Procedure: Experiment on Zeer refrigerator

- Zeer refrigerator
- RH% & Temp probe
- Data logger
Procedure: Analyze the results from Data logger

Temp 31, RH% 70.5
### Result: From experiment

Zeer refrigerator dimension: $H_{pri} = 0.3 \text{ m}$, $r_i_{pri}=0.1 \text{ m}$, $ro_{pri}=0.15 \text{ m}$, $bi_{pri}=bo_{pri}=0.01 \text{ m}$

<table>
<thead>
<tr>
<th>Condition</th>
<th>Result from model (°C)</th>
<th>Result from experiment (°C)</th>
<th>Percent difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>27.3 °C, RH% 93</td>
<td>26.7</td>
<td>26.3</td>
<td>66.67%</td>
</tr>
<tr>
<td>30.8 °C, RH% 68.2</td>
<td>26.1</td>
<td>26.5</td>
<td>8.51%</td>
</tr>
<tr>
<td>31 °C, RH% 70.5</td>
<td>26.7</td>
<td>26.8</td>
<td>2.33%</td>
</tr>
<tr>
<td>30.8 °C, RH% 65.3</td>
<td>25.7</td>
<td>26.0</td>
<td>5.88%</td>
</tr>
<tr>
<td>26.8 °C, RH% 60</td>
<td>22.9</td>
<td>22.4</td>
<td>12.82%</td>
</tr>
<tr>
<td>28.0 °C, RH% 57</td>
<td>23.7</td>
<td>23.7</td>
<td>0.00%</td>
</tr>
<tr>
<td>30.5 °C, RH% 50</td>
<td>24.9</td>
<td>25</td>
<td>1.79%</td>
</tr>
<tr>
<td><strong>Average Percent difference</strong></td>
<td></td>
<td></td>
<td><strong>14.00%</strong></td>
</tr>
</tbody>
</table>

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


References
