Development and Performance Test of Misting Cooling System for Greenhouse

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Abstract

In order to relieve the heat accumulation for greenhouse in Summer, the evaporative cooling systems was an effective method to reduce the temperatures of the inside greenhouse lower than those of outside air. Because of the higher relative humidity, the water within the pad materials could not be evaporated completely in evening. Serious development of mold and fungi would be happen. A mist cooling system developed by the evaporative cooling principle was tested in this study. The required quantity of water for evaporating was provided by nozzles operated by high pressure pump. The special design of long path for air flow encountered with mists could increase the efficiency. The results indicated the operated efficiency of cooling system was nearly 80\% to 90\%. The air temperature in greenhouse can be lower to 5–7 °C than those of outside air. The structure of this developed system was simple and inexpensive.

Keywords: Mist, Evaporative cooling, Greenhouse, Temperature

INTRODUCTION

Taiwan is located at the subtropics region. Pretty high solar energy makes the serious problem of heat accumulation in greenhouse in Summer. The mal-formed of flowers and disease development reduced the quality and quantity of numerous species because of the high temperature.

The average maximum day temperature was nearly 36 °C. The endurance maximum temperature of tomato, most popular variety: A–Sue No.1, was limited at 30 °C. The production of tomato in summer was impossible in the open field.

There are four ways to release the heat accumulation problems in greenhouse: 1) shading, 2) ventilation, 3) evaporative cooling, and 4) mechanical refrigeration. The high cost and heavy energy requirement make the

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refrigeration technique be impractical. Shading could decrease the solar entrance energy, however, the minimum requirement of light intensity for plants limited the quantity of shading rates. The air exchanges between the inside and outside of a greenhouse by natural ventilation is based on the difference in temperature between the greenhouse and the ambient air or in pressure with the outside wind. The inside temperature of greenhouse usually higher 5–15 °C than the temperature of outside air because of the insufficient of air exchange rates. The mechanical ventilation rate could be controlled by the power and numbers of fan. The lowest temperature within greenhouse controlled by fans was same as outside air. Many plants still could not survived in the greenhouse by mechanical ventilation. Considering the efficiency and cost for the environmental control techniques, evaporative cooling is the only adequate way to reduce the greenhouse temperature lower than those of ambient air.

The major subjects of climate control for temperate country are heating and energy saving. Fewer literature mentioned about the cooling problem of greenhouse. Montero et al. (1981) discussed three methods of evaporative cooling system and compared the performance by measurement of greenhouse air and plant leaf temperature, they found the fan and pad system was the best system with stable performance.

Walker and Cotter (1968) compared three different methods of evaporative cooling system. They proposed the fine, water-droplet—mist system provided the maximum cooling ability. The pad—cooling system was slightly less efficient. The coarse—mist system could not effectively cool the greenhouse. Giacomelli et al. (1985) tested two ways to cool the greenhouse temperature: a wetted overhead energy—saving blanket and fog nozzles on a moveable boom. The former could reduce the temperature up to 4 °C. The latter made the temperature reduction up to 10 °C. The temperature uniformity was improved by higher air flow rates. Garzoli (1989) reviewed four methods to cool the air temperature in greenhouse and introduced the design criteria for evaoprative cooling systems. Willits et al., (1993) studied the effect of evaporative cooling on the efficiency of external greenhouse shade cloths. Montero and Anton (1994) introduced about four factors which cause the temperature reduction, especially about the crop evaportranspiration. The results of the effect of combination of cooling systems were described detailedly.

There are two evaporative cooling system adopted by growers in Taiwan: fan and pad system and fog system. The fan and pad system is very popular. Along one wall of the greenhouse, water is circulated to pass the pad made of the cross-fluted cellulose material. Exhaust fans are placed on the other side wall. As the air passed the pad wall by the suction of fans, the evaporation of water made the air temperature decreased and relative humidity increased. Some disadvantages were found for this cooling system. As the operation of the system rested in the evening, the high humidity of the ambient air retarded the evaporation of the water within the pad materials. The algae growth was so rapidly that blocked the pass way of enter air and induced the growth of mold and
fungi. The temperature gradient across the greenhouse of the pad system led to uneven growth rates and maturation rates for plants.

In order to develop a new evaporative system for arid regions, Luchow and Zabelitz (1992) developed a spray cooling system and tested its cooling performance. The outside air was sucked through two chambers separated by plastic film then entered the greenhouse. A spray pipe with cone nozzles was installed at each chamber. The pressure of nozzle was with 200 Kpa. The evaporative efficiency was nearly 80%.

The higher ambient temperature and strong solar energy prohibited the culture of fruit vegetables and orchid flower for several months in Taiwan. In order to reduce the greenhouse temperature lower than 30 ℃, the development of cooling system is very important. The serious algae growth problem and high investment affected the adoption of pad cooling system. A simple, low cost, easy maintained and installed cooling system need to be developed. The spray misting system developed by Luchow and Zabelitz (1992) was modified in this study. The cooling performance was tested.

**MATERIALS AND METHOD**

**Experimental greenhouse**

A 25.0m by 56.0m and 3.5m height acrylic covered steel framed structure, closed-type greenhouse located at Tsaotsu town, Nantou was selected to install the mist cooling system.

Tomatoes were planted in the medium bags arranged at the floor. The ventilation system is 16 units of 48inch fans with capacity of 550CMM. The other side is the mist cooling system.

**Mist cooling system**

The sketch of the mist cooling system is shown in Figure 1. The width of the system is 1.2m and the width of each chamber is 0.4m and 0.8m. Two pipes with 24 and 48 nozzles are installed at the middle height of the chamber. The mist cooler is constructed by rigid plastic material and painted as gray color to reduce the algae grown inside the chamber. Two chambers are separated by a plastic film. The cooling chamber is 2.0m height and has the same width as greenhouse. As the fan operates, the outside air is sucked into the greenhouse through the pass way of cooling chamber. The misting droplets from the nozzle encountered the moving air then are evaporated to reduce the air temperature. Two screen nets are installed. The outer screen nets can prevent the entrance of insects. The inner nets serve as the air screen to prevent non-evaporative droplets entering the greenhouse. The water droplets are collected at the bottom of cooling chamber then flowed out the chamber as the system stop operating.

The pump pressure can be adjusted from 30 to 70kg/cm². The operating pressure in this test was usually kept at 40kg/cm². The theoretical required volume of misted water was calculated from the maximum absolute humidity data obtained from meteorological records in Taichung area. The model of nozzle is 0.15 liter/sec at 40kg/cm² pressure and could adjusted by the pump pressure. The experiment was executed from June to August, 1996.
Microclimate measurement

The location of each sensor was shown in Figure 2. Incoming solar radiation at the top of the canopy was estimated by Eppley Radiometer (Model 8–18). This device was calibrated by the ESP-type Radiometer (Eppley of Reference standard) before each tested. The air temperature and relative humidity at each position were measured by Rotronic I–100 Transmitter. Each sensor had its shield device to prevent the errors induced from solar radiation. All climate data were collected by the Delta-T LD2 Logger.

Evaporative efficiency

The definition of the evaporative efficiency of this cooling system is:

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Eff = \frac{Te-Td}{Tw-Td}
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where,

- \(Te\): the air temperature leaving cooling chamber
- \(Td\): the dry bulb temperature of ambient air
- \(Tw\): the wet bulb temperature of ambient air
RESULTS AND DISCUSSION

Evaporative efficiency of cooling system

Figure 3 indicated the evaporative efficiency of mist cooling system at four pump pressures. At the lowest pressure of 30 kg/cm², the efficiencies were ranges from 75% to 80. The cooling efficiencies were from 80 to 88% for the 40 and 50 kg/cm². No significant efficiencies could be found by statistic analysis for two data sets. The highest pressure of 60 kg/cm² had the best efficiency. The effect of the pump pressure was not only for the increase of water volume of nozzles, but also for reduction of the size of droplets. Goering et al. (1972) and Smith (1970) had reported the effect of the droplets sizes on the evaporative cooling. The drop size has not been measured in this study. More detailed experiment need to be executed.

Cooling performance of misting system

Figure 4 showed the microclimate of inside greenhouse affected by ventilation fans. The distribution pattern of the outside temperature was similar that of solar radiation. Because the solar energy was the only source of heat flowed into greenhouse. The inside temperature increased along the longitudinal distance of greenhouse because of the absorption of heat energy in the greenhouse. As the ambient temperature was at the maximum value of 33 °C, the exit temperature of air reached at 39 °C.

As all fans were turned on and enough mists provided by all nozzles, Figure 5 presented the performance of mist cooling system in a sunny day. The inside solar radiation were maintained at 500 W/m² according
Figure 3. The evaporative efficiency of mist cooling system at four pressures

Fig. 4. The effect of ventilation fans on the air temperatures
(The numbers of temperatures are shown as figure 2. The symbols of temperatures are same in following figures)
Fig. 5. The effect of fans and mists on the greenhouse’s microclimate

Fig. 6. The effect of all fans and mists on the air temperatures
the requirement of plant growth. The air temperatures were ranged from 29 °C to 38 °C. The air relative humidity were ranged from 50% to 70%. The air temperatures leaving mist cooling system were maintained about 26 °C nearly the wet bulb temperatures. The air temperatures at the middle position of greenhouse were ranged from 29 °C to 30 °C. The evaporative efficiencies for this system were ranged from 85% to 90%. Figure 6 revealed the distribution of temperatures within the greenhouse. Temperatures increased along the longitudinal direction, that is, the air temperature at the exits near fans had the maximum values. The exit temperatures were ranges from 29 °C to 31 °C. The difference between the t5 and t2 was nearly 4 °C. Figure 7 presented the distribution of relative humilities in greenhouse. The lowest of outside air RH values was at 45%, however, the inside RH values could maintain within the range from 70% to 85%. Although the outside weather was not benefit for tomatoes, the air temperature and relative humidity within the greenhouse could maintain at good conditions for crop’s growth by this mist cooling system.

Figure 8 indicated the cooling ability of this system at the other day. The highest solar radiation was 550W/m². The ambient air temperatures were higher than 35 °C. The temperatures within greenhouse (t2, t3, and t5) all lower than 30 °C.

As all fans were turned on but the mist only be supplied by half of nozzles, the cooling performance is presented in figure 9. The wet bulb temperatures were nearly 26 °C, however, the air temperatures leaving mist system were as high as 30 °C. The evaporative efficiency reduced from 30% to 40%. The temperatures of middle position were higher than outside temperature.

At the condition that enough mists were provided and only half of fans were turned on, the performance of mist cooling system is presented in Figures 10. The air temperatures leaving the cooling system were kept at stable. The evaporative efficiency was 85%. The inside temperatures at position at 14m and 28m could be maintained lower than 31 °C. The temperatures at exit position were similar as the temperatures of outside air.

From the results of Figure 9 and 10, insufficient air exchange rates or shortage of mist supply could reduce the cooling ability for back part of greenhouse.

**Long-term performance of mist cooling system**

The performance test of this system was executed from June, 1996 to July, 1997. The routines maintain work for this system was to clean the block of nozzles and changed the filters of water supply systems. Figure 11 revealed the cooling performance of this system at July 2, 1997. The air temperatures leaving cooling system all kept within 27 °C and the evaporative efficiency were maintained at 85%. The temperatures of back part greenhouse could be kept below 31 °C. The results indicated the good long-term performance for this mist cooling system.

**Equipment commercization**

The mist cooling system developed by this study have been commercized by local greenhouse manufacturing companies. Tomato and orchids have been successfully cultured in the greenhouse in Summer in 1996. All greenhouse temperature could be controlled within 30 °C by the mist cooling system.
Fig. 7. The effect of all fans and mists on the air relative humidities

Fig. 8. The effect of all fans and mists on the air temperatures in the 550W/m² solar radiation
Fig. 9. The effect of all fans and half mists on the air temperatures.

Fig. 10. The effect of half fans and all mists on the air temperatures.
Fig. 11. The effect of operated period on the performance of mist cooling systems

CONCLUSIONS

In this study, the evaporative cooling principle was adopted to develop a mist cooling system. The required water for evaporating was provided by nozzles operated by high pressure pump. The special design of long path for air flow encountered with mists increased the efficiency. The results indicated the operated efficiency of the mist cooling system was nearly 80% to 90%. The temperature of inside greenhouse can be lower to 5–7 °C than those of outside air. The structure of this system developed in this study was simple and inexpensive.
REFERENCES


細霧降溫系統之研究

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摘要：為能疏解溫室內部於夏季之熱累積問題，利用蒸發冷卻技術可使溫室內部溫度於外界溫度。台灣地區傍晚後相對濕度相當高，水漬使用後內部水份無法完全蒸發，因此產生嚴重的長霉與長菌問題，迅速降低水漬降溫效率與使用年限。此研究中以蒸發冷卻原理開發細霧降溫系統，以高壓風溝供應所需水量並配合噴頭製造細霧。空氣與霧滴接觸時間增長以提高作業效率。試驗結果顯示此細霧降溫系統之蒸發冷卻效率為 80-89%。利用於番茄栽培時溫室內溫度可低於外界溫度約 5-7 ℃。此系統簡易、成本低廉，適用於亞熱帶氣候使用。

關鍵詞：細霧、降溫系統、溫室、溫度。

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