Analysis of dehumidification method and discussion on improvement measures in solar greenhouse

Hemei Lu1, Wenjun Lei*, Chuanmin Tai1, Junbao Ye1, Xinye Qi1, Linhua Zhang1, and Xiaolong Wang2

1 School of Thermal Engineering, Shandong Jianzhu University, Jinan 250101, Shandong, China
2 School of Energy and Machinery, Dezhou University, Dezhou 253000, Shandong, China

Abstract. The solar greenhouse is a passive agricultural facility building which can realize the anti-seasonal production. The main enclosure structure of solar greenhouse is composed of thermal insulation wall, thermal insulation roof and daylighting shed film. The transmittance of sunlight is an important index affecting the healthy growth of plants in solar greenhouse. After testing, the difference between the solar radiation intensity received through the greenhouse film and the outdoor solar radiation intensity during a day has large fluctuations. The reason for this phenomenon is that the humidity in the greenhouse is large, and there is condensation on the greenhouse film, which seriously affects the transmittance of sunlight. The dehumidification methods commonly used in solar greenhouses are summarized, and their advantages and disadvantages are analyzed in this paper. In addition, the problems existing in the current dehumidification methods are discussed. In view of the characteristics of the solar greenhouse that the high temperature needs ventilation and cooling during the day and the low temperature at night needs to supplement heat, a composite ventilation system with anti-condensation, heat storage, cooling and dehumidification is proposed, and its performance is analyzed.

Keywords: Solar greenhouse; Solar radiation intensity; Condensation; Dehumidification method; Composite ventilation system

1 Introduction

Solar greenhouse is a passive agricultural facility building that can realize off-season production with thermal insulation and heat storage wall, thermal insulation roof and daylighting shed film as the main enclosure structure[1]. The environmental and economic benefits of solar greenhouse are remarkable, which has basically solved the problem of off-season vegetable supply in China, especially in the north, greatly promoted the development of rural economy and increased farmers' economic income. In recent decades, solar greenhouse has made rapid development all over the world, and facility agriculture has made a great contribution[2].

In cold weather conditions, solar greenhouse can create a greenhouse environment conducive to plant growth and development. However, the temperature difference between indoor and outdoor is large in winter, when the temperature of the inner surface of the shed film is lower than the dew point temperature of the air in the greenhouse, the phenomenon of condensation will occur on the inner surface of the shed film. When the humidity in the solar greenhouse is too high, condensation water generated by condensation on the condensation water generated by condensation on the inner surface of the greenhouse film gathers and forms water drops, which will damage the leaves of plants[3]. It was found that long-term growth under high humidity (relative humidity \( \geq 85\% \)) not only changes its physical characteristics, such as increased epidermal permeability, decreased stomatal sensitivity and decreased root water absorption capacity, but also increases the incidence of fungal diseases[4].

In addition, dew condensation on the inner surface of the greenhouse film may reduce the transmission of sunlight. The transmittance of sunlight is an important index to measure the environment of solar greenhouse, which directly affects the growth and yield of cultivated crops. Therefore, field measurement was carried out in this study to explore the influence of condensation on sunlight transmission. A variety of dehumidification methods commonly used in greenhouse are described and analyzed, and combined with the existing research, a heat storage and anticondensation ventilation system for greenhouse is proposed.

2 Field test

The test solar greenhouse is located in Weifang City, Shandong Province. The test time is December 26, 2021. Affected by the monsoon, Weifang has a humid continental climate in four seasons. Its annual average temperature is 12.70°C, the annual sunshine hours are 2536.3 hours, and the percentage of sunshine in winter is 58%[1]. The enclosure structure of the solar greenhouse is the East and west mountain walls and North walls made of earth blocks. The covering material...
is PVC plastic film. A buffer chamber is connected next and to the west mountain wall. The East-West length of the greenhouse is 53m, the North-South span is 13.4m, and the ridge height is 3.5m. In order to compare and analyze the solar transmission, a solar radiation instrument is arranged inside and outside the greenhouse (point 1 and point 2). The solar radiation measuring point 1 in the greenhouse is located at the geometric center of the solar greenhouse without shelter, with a height of 1.5m. See Figure 1 for the layout of on-site measuring points.

![Fig. 1. Layout of on-site measuring points of solar greenhouse](image)

### Table 2.1 Table of test instruments

| Instrument name | Test parameters | Model            | Test error |
|-----------------|-----------------|------------------|------------|
| Solar radiometer | Solar radiation intensity | JTR05 (TBQ-2)   | ±5%        |

### 3 Analysis of test results

Through the indoor and outdoor solar radiation test of solar greenhouse, the change of indoor and outdoor solar radiation intensity with time is obtained, as shown in Figure 2.

![Fig. 2. Difference between indoor and outdoor solar radiation intensity](image)

Without the influence of other factors, the solar transmittance of greenhouse film basically remains unchanged, that is to say, the difference between indoor and outdoor solar radiation intensity remains basically unchanged. However, the test found (Figure 2) that the difference of solar radiation intensity inside and outside the greenhouse at different times of the day is very different. As can be seen from Figure 2, the difference between indoor and outdoor solar radiation is the largest during the period from 12:00 to 14:30, that is, the intensity of solar radiation received indoors is relatively small. During the test, it was observed that there was serious condensation on the inner surface of the greenhouse film during this time period. At first, the condensation on the inner surface of the greenhouse film is bead like condensation. Under the action of gravity, some dew drops and others flow down the inner surface of the greenhouse film to form a water film. It is found that water dew and water film can reflect sunlight and reduce the transmission of sunlight[5]. The formation of water dew and water film on the inner surface of the greenhouse film reduces the transmission of sunlight, resulting in the reduction of the intensity of solar radiation entering the greenhouse.

Solar energy is the main energy for plant growth[6-8]. Existing studies have found that sunlight has a great impact on the growth of crops. More than 90% of the dry weight of plant roots, stems, leaves, flowers and fruits are composed of organic substances produced by photosynthesis[9], and the intensity of sunlight has a great impact on the quality, color and maturity of fruits, as well as the photosynthesis and Respiration and transpiration[10].

Therefore, it is very important to prevent condensation on the inner surface of greenhouse film. Condensation is due to the large temperature difference between indoor and outdoor in the solar greenhouse in winter. The temperature of the inner surface of the greenhouse film is lower than the dew point temperature of the surrounding air, and the water vapor in the air will precipitate, thus forming condensation. Therefore, many researchers have proposed dehumidification methods for solar greenhouse.

### 4 Common dehumidification methods in Greenhouse

Due to the transpiration of plants, soil moisture evaporation, large indoor and outdoor temperature difference and other factors[11-13], the problem of excessive humidity is easy to appear in the solar greenhouse. Scholars at home and abroad have conducted extensive research on this, put forward many dehumidification methods, and achieved some results. Li Suwei et al. [14] described the dehumidification methods such as mulching film and natural material moisture absorption, which are simple to operate, low cost, but laborintensive. Zhang Wenyi[15] established the dehumidification prediction model of heat exchanger, carried out the dehumidification test of solar greenhouse with sensible heat exchanger, verified the effect of dehumidification model, and obtained the empirical formula of dehumidification effect. According to the comparison of the measured results, the model better simulates the dehumidification prediction effect. However, it has not been put into practice, and its feasibility is unknown. Wang Chunye[2] and others proposed that when the outdoor temperature is too low to be ventilated, the dehumidifier can be used to dehumidify the solar greenhouse. When the set humidity is 60%, the dehumidifier works for 2.02h, and the average relative humidity is 55.10%, which is 12.97% lower than that without dehumidifier. However, due to
the limitation of temperature, the dehumidifier can not dehumidify the solar greenhouse all day, but the use of dehumidification equipment has high energy consumption and poor economy. Boulard[16] cushioned the ground with 3 cm thick sepiolite particles in the greenhouse, and turned on the fan to absorb moisture at 00:00h-06:00h and 10:00-15:00h. The results showed that 15-30 gm² water vapor could be absorbed with 1.2 kg sepiolite, even if the air with 75% relative humidity was enough for recycling. But the heat in the greenhouse is not utilized.

5 Proposal of ventilation system for heat storage, dehumidification and anticondensation

Aiming at the problem of condensation on the inner surface of greenhouse film, based on previous studies, a ventilation composite device for soil heat storage, dehumidification and anticondensation in solar greenhouse is proposed in this paper, as shown in Figure 3. The air disturbance can reduce and prevent the occurrence of condensation. Based on the principle of attached air supply, the circulating air in the greenhouse is used to attach air supply to the inner surface of the greenhouse film, so as to effectively prevent the condensation on the inner surface of the solar greenhouse and improve the transmittance of sunlight. At the same time, the heat exchange between the air in the greenhouse and the buried pipe can realize the cooling and dehumidification of the air in the solar greenhouse on the one hand, store the heat in the air into the soil on the other hand, and release the heat stored in the soil at night, which is conducive to maintaining the constant temperature of the greenhouse at night, improving the temperature of the root system and more conducive to the growth of crops. When CO² and other parameters in the greenhouse do not meet the needs of plant growth, some fresh air can be introduced through the tuyere. Due to the low outdoor temperature in winter, in order to prevent the cold air from directly entering the greenhouse and causing frostbite and damage to plants, the system mixes the outdoor fresh air with the air in the greenhouse and then sends it to the warm room. In order to ensure the balance of pressure and air volume in the greenhouse, an air outlet is set at the top of the greenhouse.

This ventilation system can realize the functions of dehumidification, anticondensation and heat storage of greenhouse. At present, this system has entered the experimental stage and needs follow-up research.

This ventilation system can realize the functions of dehumidification, anticondensation and heat storage of greenhouse. At present, this system has entered the experimental stage and needs follow-up research.

6 Conclusion

In this study, the indoor and outdoor solar radiation intensity difference of solar greenhouse widely used in North China was tested and analyzed, and the common dehumidification methods in solar greenhouse were summarized. Based on the existing research and attached jet theory, a ventilation system for soil heat storage, dehumidification and anticondensation in solar greenhouse is proposed. It is found that the difference of indoor and outdoor radiation intensity is large and fluctuates during the day, and the main reason for this phenomenon is the condensation on the inner surface of the greenhouse film, which affects the transmittance of sunlight on the greenhouse film. Due to the large indoor and outdoor temperature difference in winter, the inner surface temperature of the greenhouse film is low, while the indoor temperature is high. When the temperature of the inner surface of the greenhouse film is lower than the dew point temperature of the surrounding air, the water vapor in the saturated air will condense into water droplets, that is, condensation. The commonly used dehumidification methods include mechanical ventilation and natural ventilation. The ventilation system for solar greenhouse proposed in this paper realizes the functions of dehumidification, anticondensation and heat storage of greenhouse, and effective ventilation can realize dew removal. The air temperature of the air supply will affect the results. When the air supply temperature is greater than the indoor temperature difference, the smaller the air supply volume is required. However, in winter, the indoor and outdoor temperature difference is large, and the outdoor fresh air temperature, that is, the air supply temperature, is low, so the indoor cooling speed is faster. Therefore, a small air supply volume can effectively reduce the temperature in the solar greenhouse and achieve the dehumidification effect. However, the actual effect of the system needs further numerical simulation and experimental verification.

This work was supported by the National Natural Science Foundation of China (No. 51908333), the Plan of Introduction and Cultivation for Young Innovative Talents in Colleges and Universities of Shandong Province, China and the Scientific and Technological Innovation Project for Youth of Shandong.

Fig. 3. Ventilation composite device for soil heat storage, dehumidification and dew prevention in Solar Greenhouse
Provincial Colleges and Universities (No. 2019KJH012), China.

References

1. Lin Huang. Research on dynamic thermal environment and heating load forecast of Solar Greenhouse[D]. Xi'an University of architecture and technology (2021)

2. Yueming Yuan, Chunye Wang, Haizhi Liu, et al. Dehumidification technology of Solar Greenhouse in winter of the northern area[J]. Journal of Jilin Agricultural University. 38(1): 122-126(2016)

3. Luo W, Goudriaan J. Effects of altering water temperature on leaf wetness in paddy rice crops[J]. Agricultural and forest meteorology, 97(1): 33-42 (1999)

4. Weiwei He. Simulation and ventilation regulation of cucumber leaf dewing in Solar Greenhouse[D]. Shenyang: Shenyang Agricultural University (2018)

5. Xiangmei Liu, Junhui He. Research progress of antifogging technology—from surface engineering to functional surface[J]. Chemical progress, 22 (0203): 270 (2010)

6. Sarkodie S A, Strezov V, Weldekidan H, et al. Environmental sustainability assessment using dynamic autoregressive-distributed lag simulations—nexus between greenhouse gas emissions, biomass energy, food and economic growth[J]. Science of the total environment, 668: 318-332 (2019)

7. Villagran E, Bojacá C. Experimental evaluation of the thermal and hygrometric behavior of a Colombian greenhouse used for the production of roses (Rosa spp.){J}. Ornamental Horticulture, 26: 205-219 (2020)

8. Villagran E, Leon R, Rodriguez A, et al. 3D numerical analysis of the natural ventilation behavior in a Colombian greenhouse established in warm climate conditions[J]. Sustainability, 12(19): 8101(2020)

9. Yiwu Lu, Lingjun Zeng, Sulan Zhang, et al. Effects of agricultural rare earth on Photosynthesis and respiration of crops[J]. Journal of Sichuan Agricultural University, 11(01): 163-167 (2017)

10. Xueping Zhang. Principles of ecology[J]. 2011.

11. Campen J B, Kempkes F L K, Bot G P A. Mechanically controlled moisture removal from greenhouses[J]. Biosystems engineering, 102(4): 424-432 (2019)

12. Campen J B, Bot G P A. SE—Structures and Environment: Dehumidification in Greenhouses by Condensation on Finned Pipes[J]. Biosystems Engineering, 82(2): 177-185 (2002)

13. De Halleux D, Gauthier L. Energy consumption due to dehumidification of greenhouses under northern latitudes[J]. Journal of Agricultural Engineering Research, 69(1): 35-42 (1998)

14. Suwei Li, Guangying Zhou, Ning Gao, et al. Dehumidification measures in solar greenhouse[J]. Modern rural science and technology (2020)

15. Wenyi Zhang. Study on heat exchange dehumidification based on humidity model of solar greenhouse[D]. Beijing: Chinese Academy of Agricultural Sciences (2006)

16. Boulard T. Proceedings of the French-Israeli Symposium on Greenhouse Technology, 127: 11 (1987)