Temperature Reduction in Hydroponic Planting System Using Heat Pipe

Paramet Suttiprapa*, Phurt Sakulchangsatjatai, Nednapa Insalud and Pradit Terdtoon
Department of Mechanical Engineering, Faculty of Engineering,
Chiang Mai University, Chiang Mai, Thailand 50200
Tel. +66-539-4151 ext. 911 Fax. +66-5322-6014
Corresponding author: bigon_fatdog@hotmail.com, g510631038@cm.edu

Abstract

This paper presents an establishment of a mathematical model to determine the optimal size of heat pipe (thermosyphon) heat exchanger for reduce the inlet air temperature in evaporative cooling system of greenhouse. The condition of a mathematical model is the total length of heat pipe is 1.5 m. A mathematical model will determine the optimal value of evaporator section and condenser section. The range of evaporator length is 0.5 – 1.4 m with an increment of 0.1 m and condenser length is in range of 0.1 – 1.0 m with an increment of 0.1 m. The inlet air temperature in evaporative cooling of greenhouse is depend on ambient temperature about 35 degree Celsius. While, the cooling water temperature is 20 degree Celsius. Evaporative pad of evaporative cooling system is 2 m in width and 7 m in length. From the conditions above, the optimize results from a mathematical model are as follows: evaporator section length is 0.9 m and condenser section length is 0.6 m moreover, it was shown that investment, net saving and maximum heat rate are 79.83 Thousand Baht, 0.552 Million Baht and 15.6 kW respectively.

Keywords: Evaporative Cooling, Greenhouse, Heat Pipe, Hydroponic System, Thermosyphon.

1. Introduction

In the present, hydroponics planting system is popular in Thailand; due to it is free toxic in planting system. Consumer is safety from pesticide and herbicide. However, hydroponic system has an important condition, that is a environmental control. The environments under the greenhouse have to be controlled are air temperature, nutrient solution temperature, humidity etc [3], [6]. The temperature inside the greenhouse is the most important for plant growing, especially in central of Thailand which has air temperature more than 30 degree Celsius throughout. Therefore, hydroponic plant growing under greenhouse needs evaporative cooling system to reduce air temperature, while the refrigeration system reduces the nutrient solution temperature. The increasing in both air and solution temperature under greenhouse increases the operation of evaporative cooling and refrigeration system. It results in higher energy consumption. Therefore, this paper concept is to reduce the operation and energy consumption of greenhouse by reducing the inlet air temperature at evaporative cooling system. Heat pipe (Thermosyphon) is the temperature reduction device. It can transfers heat by itself and do not need any power input. It transfers heat from higher temperature source to lower temperature source. Moreover, at the same dimension, heat pipe has heat transfer better than copper tube about 400 times [2]. It is reliability and long useful life, thus heat pipe is generally used for heat transfer in laptop and PC.

Heat pipe consist of container, wick and working fluid. Wick inside heat pipe is saturated with working fluid which is small amount. In operation part, heat pipe can be divided to two sections as an evaporator section or receive heat section and condenser section or reject heat section. The evaporator section are received heat, working fluid in wick are evaporated and flow into cooling section. Then working fluid is condensed by capillary force in wick and pumps its back to evaporator section [2].

Thermosyphon is a kind of heat pipe, it do not have inside wick. Thermosyphon use the gravity force for transferring heat from heat source which is below the cooling section. The evaporator section is below the condenser section. Added heat in evaporator section, working fluid are evaporated and flown to condenser section, and then it is condensed to liquid and flown back by gravity force. Both of heat pipe and thermosyphon can transfer heat between hot air and cold air, hot liquid and cold liquid, hot air and cold liquid or hot liquid and cold air. Figure 1 shows the operation principal of heat pipe and thermosyphon.

The computer program was established in the research by assumption of heat pipe was install at the front of evaporative cooling pad for reduce inlet air temperature in greenhouse. The computer program can be predicted optimum size, thermal performance and economic value of heat pipe.

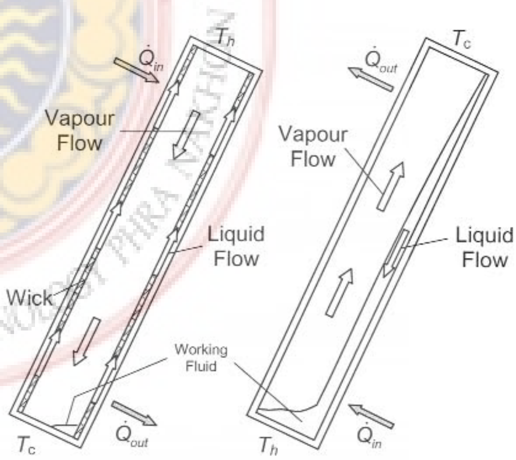

Fig. 1: Operation principal of Heat pipe and Thermosyphon (Dunn and Reay, 1982).

2. Theory

2.1 Theory of Heat Pipe (Thermosyphon)

Performance of heat pipe can be shown in the overall thermal resistance (Z_{total}), heat transfer rate (Q) and temperature difference between heat source and heat sink (ΔT) which are shown as:

$$Q = \frac{\Delta T}{Z_{total}} \qquad \text{Eq. (1)}$$

where

$$Z_{total} = Z_1 + \left(\frac{Z_{int} \times Z_{10}}{Z_{int} + Z_{10}} \right) + Z_9$$

and

$$Z_{int} = Z_2 + Z_3 + Z_4 + Z_5 + Z_6 + Z_7 + Z_8$$

The value of overall thermal resistance is in a form of overall thermal resistance series (Z_1 to Z_{10}) as shown in Figure 2.

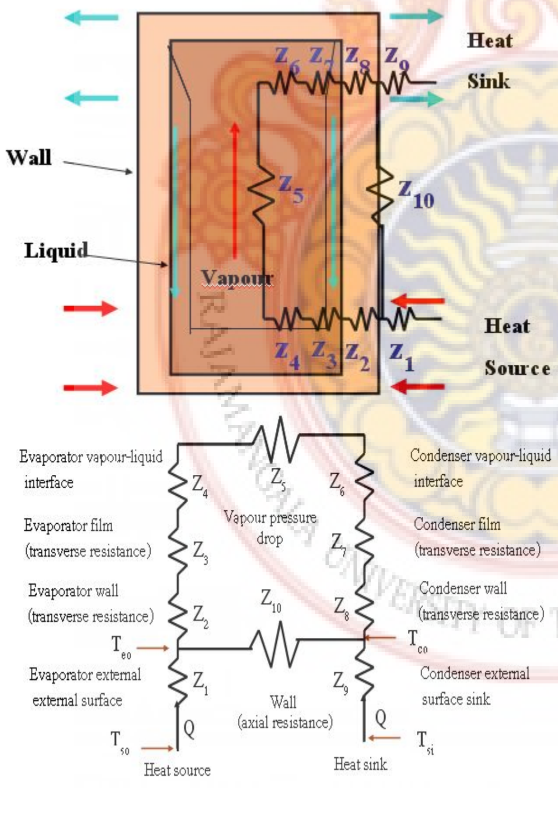

Fig. 2: The overall thermal resistance series of heat pipe

2.2 Economic Analysis

For design of heat pipe are considered an economic analysis for Economic value, which are shown follow below.

Net saving

$$S = P_1 \frac{Diesel}{C_E} HQ - (1 - (Rv(1+d)^{-yr}))x \; Cu\_tube\_price \qquad \text{Eq. (2)}$$

Investment

$$I = (Cu\_price + weld\_Cu + Cap\_Cu + WF\_price) tube \qquad \text{Eq. (3)}$$

where

P1 = Year (yr)
Diesel = Diesel Fuel (baht / liter)
CE = Heating Value (MJ / liter)
H = Annual time of operation (hrs / yr)
Heatrate = Heat transfer rate (Watt)
Rv = Resale Value (%)
d = Interest (%)
Yr = year (yr)
Cu_tube_price = Tube building price (baht)
Cu_price = Copper price (baht)
weld_Cu = Tube welding price (baht)
Cap_Cu = Cap tube price (baht)
WF_price = Working fluid price (baht / kg)
tube = Total tube (tube)

3. Materials and Method

A mathematical model is established to finding the optimal size of heat pipe (thermosyphon) for reduce the inlet air temperature at evaporative cooling of greenhouse. The condition is shown in Table 1 and 2:

Table 1: Condition of greenhouse

Ambient Temperature (^oC)	35
Inside Temperature (^oC)	20
Evaporator pad width (m)	7
Evaporator pad height (m)	2

Table 2: Condition of heat pipe

Diameter (mm)	15.88, 28.58, 41.28, 53.98
Filling Ratio (%)	0.5
Evaporator Length (m)	0.6:0.2:6
Adiabatic Length (m)	0
Condenser Length (m)	0.6:0.2:3
Number of tube	50:50:2000
Stagger alignment	ST_D=2.5:3.0 SL_D=2.5:3.0
Air velocity (m/s)	2
Water velocity (m/s)	0.2

According to the greenhouse size and material are limited, thus the new condition are considered to finding optimal size in the model as Table 3. The diagram of mathematical model are shown in Figure 3.

Table 3: New condition of heat pipe

Diameter (mm)	28.58
Filling Ratio (%)	0.5
Evaporator Length (m)	0.5:0.1:1.4
Adiabatic Length (m)	0
Condenser Length (m)	1.0:-0.1:1
Number of tube	162
Stagger alignment	ST_D=2.5:3.0 SL_D=2.5:3.0
Air velocity (m/s)	2
Water velocity (m/s)	0.2

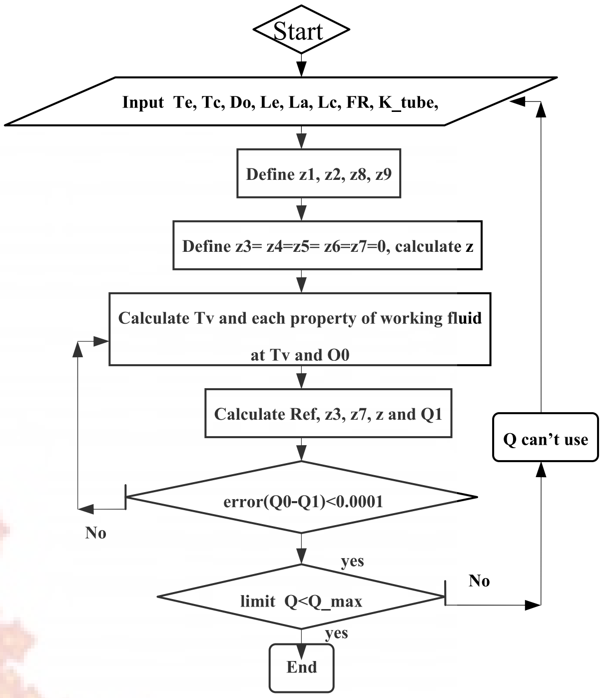

Fig. 3: Flow diagram for program

4. Results and Discussion

4.1 Result of model

Table 4 and Figure 4 show the result from the mathematical model, which the condition as

Table 2 and Table 1 are input.

Table 4: Result of model

Diameter (mm)	41.28
Evaporator Length (m)	3.2
Condenser Length (m)	2.8
Number of tube	2000
Stagger alignment	ST_D=3.0 SL_D=2.5
Number of tube per row	43
Number of row	47

Figure 4 shows the optimum value of investment and net saving which are in range 0 - 20 Million Baht and -10 - 11 Million Baht, respectively. From Figure 4, when the investment increased and net saving divided to two parts, it deceased to -10 Million Baht when investment increased to maximum, and another part, it increased to maximum at 10.7 Million Baht and decreased when investment increased to maximum. Therefore, From Figure 4 can be estimated the optimum values of investment and net saving are 7.9 Million Baht and 10.7 Million Baht, respectively. Table 4 shows the optimum geometry of heat pipe that are result from program. However, the limit of greenhouse size, it can not build up. Therefore, the conditions as Table 3 are adjusted.

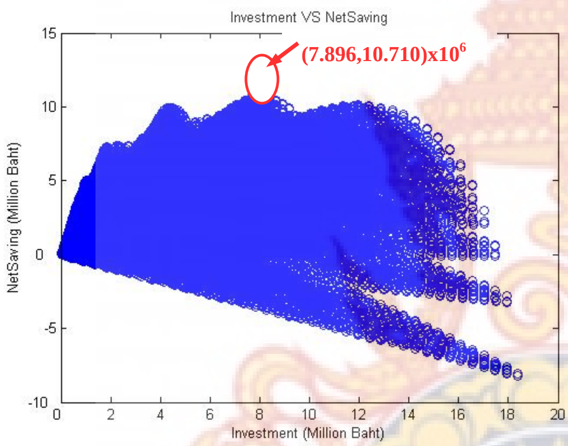

Fig. 4: Graph between investment and net saving

From the condition adjustment in the model, the optimum size of heat pipe that can be build. Table 5 and Figure 5 shows the result of optimum investment and net saving of greenhouse. From Figure 5 has been found that the value of investment and net saving which is in range of 78 - 88 thousand baht and 200 to 600 Thousand Baht, respectively. When investment increased to 79.8 Thousand Baht, net saving increased to 0.6 million baht which is optimum point. Also, when investment increased to maximum at 88 Thousand Baht net saving decreased to about 229 Thousand Baht. The optimum geometry are shown in Table 5.

Table 5: Results of model have adjusted.

Diameter (mm)	28.58
Evaporator Length (m)	0.9
Condenser Length (m)	0.6
Number of tube	162
Stagger alignment	ST_D=3.0 SL_D=2.5
Number of tube per row	81
Number of row	2

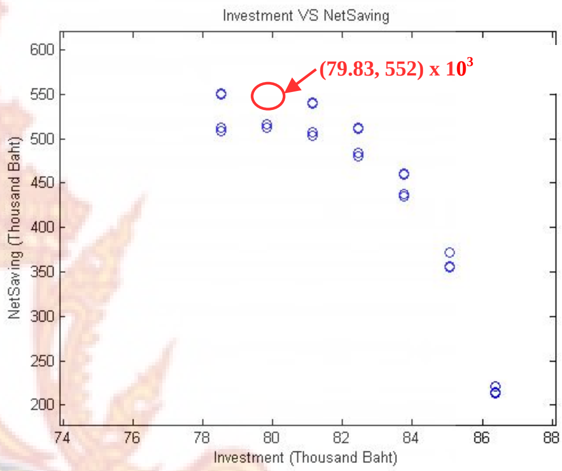

Fig. 5: Relationship between investment and net saving

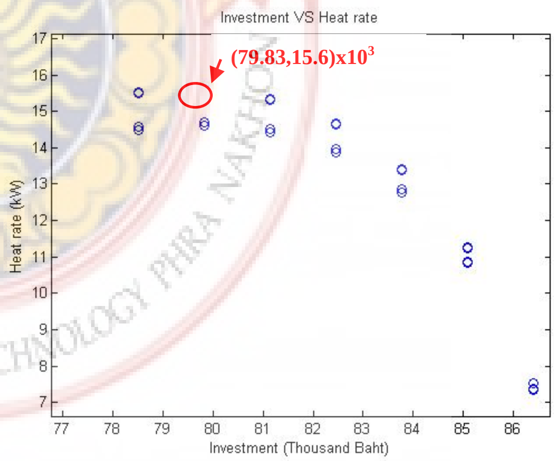

Fig. 6: Relationship between investment and heat transfer rate.

Figure 6 shows the investment and maximum heat rate of heat pipe which is in range of 76 - 88 Thousand Baht and 7 - 17 kW, respectively. The investment increased to 79.8 Thousand Baht, the maximum heat rate also increased to 15.6 kW which is optimum point. While, the investment increased to maximum at 88 Thousand Baht maximum heat rate decreased to about 7.5 kW.

As above, the result is agreed with [1] and [5] which used heat pipe (thermosyphon) as equipment for transferring heat. Therefore, geometry optimum of heat pipe as total length, evaporator length, condenser length and diameter are 1.5 m, 0.9 m, 0.6 m and 28.58 mm, respectively.

5. Conclusion

Mathematical model can find the optimum size of heat pipe (thermosyphon), which follow the condition limit of greenhouse as: total length, evaporator length, condenser length and diameter are 1.5 m, 0.9 m, 0.6 m and 28.58 mm, respectively. The investment, net saving and maximum heat rate are 79.8 Thousand Baht, 552 Thousand Baht and 15.6 kW, respectively.

6. Acknowledgement

We gratefully acknowledge the Thailand Research Fund Grants under TRF-MAG project MRG-WI525E065 and ACKhydrofarm (Thailand) Ltd. The authors would like to express their sincere appreciation for all of the support provided.

7. Reference

[1] A Meyer & R. T. Dobson. "*A heat pipe heat recovery heat exchanger for a mini-drier*", Journal of Energy in Southern Africa. Vol. 17, No. (1). 2006. pp. 50-55.

[2] Dunn and Reay, *Heat pipes*, 1982.

[3] Holaday AS, Martindale W., et al., "*Changes in activities of enzymes of carbon metabolism in leaves during exposure of plants to low temperature*", Plant Physiol. Vol. 98, No. 3, 1992. pp.1105-1114.

[4] Ong, K.S. & Haider-E-Alahi, "*Performance of a R-134a filled thermosyphon*", Applied Thermal Engineering, Vol. 23, Issue 18, 2003, pp. 2373-2381.

[5] Srihajong, N., Ruamrungsri,S. et al. "*Heat pipe as a cooling mechanism in an aeroponic system*", Applied Thermal Engineering. Vol. 26 , Issue 2-3, 2005. pp. 267-276.

[6] Te-Chen Kao, "*The Dynamic Root Floating Hydroponic Technique: Year-Round Production of Vegetables in Roc on Taiwan*", Taichung District Agricultural Improvement Station Tatsuen Hsiang, Changhua, ROC on Taiwan, Food & Fertilizer Technology Center for the Asian and Pacific Region, 1991, pp. 1-17.

[7] Terdtoon P., *Heat pipe*, 1993.