eISBN 978-967-16145-1-8

Konvensyen Kebangsaan Kejuruteraan Pertanian Dan Makanan 2019
21 Mac 2019, Wisma Tani, Kementerian Pertanian Malaysia, Putrajaya

MSAE2019-AMA23

Minimum Energy Performance Standards of Hydroponic Root Zone Cooling System For Lettuce Cultivation on Roof Top Garden

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Abstract
Hydroponic cultivation techniques usually apply for growing leafy vegetables and sometimes fruit vegetables. Problems commonly associated with hydroponic system are water temperature can easily increase under direct sunlight in the tropics region especially under crop protection structure thus can affects the quality of fertilizer given. A study to develop a cooling system for hydroponic technique which can control the water-dissolved nutrient temperatures that suits the crop growth needs have been conducted to overcome the problem. This paper highlights the development and minimum energy performance determination of the hydroponics root zone cooling (HRZC) system for lettuce cultivation on (6.06 m x 2.35 m) roof top garden. It was found that with the using of only 0.5 hp water pump, the HRZC system was able to distribute and control the hydroponic water-dissolved nutrient temperatures flow to the hydroponic growing container which has a length of 10m long at different height levels of the structure wall. By using only 1.0 hp chiller water system, the ranges of temperatures that can be controlled using the HRZC system were between 15 °C to 25 °C which meets the crop-root zone temperature needs.

Keywords: energy performance, hydroponic, root zone cooling, roof top garden

Introduction

Malaysia Agriculture Research and Development Institute (MARDI) have developed several cooling techniques in greenhouse to increase the production of temperate crop in lowland. Research have been done to explore the alternative technology of cooling such as root zone cooling system, misting fan, evaporative pad and ventilation fan which can reduce the production cost (Ahmad Syafik et al, 2010). This root zone cooling system can be adapted to the hydroponics cultivation method which enables the water-dissolved nutrient temperature to be controlled. By manipulating the root zone temperatures with adequate lighting system, it would increase the crop productivity (Gosselin & Trudel, 1984). It was reported that the effect of root zone temperature is greater on root growth especially in early stage of crop development (Mohammud et al., 2012). Studies have shown that crop roots are more sensitive to fluctuation in temperature than crop shoots However, extreme root zone temperature manipulation can cause excessive vegetative growth, flower abscission and poor fruit set. Thus, it is important to consider the crop requirements before planning for cooling technique (Mat Sharif, 2006). In this study, hydroponic root zone cooling (HRZC) system was developed to cultivate high value vegetables in tropics and to determine the effects of HRZC on crops growth and yields. Among the many varieties of high valuable vegetables in Malaysia, Lettuce of *Lactuca Sativa* varieties have been chosen as selected vegetable in this study due its affordable price in Malaysia markets which is between RM 6/kg and RM 8/kg. Moreover, *Lactuca Sativa* also known and popular because it can be grown easily with the hydroponics system besides having simple maintenance procedure. The hydroponic root zone cooling system includes the chiller, cooling water pump, and hydroponic growing container. Among these devices, the chiller consumes most power of the HRZC system. The consumed energy is related to the loading of the system and it is necessary to determine the precise minimum power of the chiller to be used in order to reduce the production cost. The were several literatures discussing how to optimize the chiller loading. Braun et al. (1989) proposed the equal loading distribution (ELD) method. This method was established under the same operating characteristic of the chiller. Due to the different operating characteristic of the chiller, Braun et al. suggested that the power consumption of the chiller was correlated with load of air conditioner, cooling water return temperature, and chiller water supply temperature. This correlation may explain the optimal chiller loading (OCL) method. The objectives of the study were: (1) to determine minimum energy performance standards of hydroponic root zone cooling system for lettuce cultivation on (6.06 m x 2.35 m) roof top garden, (2) to evaluate the HRZC system performance in distributing and controlling water-dissolved nutrient temperatures to meet crop-root requirement needs.

Materials and methods

The study was conducted at Engineering Research Centre, Malaysian Agricultural Research and Development Institute (MARDI) in Serdang, Selangor Malaysia with latitude 20 59, N, longitude1010 42, E and 37.8m above sea level (Diyana, 2009).

Hydroponics root zone cooling systems development

HRZC was developed by the integration of 1 hp chiller system that can control the water-dissolved nutrient temperature inside the hydroponic water tank (Figure 1 and 2). The water-dissolved nutrient will be chilled till 10 ^{0}C and flowed using a 0.5 hp water pump to the hydroponic growing container which was 10 m long and vertically arranged at 4m long each level at the wall of the crop protection structure (figure 1). The water-dissolved nutrient temperature inside the 10 m length of hydroponics growing container at different levels will be controlled between 15-25 ^{o}C using a pipe valve and water with velocities between 5-10 m^3/s. The chiller will be on for 12 hours from 7.00 am in the morning till 7.00 pm in the evening.

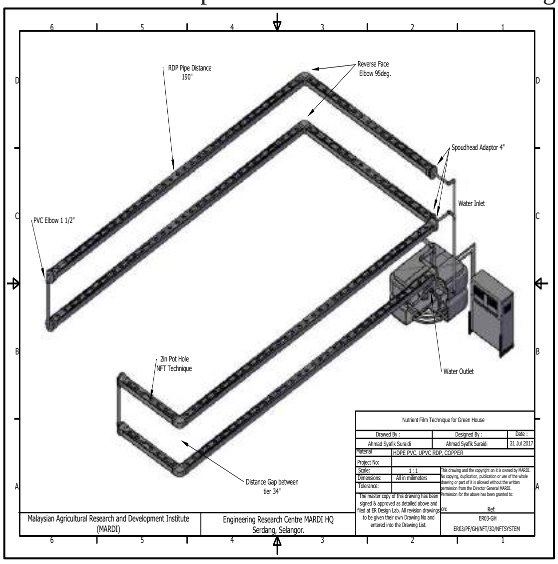

Figure 1: Systems schematic drawing

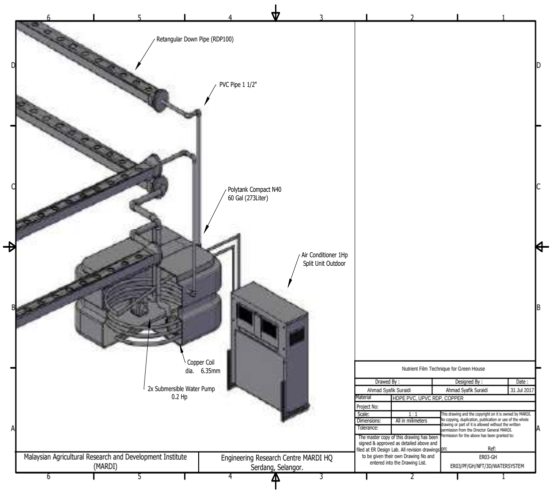

Figure 2: Cooling System

***Lactuca Sativa* cultivations**

Lactuca Sativa were planted in a Nutrient Film Technique (NFT) hydroponics plot of 20 cm wide, 10 cm thick and 4 m long (4m long at each level) that vertically arranged inside a crop protection structure (figure 3). The water level inside the growing container was 8cm which can reach by the crop roots. The crop spacing was 10 cm, and for 8m long of growing container it can accommodate near 300 crops. *Lactuca Sativa* was transplanted under the crop protection structure after 3 weeks of seeding in nursery. The crops were transplanted and grow inside the structure for 3 weeks (Figure 4) before harvested.

Figure 3: Cultivation inside crop protection

Figure 4: Lactuca Sativa after 2 weeks

Data collection

The data of average water-dissolved nutrient temperature for 10 points i.e. from H1.1 to H1.10 along the growing container (10 m long) were collected for 4 weeks started from 2 April to 23 April 2018 between 8.00 am and 5.00 pm in order to evaluate the water-dissolved nutrient temperature distribution along the pipe line. The ambient temperature was also collected at the same interval and time to study the correlation between the ambient temperature, conservative hydroponic water-dissolved nutrient temperature without cooling systems and hydroponic water-dissolved nutrient temperature with cooling systems (HRZC).

Results and discussion

Determination of chiller cooling capacity

The water chilling cooling capacity was estimated based on the heat required to reduce the water temperature from the ambient water temperature of about 30 ºC to the target chilled water temperature of 10 ºC. The cooling capacity was calculated using the following heat transfer formulas (ref. used from Accurate Heating and Cooling Load Calculation, Arthur Burlick 2010). The water flow rate of chilled water into the 60 gallon hydroponic tank is 0.0995 m3/s, the inlet temperature is 25 ºC and the outlet temperature is 10 ºC. This means the average temperature is 17.5 ºC so we lookup the water properties at this temperature to find the density of the specific heat capacity of 4.19 kJ/kg/K.

Using the energy equation of $Q = \dot{m} \times Cp \times \Delta T$ we can calculate the cooling capacity.

^{0}C= celcius P= density of water kg/m^3

Cp= specific heat kJ/kg/K Q= heat transfer kW

K= kelvin temperatures V= volume flow rate m^3/s

Q= cooling capacity kW m= P x V

ΔT= temperatures difference

The hydroponic tank volume capacity is 60 gallons, so P= 60 gallon = 227.12 liter or kg, Volume = 70cm x 36 cm x 100 cm = 252000 cm^3 = 2520 m^3. Density, P = m/v = 227.12/2520 = 0.1079 kg/m^3 of water density. Q = (0.1079 kg/m3 x 0.0995 m^3/s) x 4.19 kJ/kg/K x ((25^{0}C +273.15K) – (10 ^{0}C +273.15K))

Q= 0.0107 x 4.19 x 15

This gives us a final answer of Q = 0.672 kW of cooling.

Equal to **<u>0.905</u>** hp #

We add 273.15K to the celcius to convert it to units of Kelvin. The Specific heat capacity (Cp) is measured in units of kJ per kg per Kelvin.

Determination of water pump capacity

Water and Pump Horsepower

To fully understand water horsepower, it is important to understand the terminology involved in deriving such a unit. The term "energy" is defined as the capacity to do work. "Power" is the rate at which energy flows or at which energy is used per unit of time; it is also the rate at which work is performed. In other words, power is the amount of energy that is used to do work or how quickly work can be done. Water horsepower is the minimum power that is required to move the water (Figure 6). In other words, it is the power that the pump would require if the pump were 100% efficient. The water horsepower can be determined if the flow rate of the water and the force (pressure) required to produce that flow are known.

The following formula can be used to calculate water horsepower (WHP).

WHP = HQ / 3960

Where H is the change in pressure measured in height of water in feet and Q is the water flow rate in gallons per minute.

This equation was derived knowing that one horsepower is equal to 550 ft-lb/s.

For example, if an irrigation pump located at water tank is pumping 60 gallons of water per minute from a water tank whose water needs to travels along 10 meter or 32.81 feet long of NFT hydroponic growing container, the water horsepower that the pump is delivering is:

WHP = (32.81 x 60) / 3960 = <u>0.497</u> #

So the pump is providing 0.497 WHP when it lifts water 32.81 feet at a rate of 60 gallons per minute.

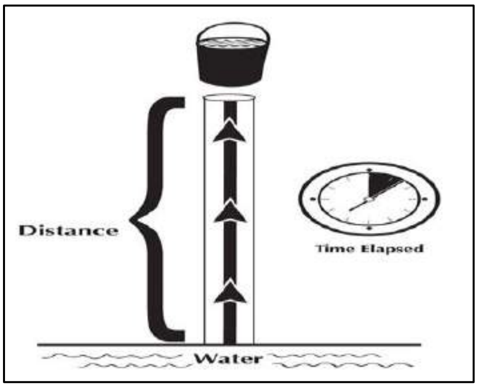

Figure 5: Diagram illustrating water horsepower by moving a volume of water a specified distance per period of time.

Pump Efficiency

No pump can convert all of its mechanical power into water power. Mechanical power is lost in the pumping process due to friction and other physical losses. It is because of these losses that the horsepower going into the pump must be greater than the water horsepower leaving the pump. The efficiency of any given pump (η) is a ratio defined as the water horsepower out divided by the mechanical horsepower into the pump.

η = water hp out / hp into pump 0 < η < 1

If the pump in the last example uses 17.0 HP to provide 13.0 WHP, the pump efficiency is:

η = 13 / 17 = 0.76 or 76%

The pump is 76% efficient, and 24% of the input energy is lost to friction and other losses. Most modern pumps have an efficiency of 50 to 85%.

When choosing a pump, it is important to consider the relationship between efficiency and overall cost. More efficient pumps tend to be more expensive. However, with better efficiency comes lower fuel costs to run the pump. Although more efficient pumps usually come with an increase in capital cost, the overall fuel consumption will be lower, resulting in lower annual fuel or electricity costs.

It should also be noted that the discussion in the previous paragraphs was for a pump properly sized for the application. If the pump does not match the application, it may have to operate in an inefficient range, and fuel or electricity will be wasted. Consult with a Professional Engineer or a pump supplier if you have questions about a specific pump or application.

Hydroponic root zone cooling system performance

Average water- dissolved nutrient temperature distribution profile of HRZC system for 4 weeks from 8.00 am to 5.00 pm daily at different 10 points and levels were as illustrated in Figure 6. Based on the graph, there was no significant difference between 10 points data along 4m of hydroponics growing container at different levels. In average, the HRZC system was found to be able to maintain the root zone temperature at different length and height of hydroponics growing container. The minimum water-dissolved nutrient temperature was 12.33 °C at 10.00 am, located at the early entrance of the flowing water from the water tank at 4 points which were H1.1, H1.2, H1.3, and H1.4. The heat loss was very minimum at these points due to length, water velocity, water level and ambient temperature factors. The maximum water-dissolved nutrient temperature was 23.5 °C at 3.00 pm which located at points H1.7 and H1.8. This was due to that points were located at the end of the growing container which having accumulated heat loss along the pipe length. Moreover, at 3.00 pm, ambient temperature was at the maximum conditions which can increase the heat loss of water-dissolved-nutrient temperature that flows inside the growing container.

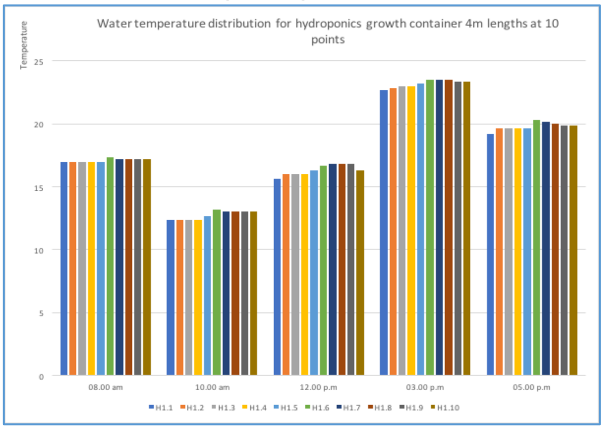

Figure 6: Average water-nutrient temperature distribution profile of HRZC

Conclusions

As a conclusion, it was found that the HRZC system using 0.5 hp water pump was able to distribute and control the hydroponic water-dissolved nutrient temperatures flow to the hydroponic growing container at different height levels of crop protection structure wall. The ranges of temperatures that can be controlled by HRZC using 1.0 hp chiller system were between 15 °C to 25 °C which meets the crop-root zone temperature needs. The ambient temperatures have a significant effect to the water-dissolved nutrient temperatures, in which the increase of ambient temperature can increase the water-dissolved nutrient temperatures inside both of the hydroponic cultivation methods.

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