Journal of Energy Research and Environmental Technology (JERET)
p-ISSN: 2394-1561; e-ISSN: 2394-157X; Volume 3, Issue 1; January-March, 2016; pp. 19-23

http://www.krishisanskriti.org/Publication.html

Study the Performance of a Fogging System for a Naturally Ventilated, Fog-cooled Greenhouse

A.S. Mirja[1], D. Misra[2] and S. Ghosh[3]

[1,3]Department of Mechanical Engineering, Indian Institute of Engineering Science and Technology, Shibpur, India-711103
[2]Department of Mechanical Engineering, Saroj Mohan Institute of Technology, Guptipara, Hooghly, India-712512
E-mail: [1]mirjaamarsekh@gmail.com, [2]dmbesu@gmail.com, [3]sudipghosh.becollege@gmail.com

Abstract—*This paper presents an analysis of the cooling performance of a naturally ventilated fog-cooled greenhouse. In a fog-cooled greenhouse, it is seen that only a part of the fogging water evaporates, and some part of the fogging water remains unevaporated. A methodology is evolved to calculate the fraction of evaporated water from the fogging nozzles and thus to evaluate the performance of the fogging system in a naturally ventilated greenhouse. A theoretical model for the fogging system has been proposed and the same has been evaluated through experimental data. The performance of the fogging system was studied for two distinct fogging durations and different fogging intervals. The study revealed that the fraction of evaporated liquid depends upon the fogging duration and fogging interval as well as the ventilation rate. The experiments were done in a single span polyethylene covered greenhouse located at Coochbehar (Latitude: 26.2°N, Longitude: 89°E), India, considering spraying duration of 1.5min followed by interval of 4.5 min and spraying duration of 0.5 min followed by interval of 2 min. We have compared the values of the fraction of fog evaporation for both fogging conditions (fogging duration-interval time) fixed which fogging time gives maximum values of the fraction.*

1. INTRODUCTION

Greenhouses are the structures covered with a transparent material in which crops are grown under controlled environment conditions. Greenhouses and other technologies for controlled environment plant production are associated with the off-season production of foods of high value in cold climate areas where outdoor production is not possible.

The greenhouses must be cooled during the hot summer season to increase productivity. For cooling purpose, different types of greenhouse cooling systems are used. Natural ventilation is an effective way to reduce the temperature of greenhouse when the summer temperature is below 32°C. But proper cooling of a greenhouse can't be done with natural ventilation without wind and when the ambient temperature is above 32°C. Thats why forced ventilation came into the picture where exhaust fan, blower can supply high air exchange rates whenever needed. Although forced ventilation increases the number of air changes through the greenhouse, but it is seen that the use of fan is not sufficient to remove the inside hot air with closed greenhouse in peak summer. It is also seen that use of fan includes large heterogeneity in the temperature field. In shading, which is cheap, easy and effective method of controlling the excessive solar radiation in summer, but it is seen in the literature reviews that not much drop in the inside air temperatures can be achieved in hot climatic conditions. Another cooling process is the fan-pad cooling process which lowers the greenhouse air temperature by 5-6°C. But, continuous operation and poor water quality cause progressive clogging of the pad, resulting in decline in cooling performance. Due to this another cooling system called fogging system came to the picture.

Fogging systems are based on spraying water as small drops in the fog range (≤ 60μm in diameters) in order to increase the water surface in contact with the air. The drops are easily carried by the air stream in the greenhouse and evaporate by absorbing latent heat from the air, resulting in a decreased dry bulb temperature and increased air humidity.

In case of fogging system, highest possible uniformity of temperature distribution occurs. This type of cooling system can provide a wide range of desired temperatures and relative humidities in greenhouses during most months of the year. Fogging systems are less expensive to install and operate, therefore, these systems have been used in Japan and other countries for cooling greenhouses. The popularity of fogging systems is due to their ability to economically maintain the desired growth conditions in the greenhouses (temperature and relative humidity). Evaporation of water drops depends on the design parameters of the fogging system and on the environmental factors in the greenhouse, which are essentially air temperature, air speed and air humidity. However, not all the drops evaporate completely before reaching the floor. A portion of these drops, which depends on their descending velocities, fall on the floor. This portion is referred to as non-evaporated fog. The fraction of fog that evaporates by absorbing latent heat from the greenhouse air is an essential parameter to be determined for evaluating the system performance and cooling efficiency. The fraction is the difference between sprayed fog and non-evaporated fog divided by the sprayed fog. Increasing the factor increases the cooling efficiency of the system.

Arbel *et al*. [1] established the performance comparison of fogging system and fan-pad system. They described that in case of fan-pad system, the air must be forced through the pad, which offers appreciable resistance to the passage of air, and also significant temperature and humidity gradients, along the greenhouse, are created. On the other hand, uniform conditions of temperature and relative humidity in the greenhouse were observed for the fog system.

Sethi *et al*. [2] reviewed the available worldwide cooling technologies for agricultural greenhouses. It was seen that Natural ventilation systems which can lower the greenhouse air temperature (2–3°C), are generally less efficient and are not satisfactory in sunny days without wind. Forced ventilation is also not sufficient to lower the inside air temperature in peak summer. They had concluded that in the extreme environmental locations, where ambient temperatures in summer generally exceeds 40°C, evaporative cooling methods (fogging and fan-pad system) are most useful.

Toida *et al*. [3] had discussed enhancing of fog evaporation rate to increase the cooling efficiency of greenhouse. To increase the cooling efficiency and to keep the floor relatively dry, the ratio of evaporated fog to generated fog needs to be increased. They used a vertically installed conventional nozzle with two small fans to provide an upward air stream for enhancing fog evaporation in compared with a vertical nozzle and an approximately horizontal nozzle, both without any fan. They concluded that the nozzle with fans gives 1.5 times better evaporation ratio, so more cooling efficiency in compared to the nozzle without fans under similar conditions.

2. EXPERIMENTAL GREENHOUSE

A single-span polyethylene covered greenhouse with plants having leaf area index 0.25 was selected for collecting experimental data. The greenhouse was located at the city of Coochbehar (Latitude: 26.2°N, Longitude: 89°E), which is about 700 km distance from Kolkata. The greenhouse was 20 m in length, and the span was 12.5 m. The ridge of the greenhouse was 5.5 m and gutter was 4 m above the soil surface. The greenhouse was equipped with fog cooling system. There were 32 fog nozzle evenly distributed at 2.2 m height from the floor. The greenhouse had continuous roof vent at ridge and continuous side vents, and were oriented in east west direction. The side ventilators are 0.9 m wide and covered by insect proof screen. During the experimental period meteorological parameters in the greenhouse were measured when all ventilators were completely opened.

The main elements of fogging system of the greenhouse were a water reservoir, water softener and filters to prevent nozzle clogging, pumps and a pressure regulator, and the fog nozzles. Four fog nozzle lines were equipped with 2.5 m spacing and connected to central water feed system. There were total 32 fog nozzles in nozzle line. At each nozzle line, 8 fog nozzles were uniformly located with 2 m spacing. Fog nozzles sprayed water to the greenhouse by electrically operated pump at a pressure of 3 bar.

Fig. 1: Experimental greenhouse

3. MATHEMATICAL EQUATIONS

3.1 The cover and floor temperatures

The energy balance equations of the cover and floor surface as given by Abdel-Ghany [4] are as follows

$$R_c - Q_{c-i} - Q_{c-o} - 2E_c = 0 \quad (5)$$

$$R_f - Q_{f-i} - F_x - E_f = 0 \quad (6)$$

The convection heat transfer coefficients can be estimated from the following equations as mentioned by G.N Tiwari [5]

(i) Between the cover surface and the outside air

$$h_{c-o} = 5.7 + 3.8V \quad (7)$$

(ii) Between the cover surface and inside air

$$h_{c-i} = 1.95(T_c - T_{db,i})^{0.3} \quad (8)$$

(iii) Between the floor and the inside greenhouse air

$$h_{f-i} = 2.38(T_f - T_{db,i})^{0.25} \quad (9)$$

3.2 The Ventilation Rate

Based on the assumptions of a steady state condition in the greenhouse, the ventilation rate can be estimated from the heat balance equation as mentioned by Arbel [6].

$$m_a = \frac{G_i - U(T_{di} - T_{do})}{I_i - I_o} \quad (10)$$

The enthalpy of the air inside and outside the greenhouse ($I_i and I_o$) can be written as mentioned by Arbel [2].

$$I = (1.007T - 0.026) + \omega(2501 + 1.84T) \quad (11)$$

3.3 Uncooled Air Temperature

Uncooled air temperature (T_u) was formulated based on the sensible heat balance of the inside air at the absence of fogging effect as mentioned by Abdel-Ghany [4]

$$T_u = \frac{(m_a C_{pa} T_{do}) + (h_{c-i} T_c) + (h_{f-i} T_f)}{m_a C_{pa} + h_{c-i} + h_{f-i}} \qquad (12)$$

Fig. 2: Psychrometric chart showing the processes of: sensible heating (O–S), latent heating (S–U) and fogging (U–I) in the naturally ventilated, fog-cooled greenhouse

The absolute humidity of the un-cooled air (ω_u) can be estimated from the following equation

$$\omega_u = \omega_{si} - \frac{C_{pa}[T_u - T_{wi}]}{k} \qquad (13)$$

3.4 Fraction of fog evaporation (β)

Fraction of fog evaporation (β) can be estimated from water vapour balance of the greenhouse air during the fogging process.

$$\beta m_w = m_a(\omega_i - \omega_u) \qquad (14)$$

4. RESULTS

4.1 Experimental Measurements

Experiments were conducted for the naturally ventilated greenhouse taking both roof ventilator and side ventilators open and with intermittent spraying water fog. A constant fogging rate of 0.175 gm/m^{2}s was supplied to the greenhouse. Experiments were done considering fogging conditions (spraying time-interval time) of 1.5-4.5 min and 0.5-2 min. Water at 3 bar pressure was pumped to the nozzles through plastic pipes. The measurements were conducted on a particular day of summer in 2015 and on a particular day of winter in 2016 respectively. The following parameters were recorded (i) outside dry and wet bulb temperatures using digital psychrometers (HTC HD304), (ii) inside temperature by aspirated temperature sensor, (iii) outside wind speed using an anemometer (HTC AVM06). Model results have been graphically presented in this section.

Table 1: Experimental values of the greenhouse parameters for fogging duration of 0.5 min and interval of 2 min

Time of the day	Ambient Temperature Ta (°C)	Wind speed V (m/s)	Greenhouse inside temperature after fogging T_g (°C)	Cover Temperature T_c (°C)	Floor Temperature T_f (°C)
7	20.2	0.35	20.5	29.95	29.97
8	21.6	0.27	21.6	31.21	31.21
9	22.1	0.42	22.9	32.08	32.14
10	23.2	0.37	24.2	33.27	33.35
11	24.8	0.29	25	34.5	34.52
12	25.2	0.38	26.4	35.36	35.45
13	25.7	0.42	26.6	35.72	35.79
14	26.2	0.46	26.7	36.03	36.08
15	24.9	0.48	25.6	34.83	34.89
16	24.1	0.3	24.7	33.98	34.03

Table 2: Experimental values of the greenhouse parameters for fogging duration of 1.5 min and interval of 4.5 min

Time of the Day	Ambient Temperature T_a(°C)	Wind Speed V (m/s)	Greenhouse inside temperature after fogging T_g (°C)	Temperature of the Floor T_f(°C)	Temperature of the Cover T_c(°C)
6	27	0.6	24.3	28.5	29.7
7	29.8	0.7	26.5	30.4	31.4
8	31.3	0.9	27.7	32.6	33.6
9	33.1	1.1	29.1	33.7	36.2
10	34.8	0.9	30.7	34.2	37.3
11	35.2	1.2	31.2	35.8	39.1
12	36.4	1.1	32.1	36.7	40.5
13	36.7	0.8	32.7	37.5	41.2
14	36.9	0.6	33	37.7	41.4
15	35.6	0.9	32.2	36.8	40.6
16	33.5	1.1	29.6	35.1	38.3
17	32.2	0.7	28.7	33.7	36.4
18	30.8	0.6	27.2	32.2	33.1

By using the experimental values of different parameters of the greenhouse, we have calculated the values other parameters of the greenhouse by using EES software.

Table 3: Calculated values of different parameters of the Greenhouse for fogging duration of 1.5 min and interval of 4.5 min

Time of the day	Ventilation Rate m_a (kg/m^{2}s)	Fraction of Fog Evaporation (β)
6	0.191	0.44
7	0.097	0.27
8	0.095	0.28
9	0.095	0.29
10	0.082	0.22
11	0.080	0.28
12	0.063	0.25
13	0.075	0.30
14	0.086	0.31
15	0.086	0.35
16	0.082	0.35
17	0.092	0.36
18	0.133	0.33

Table 4: Calculated values of different parameters of the Greenhouse for fogging duration of 0.5 min and interval of 2 min

Time of the day	Ventilation Rate m_a (g/m^2s)	Fraction of Fog Evaporation (β)
7	123.9	0.23
8	111.4	0.21
9	79.0	0.15
10	96.7	0.18
11	96.4	0.18
12	88.6	0.16
13	88.5	0.16
14	100.6	0.19
15	92.3	0.17
16	85.3	0.16

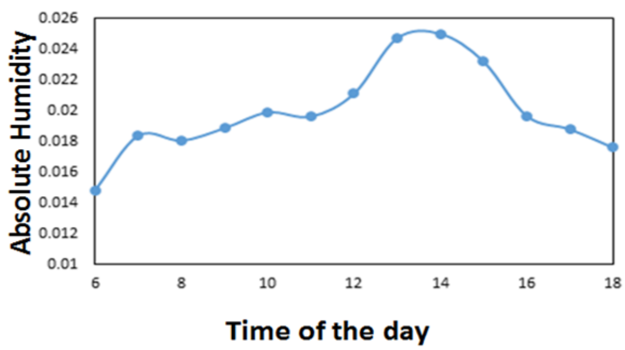

Fig 3: Variation of Absolute Humidity with Time of the day for fogging duration 1.5 min and interval of 4.5 min

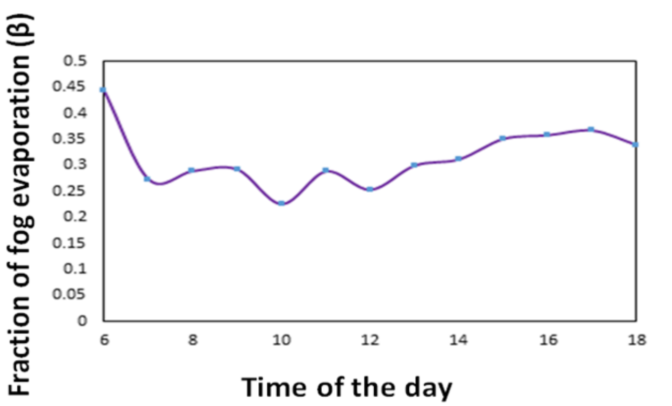

Fig 4: Variation of β With Time of The Day for fogging duration 1.5 min and interval of 4.5 min

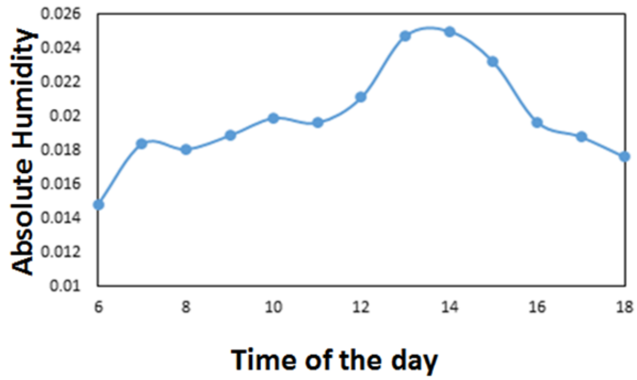

Fig 3: Variation of Absolute Humidity with Time of the day for fogging duration 1.5 min and interval of 4.5 min

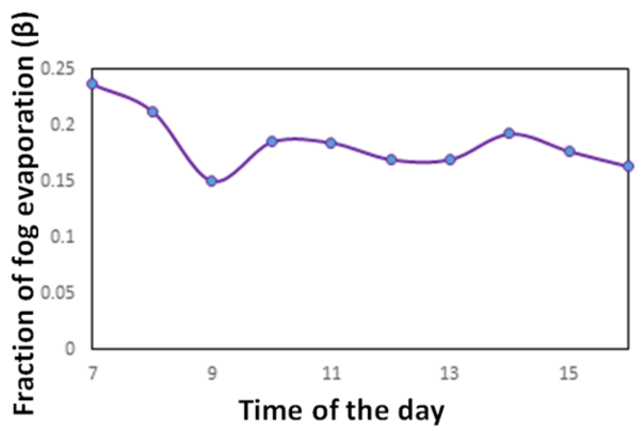

Fig 6: Variation of β with time of the day for fogging duration 0.5 min and interval of 2 min

5. CONCLUSION

In this paper, the fraction of fog evaporation (β) for fogging conditions of 1.5-4.5 min and 0.5-2 min has been calculated. It is observed that, maximum value of the fraction of fog evaporation (β) is 0.44 for the fogging cycle of 1.5-4.5 min. It is also seen that maximum value of fraction of fog evaporation for the fogging cycle 0.5-2 min is 0.23. In this cycle, fog evaporation rate is low as ventilation rate for that period is very low, though weather conditions is dry. From the results, it is clearly seen that this type of fogging system is very much useful when ventilation rate lies in between 0.075-0.191 (kg/m^2s).

REFERENCES

[1] Arbel A., Yekutieli O., Barak M., Performance of a fog system for cooling greenhouses, 1998, J. Agric. Engng Res., 72,129-136.

[2] Sethi V.P, Sharma S.K, Survey of cooling technologies for worldwide agricultural greenhouse applications, 2007, Solar energy, 81, 1447-1459.

[3] Toida H., Kozai T., Ohyama K., Handarto, Enhancing Fog Evaporation Rate using an Upward Air Stream to improve Greenhouse Cooling Performance, 2006, Biosystems Engineering, 93 (2), 205-211.

[4] Abdel-Ghany A.M., Kozai T., Cooling efficiency of fogging systems for greenhouses, 2006, Biosystems Engineering, 94, 97-109.

[5] G.N Tiwari, Greenhouse Technology for controlled Environment, 2003,Elements of heat transfer, page no 242-260

[6] Arbel A., Barak M., Shklyar A., Combination of forced ventilation and fogging systems for cooling greenhouses, 2002, Biosystem Engineering, 84, 45-55.

[7] Abdel-Ghany Ahmed M., Goto Eiji, Kozai Toyoki, Evaporation characteristics in a naturally ventilated, fog-cooled greenhouse, 2005, Renewable Energy, 31, 2207-2226.

[8] Li S., Willits D.H, Comparing low-pressure and high-pressure fogging systems in naturally ventilated greenhouses, 2008, Biosystems Engineering, 101, 69-77.

[9 Sethi V.P, Sharma S.K, Survey and evaluation of heating technologies for worldwide agricultural greenhouse applications, 2008, solar energy, 82, 832-859.

[10] Abdel-Ghany Ahmed M, Kozai Toyoki, Dynamic modeling of the environment in a naturally ventilated, fog-cooled greenhouse, 2006, Renewable Energy, 31, 1521-1539

Nomenclature

C_p	Specific heat (J/kg °C)
E_c	Emissive power of the cover (W/m^2)
E_f	Emissive power of the floor (W/m^2)
G_i	Solar radiation flux inside the greenhouse (W/m^2)
h_{c-i}	Convective coefficient between the cover and the inside air (W/m^2°C)
h_{c-o}	Convective coefficient between the cover and the outside air (W/m^2°C)
h_{f-i}	Convective coefficient between the floor surface and the inside air (W/m^2°C)
I_i	Enthalpy of the air inside the greenhouse (kJ/kg)
I_o	Enthalpy of the air outside the greenhouse (kJ/ kg)
m_a	Ventilation rate of air in the greenhouse (kg/m^2s)
m_f	Evaporation rate of the non-evaporated fog (kg/m^2s)
m_w	Fogging rate (kg/m^2s)
Q_{c-i}	Convective heat rate from the cover to the inside air (W/m^2)
Q_{c-o}	Convective heat rate from the cover to the outside ambient (W/m^2)
Q_{f-i}	Convective heat rate from the floor surface to the inside air (W/m^2)
R_c	Solar radiation energy absorbed by the cover (W/m^2)
R_f	Solar radiation energy absorbed by the floor (W/m^2)
T_c	Cover surface temperature (°C)
T_{di}	Dry bulb temperature inside the greenhouse (°C)
T_{do}	Dry bulb temperature outside the greenhouse (°C)
T_f	Floor surface temperature (°C)
T_u	Dry bulb temperature of the un-cooled air in the greenhouse (°C)
T_{wi}	Wet bulb temperature inside the greenhouse (°C)
U	Overall heat transmission coefficient (W/m^2°C)
V	Free Wind speed outside the greenhouse (m/s)
β	Fraction of fog that evaporates in the greenhouse air
φ	Relative humidity (%)
ω_i	Absolute humidity of the greenhouse air after fogging
ω_o	Absolute humidity of the outside air
ω_u	Absolute humidity of the un-cooled air in the greenhouse