THE EFFECT OF PAD COOLING MATERIALS ON ENVIRONMENTAL CONTROL FOR GREENHOUSES

KASSEM, A.M., A.M.F BAHNASSY AND Y.F. SHAROBEEM

Ag.Eng. Res. Inst., A. R. C. Dokki, Giza.

(Manuscript received 9 May 2004)

Abstract

Pad cooling system is a solution of the heat problem in cucumber greenhouses. The objective of this research is to study the possibility of using local materials such as palm fibers and sponge to replace the imported pads (Corrugated cellulose). Three gable greenhouses were used to compare three different pad cooling system using palm fiber, sponge and corrugated cellulose. The experiments were carried out during the summer months (June, July and August) of year 2002 and 2003. The results indicated that the best cooling efficiency was 79.4% obtained in greenhouse with corrugated cellulose and the minimum was 49.2% in greenhouse with spongy pad. The experiment showed that there were slight difference of cooling efficiency between palm fiber and corrugated cellulose. The mean cooling efficiency for corrugated cellulose, palm fiber and sponge were 79.4, 71.6 and 49.2 respectively. The total fresh yields were 13255.4, 13065.0 and 8353.4 kg for corrugated cellulose, palm fiber and sponge pad cooling, respectively.

INTRODUCTION

Evaporative cooling has many practical applications in agricultural buildings or farm structures. It has become an ideal solution of the heat problem in many greenhouses. Evaporative cooling is divided into two systems, namely misting and pads cooling systems. Evaporative cooling has been used to reduce the inside air temperature and the associated heat stress in broiler production. Evaporative cooling for broiler housing is typically provided by pad or misting systems. Evaporative pad systems tend to be more efficient in evaporating water than misting systems. Pad systems have also been credited by growers and equipment dealers since they provide substantially more cooling effect than misting systems in intensive broiler housing. (Yanagi *et al.*, 2001, Bridges et al., 2003, Tinôco *et al.*, 2003, Xiuping and Hongwei, 2003). The evaporative efficiency of pad system typically changes only slightly over a wide range of air velocities through the pad, so that the water evaporation rate given outside psychometric conditions is essentially proportional to ventilation rate. At the moment, pads which present the back bone of the system are imported. The objective of this research is to study the possibility of using local materials such as palm fibers and sponge to replace the imported pads.

REVIEW OF LITERATURE

Evaporative pads are commonly used to aid greenhouse cooling in warm climates by lowering the dry bulb temperature of the inlet air. Pads at inlets are sized to maintain the face velocities that can be expected to reduce inlet air temperature to within 2.0 °C (3.6 °F) of the outside wet bulb temperature at pressure drop through the pads not exceeding 0.015 kPa (0.060 in. H_2O). Higher face velocities typically result in reduced cooling. Temperature rise in a house cooled with evaporative pads will generally be greater, all other parameters being equal, than in a house where evaporative pads are not used; however, average inside temperatures will generally be significantly lower (ANSI/ASAE. 2003).

ASHRAE (1983) stated the following equation to be employed for calculating the evaporative cooling efficiency or saturation effectiveness:

$$\eta = \frac{(T_{odb} - T_{cdb})}{(T_{odb} - T_{owb})} \times 100$$

where :

η = evaporative cooling efficiency, %

T_{cdb} = dry-bulb temperature of cooled air, °C.

T_{owb} = wet-bulb temperature of outside temperature, °C.

T_{odb} = dry-bulb temperature of outside air temperature, °C.

Timmons and Baughman (1984) concluded that by using evaporative pad cooling system, for a plenum concept, evaporative efficiencies of 80% can be obtained with reasonable ventilation rates while simultaneously maintaining average inlet velocities above 3 m/s and average floor velocities of 0.9 m/s. Pad location effects can cause differences in evaporative efficiencies of up to 15%, apparently due to direct solar radiation effects.

Simmons and Lott (1996) studied the effect of water temperature on the performance of an evaporative cooling system. Results showed that for each inlet-air temperature tested, the performance of the evaporative cooling system decreased as the water temperature increased.

Hellickson and Walker (1983) stated that an increase in pad thickness directly increases the resistance to air flow while increasing the contact time of air traveling through the pad. However, as air passes through additional thickness of the pad, the vapor pressure differential decreases. The results increasing in the rate of evaporation into a given element while it continues its path through the pad. The precise relationship is not well known. Increased pad density enhances overall porosity or capillarity providing more uniform distribution of water. It also requires higher water flows and increases resistance to air flow. While in the vertical orientation, dense pads tend to be somewhat more self-supporting than looser pads, but pads of any density require some supporting framework to prevent sagging. Any sagging that opens up holes for direct airflow should especially be prevented since it seriously affects cooling efficiency.

Abdellatif and Helmy (1988) indicted that the angle of incidence for North-South direction increases gradually with solar time from sunrise until it reaches the maximum value at noon (near 90°). It then decreases gradually till it reaches the minimum value at sunset (near 10°) whilst the solar incident angle for East-West orientated greenhouse decreases gradually with solar time until it reaches the minimum value at noon (near 10°). It then increases gradually till it reaches the maximum value at sunset (near 80°). Therefore, the daily average solar radiation available inside the East-West and North-South orientated greenhouse for winter months were 4.91 $kWh/m^2/day$ and 3.74 $kWh/m^2/day$ respectively. Consequently, the East-West increases available solar radiation by 1.17 $kWh/m^2/day$ (31.3%).

Abdellatif and Lieh (1992) developed a computer model of glasshouse planted ornamental crops in order to assess heat requirements for maintaining optimum ambient air temperature glasshouse. They showed that ventilation and infiltration losses are negligible in a wall-constructed glasshouse. The steady state energy balance can be computed from the following equation:

$Q_{load} - Q_{loss} - Q_{gain} = 0$

$Q_{load} = Q_{loss} + Q_{gain}$ Watt

$Q_c = U_0 A (T_{ai} - T_{ao})$ Watt

$Q_{inf} = m_0 . c_p (T_{ai} - T_{ao})$ Watt

Where:-

Q_{gain} = Solar heat gain Q_{loss}= Heat losses. Q_{load}= Heat load.

Q_c = Combination heat losses or gain (by conduction, convection, and radiation) through the concrete blocks and glass cover of the glasshouse.

Q_{inf} = Heat losses due to cold air infiltration (through the structure) from outside to inside of the greenhouse

U_0 = Overall heat transfer coefficient.

A = Wall surface area.

c_p = Specific heat of air.

m_0 = Mass flow rate of air.

T_{ai} =Inside ambient temperature

T_{ao} = outside ambient temperature

The solar heat gain can be estimated by the following equation (ASHRAE, 1983):

$Q_{gain} = L_s A_f \lambda$

Where:-

L_s = Solar radiation flux incident, W/m^2

A_f = Floor surfaces area of greenhouse, m^2

λ = Effective transmittance of the greenhouse cover, decimal

Kittas et al. (2001) investigated temperature and humidity gradients during summer in a commercial greenhouse producing cut roses, equipped with a ventilated cooling–pad system. In a steady regime, the cooling process reached 80% efficiency and succeeded in maintaining greenhouse temperatures that were cooler (up to 10 ^{0}C lower) than outside. In early morning and late afternoon, the moist and cool air coming from the pads seemed to induce condensation on the soil. The physical data were compared with those predicted by an analytical model describing the greenhouse as a heat exchanger. The model helped to clarify the particular temperature and humidity profiles of the air flow along the greenhouse.

Arbel *et al.* (2003) developed fogging system mathematical model, and the operational characterization of the fogging system in combination with forced ventilation for cooling greenhouses. The cooling system was installed and operated according to the following scheme: high-pressure spray nozzles with the highest possible uniformity of distribution, fans at both ends of the greenhouse (north & south) were placed at ground level, roof openings and two side openings (east & west). The results obtained revealed that inside greenhouse air temperature and relative humidity of 28 °C and 80% respectively, were maintained during the summer at midday and generally high uniformity of the climatic conditions (the same magnitude of temperature measurements error ±0.5°C), within the greenhouse, in the lengthwise (north-south) and vertical directions. In contrast to that, there was significant variation across the width of the greenhouse (east-west), which arose as a result of wind action; however, under the conditions of a greenhouse with developed plants or with the windward openings closed, uniform conditions were obtained.

MATERIALS AND METHODS

Three structural frame experimental greenhouses were designed to cultivate cucumber crop, constructed and installed at the Agricultural Engineering Research Institute (AEnRI) as shown in Figure 1. The experiments were carried out during the summer months (June, July and August) of years 2002 and 2003. The greenhouses were constructed on gable even span form each one having a gross dimensions of 4m long, 2m wide and 2.8m height, with a net floor surface area of 8 m^2. The structural frame of the greenhouse is made of the water-galvanized pipes. The rafter length of the gable of greenhouse is 1.25 m the gable height is 0.8 m, and height of each side wall is 2 m. The rafters are tilted at 30°, to minimize the side effects of wind load on the roof of greenhouse and to reduce the intensity of solar radiation during summer months. At the same time it may maximize the solar radiation flux incident on the inclined roof of the greenhouse during winter months. The experimental greenhouses were covered using 0.2 mm thick UV polyethylene sheet. To increase and maintain the durability of structural frame and polyethylene cover, twenty-five tensile galvanized wires (2.0 mm diameter) were tied and fixed throughout the rafters, curvatures, and vertical pipes in each side of the greenhouse frame.

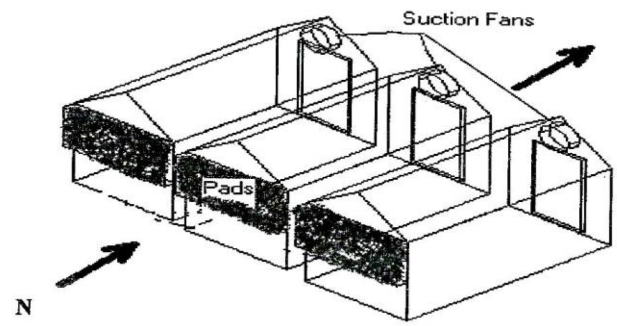

Fig. 1. Sketch of the plastic greenhouse with different pad system

The experimental greenhouses were orientated to North-South direction. This direction of orientation was found to be the best direction for maximizing solar energy available inside the greenhouse (Arbel et al., 2003).

A 48-channel chart recorder recorded temperature, relative humidity, solar radiation and air flow rate inside and outside the greenhouse. Thermocouples, disk solar meter and anemometer were used.

Three materials of local and imported pads were used. These materials were palm fibers, sponge and corrugated cellulose. Metal frame of 2 m long 0.5 m pad width and 0.15 m thickness were fabricated for each pad. The metal frame was used as a carrier for the pad materials. The three pads had the same weight and density of 2.328 kg and 15 kg/m^3 respectively.

RESULTS AND DISCUSSIONS

Figure (2) shows that the temperature inside the greenhouse gradually increased with the time of the day from 20.86°C, 20.6°C and 22.9°C at 6.00 am hour to 30.26°C, 29.8°C and 31.1°C at 12 moon and remained above this level until it reached a maximum value of 31.18°C, 31°C and 32°C at 2.00 pm. It then decreased gradually to 29.56°C, 29.30°C and 31.50°C at 6 pm for the three greenhouses with palm fiber, corrugated cellulose and sponge pad cooling, respectively. The low temperature at the begining of the day and the high temperature at the end of the day are due to the natural specification of the polyethylene sheet. The mean values for the inside temperature were 27.67, 28.80, and 27.31 °C, palm fiber sponge and corrugated cellulose respectively.

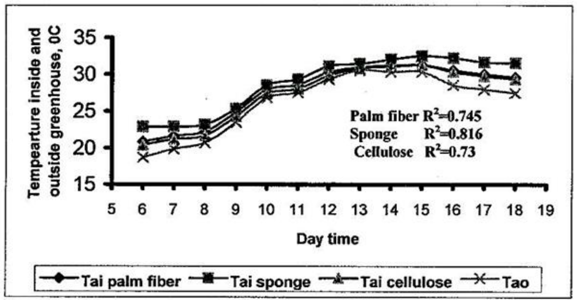

Fig.2.Relationship between day time and average air temperature inside greenhouses.

The hourly cooling efficiency of pad cooling is illustrated in Figure (3). It shows that for three different pad cooling system, the mean values for the cooling efficiency were 71.60, 49.20 and 79.37 %, for palm fiber, sponge and corrugated cellulose pads respectively. It clearly reveals that pad cooling efficiency increased sequentially from the early morning to a peak around mid-after noon when normally the maximum daily ambient air temperature occurred. After which the cooling efficiency decreased.

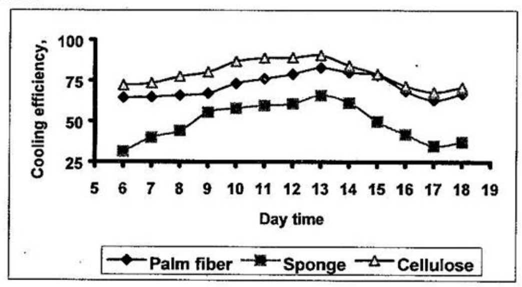

Fig.3. Relationship between day time and cooling efficiency

Figure (4) shows the total heat losses from the three different system of pad cooling (by convection, radiation and infiltration). It obviously shows that the greatest magnitude of heat losses (1334.10 W/day) occurred from greenhouse with corrugated cellulose when ambient outside air temperature at morning was (18.7 °C). Whilst, the lowest magnitude of heat losses (577.07 W/day) occurred from greenhouse with sponge pad when outside temperature at noon was (30.5 °C).

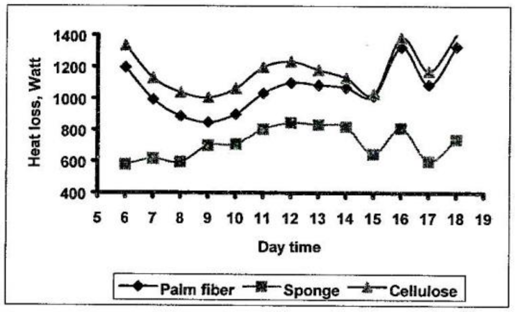

Fig.4. Effect of day time increase on heat losses for three different systems of pad cooling.

Figure (5), indicted that the mean value for inside relative humidity (%) were 43.53, 47.24, and 47.05 for palm fiber pads, sponge and corrugated cellulose, respectively. The relative humidity inside greenhouse gradually decreased with the time of the day from 65.83, 67.2 and 68.72 at 6.00 am hour to 28.15, 36.43 and 35.41 at 3 pm. It then increased gradually at 6.00 pm for the three green houses with fiber palm, corrugated cellulose and sponge pad cooling.

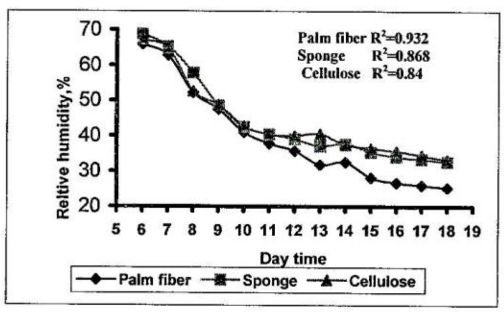

Fig.5. Effect of day time increase on relative humidity inside greenhouse using the different pad cooling systems.

CONCLUSION

The results observed in the cooled greenhouse were encouraging. It was quite satisfying the findings that the cooling system could totally prevent greenhouse overheating in summer.

There were slight differences between cooling efficiency using palm fiber and corrugated cellulose. The mean cooling efficiency for corrugated cellulose and palm fiber were 79.37 and 71.60 %, respectively. The total fresh cucumber yields were 13255.4, 13065.0 and 8353.4 kg for corrugated cellulose, palm fiber and sponge pad cooling, respeetively. It is recommended that palm fiber pad cooling which has nearly the same yield could be effectively used, add to that it is more cheaper and available in the prevailing environment.

REFERENCES

1. Abdellatif, S.M. and H.J. Lieth 1992c. Heat requirements for maintaining optimum ambient air. Misr J. Ag. Eng. Vol. 9(4):635-655.
2. Abdellatif, S.M. and M.A. Helmy 1988. Some parameters affecting solar energy available inside the greenhouses under Kafr El-Sheikh conditions. Misr, J. Ag. Eng., Vol. 5(2):167-178.
3. Arbel, A., M. Barak, and A. Shklyar 2003. Fogging Systems for Cooling Greenhouse. ASAE Annual International Meeting Las Vegas, Nevada, USA
4. ANSI/ASAE EP406.4 JAN03 2003. Heating, Ventilating and Cooling Greenhouses. ASAE. St. Joseph, MI.49085-9659.
5. ASHRAE 1983. Evaporative air-cooling equipment. Chapter 4., In equipment handbook, American Society of Heating Refrigerating Air Conditioning Engineers, Inc.
6. Bridges,T.C., L. W. Turner, R. S. Gates, D. G. Overhults 2003. Assessing The Benefits of Misting-Cooling System for Growing Finishing Swine as Affected by Environment and Pig Placement Date. Applied Engineering in Agriculture. Vol. 19(3): 361–366.
7. Hellickson,, M.L. and J.N. Walker 1983. Ventilation of agricultural structures. ASAE. St. Joseph, MI.49085-9659.

8. Simmmons, J.D. and B.D. Lott 1996. Evaporative cooling performance resulting from changes in water temperature. Applied Engn. In Agr. ASAE vol. 12 (14):497-500.
9. Kittas, C., T. Bartzanas, and Jaffrin 2001. Greenhouse Evaporative Cooling: Measurement And Data Analysis. Transactions of the ASAE, Vol. 44(3): 683–689
10. Timmons M.B. and G. R. Baughman 1984. A plenum concept applied to evaporative pad cooling for broiler housing. Trans. of the ASAE. 31(21):1877-1881.
11. Tinôco, F.F., R.S.Gates, A.L.A.Tinôco, F.C.Baêta, P.R.Cecon, and H.Xin 2003. Evaluation of Broiler breeder housing in high temperature Brazilian conditions. Paper number 034038, ASAE Annual Meeting .
12. Yanagi Jr.,T., H. Xin,and R. S. Gates 2001. Modeling partial surface Evaporative cooling of chickens. Paper number 013011, ASAE Annual Meeting.
13. Xiuping T, and X, Hongwei 2003. Optimization of surface wetting to cool broiler chickens. Paper number 034088, ASAE Annual Meeting.

8. Simmmons, J.D. and B.D. Lott 1996. Evaporative cooling performance resulting from changes in water temperature. Applied Engn. In Agr. ASAE vol. 12 (14):497-500.
9. Kittas, C., T. Bartzanas, and Jaffrin 2001. Greenhouse Evaporative Cooling: Measurement And Data Analysis. Transactions of the ASAE, Vol. 44(3): 683–689
10. Timmons M.B. and G. R. Baughman 1984. A plenum concept applied to evaporative pad cooling for broiler housing. Trans. of the ASAE. 31(21):1877-1881.
11. Tinôco, F.F., R.S.Gates, A.L.A.Tinôco, F.C.Baêta, P.R.Cecon, and H.Xin 2003. Evaluation of Broiler breeder housing in high temperature Brazilian conditions. Paper number 034038, ASAE Annual Meeting .
12. Yanagi Jr.,T., H. Xin,and R. S. Gates 2001. Modeling partial surface Evaporative cooling of chickens. Paper number 013011, ASAE Annual Meeting.
13. Xiuping T, and X, Hongwei 2003. Optimization of surface wetting to cool broiler chickens. Paper number 034088, ASAE Annual Meeting.

تأثير الوسائد المبردة على التحكم البيئى داخل البيوت المحمية

احمد محمد قاسم ، احمد محمد فوزى بهنسى ، يوسف فرج شاروبيم

معهد بحوث الهندسة الزراعية – مركز البحوث الزراعية – دقي – جيزة

يعتبر التبريد عن طريق استخدام الوسائد المبردة من أهم وسائل التبريد التى تستخدم فى مزارع الدواجن والبيوت المحمية والدراسة الحالية تتعرض لثلاث أنظمة من وسائل التبريد باستخدام ثلاث مواد مختلفة محلية ومستوردة، بهدف مقارنة كفاءة تبريد هذه المواد ومعرفة انسبها لزراعة الخيار تحت ظروف البيوت المحمية خلال فصل الصيف سنوات ٢٠٠٢ ، ٢٠٠٣.

لتحقيق هذا الهدف تم إنشاء ثلاث صوب جمالونية طولها ٤م وعرضها ٢م وارتفاعها ٢,٥م ومساحة أرضيتها ٨م^{2} وزاوية الجمالون ٣٠° مصنوع من أنابيب المياه المجلفنه. غطاء الجمالون عبارة عن بلاستيك من البولى اثيلين سمكه ٠,٢ مم. أبعاد الإطار الذى يحتوى على المادة المستخدمه فى التبريد هى ٢م طول، ٠,٥م وعرض وهو مصنوع من الحديد. كثافة مادة التبريد داخل الإطار هى ١٥ كجم/م بوزن ٢,٣٢٨ كيلو جرام لجميع المواد المستخدمة. تمت التجارب على محصول الخيار خلال أشهر يونيو ، يوليو واغسطس من عامى ٢٠٠٢ــ ٢٠٠٣. استخدم حساس لقياس كل من درجة الحرارة والاشعاع الشمسي داخل وخارج الصوب وتسجيل البيانات على جهاز تسجيل بيانات ذات ٤٨ نقطة.

أظهرت النتائج ان متوسط الناتج لكل صوبة ١٣٢٥٥,٤، ١٣٠٦٥ و٨٣٥٣,٤ كيلوجرام خيار لكل من الصوب الثلاث الملحق بها وسائد تبريد السليلوز ولباد النخيل و الإسفنج على التوالي. لا يوجد فرق معنوى فى كفاءة التبريد بين استخدام السليلوز المرتفع الثمن أو استخدام لباد النخيل المتوفر تحت ظروف مصر، لذلك يوصى البحث باستخدام وسائد التبريد المصنعة محليا بخامات متوفرة فى البيئة كبديل ذو كفاءة عالية ورخيص الثمن ومتوفر فى جمهورية مصر العربية.