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Thermal environment regulating effects of phase change material in Chinese style solar greenhouse

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Abstract

Phase change material (PCM) can store and release heat within a certain temperature range during the phase transitions. Compared with sensible heat material, latent heat phase change material (PCM) is very attractive, because of its high-energy storage density and isothermal behavior during the phase change process. This paper attempts to research the application of PCM in Chinese style solar greenhouse. The PCM we used is butyl stearate with the phase change temperature about 18 ℃, and spinach of F1 from Italy is chosen to be the test plant. The research is a contrast test with the same two greenhouse models, one is installed with PCM and the other is not. By recording the temperature with T type thermocouples on the different set-points and observing the growth situation of the plants in two greenhouses, we can recognize the effect of the PCM on the thermal environment of greenhouse.

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Keywords: Phase change material; Latent heat; Greenhouse model; Thermocouple; Environmental regulation and control

1. Introduction

Phase change material（PCM） is a kind of materials that can absorb or release energy by changing physical state of material in order to achieve temperature control [1]. Compared with sensible heat material, latent heat PCM can improve the heat of building by several times or even hundred times [2], and it is more widely applied in research. Recently, the applications of PCM have been discussed in solar, architecture, textile industry, medical and agriculture [3],[4].

In the field of agriculture, PCM was used as a kind of construction materials to build envelopes of greenhouse to improve the energy-saving performance, and the result indicated that fixing appropriate PCM to the inner surface of the north wall in the greenhouse can increase both the indoor air temperature and inner surface temperature of walls as well as reduce the energy consumption significantly [5],[6], [7]. So the application of compound PCM wall in greenhouse could decrease fuel energy consumption， improve

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thermal insulation effects and reduce environmental pollution[8]. This paper contributed to proposing a new method which help to apply PCM in greenhouse, we suggested that latent heat PCM built-in has the function to reduce the volatility of temperature in greenhouse[9], and conducive to improve the plant production efficiency in Chinese style solar greenhouse.

2. Experiment research

2.1 Experimental purpose and method

Application of PCM in greenhouse is certain feasible and practicable. By fixing the storage device of PCM in the greenhouse, it will help to achieve the purpose of regulating temperature, and create a better condition for the growth of crops. This experiment mainly adopted the method of contrast test by setting up two greenhouse models (see Fig.1 and Fig.2). The one placed with PCM was named NO.1 greenhouse, the other model without PCM was named NO.2 greenhouse. A temperature data acquisition meter was used to record temperatures of different points in two greenhouse models. By comparing the difference of temperatures in two greenhouse models, and making a comparative analysis, we verified that the PCM can play a positive role in improving the thermal conditions in greenhouse.

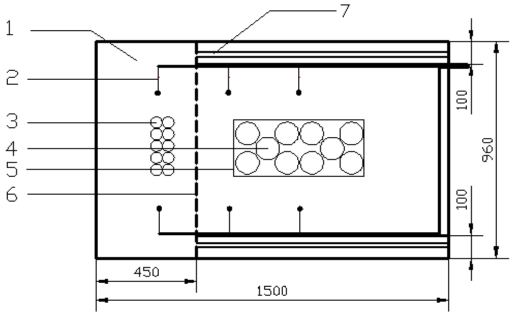

Fig.1. Orthograph of greenhouse model

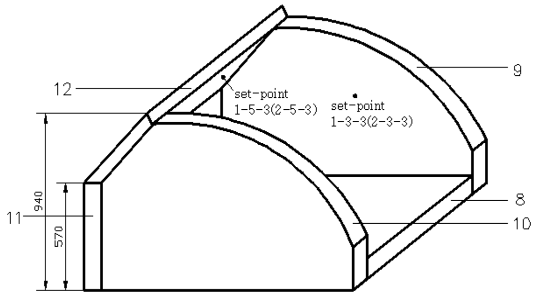

Fig.2. Perspective of greenhouse model

1-greenhouse model; 2-T type thermocouples; 3-PCM; 4-planting pots; 5-a device for storing planting pots; 6-projection of roof ; 7-card slot; 8-the bottom of the greenhouse model; 9-the right wall of the greenhouse model; 10-the left wall of the greenhouse model; 11-north wall of the greenhouse model; 12-north roof of the greenhouse model

2.2 Experimental materials and instruments

The experimental materials include two greenhouse models, planting pots and PCM. The PCM named butyl stearate with the phase change temperature about 18 ℃, latent heat 140J/g. Its phase change temperature meets the requirement of greenhouse and the comfort degree of plant growth, and its phase change process is reversible [10]. For more, butyl stearate is non-toxic, non-corrosive that it would not have an adverse impact on plant growth [11]. In winter, butyl stearate could become liquid by absorbing solar energy in daytime and then change to solid after releasing heat at night [12], its range of phase transition temperature was suitable for greenhouse experiment. Furthermore，it was stored in cylindrical stainless steel bottles (10 bottles in total and 550ml per one)and fixed in NO.1 greenhouse .

The experimental instruments include a data acquisition meter and T type thermocouples. In this experiment, the data acquisition meter with three slots was named Agilent 34970A. And T type thermocouples with a temperature measurement range from - 200℃ to 400 ℃ was used to measure the set-point temperatures.

2.3 Experimental Process

Firstly, two greenhouse models were set on the platform of roof of our laboratory. Thermocouples as sensors to test the temperatures of set-points both inside and outside of two greenhouse models were arranged. Two points were set outdoor, and 20 points were set in each greenhouse model. Secondly, 42 channel wires of T type thermocouples were fixed respectively to the connection caps for measurement. And Agilent program software was used to record data of temperature. In addition, channel configuration and parameters adjustment were necessary. Thirdly, each greenhouse model was fixed with 10 planting pots and each pot was filled with 0.9 kg substrate and sowed with 5 spinach seeds. Two rectangular plastic boxes were used to store the 10 pots, and temperature data were collected once 2 or 3 days.

During this experimental process, we observed that many small water droplets were found on the inner side of covering film of the NO.1 greenhouse, while the film of the NO.2 greenhouse was dry. Hence, one reason should infer that temperature inside the greenhouse fixed with PCM was higher than that of NO.2 greenhouse, and moisture evaporated more exuberantly in NO.1 greenhouse.

3. Analysis of experimental results

After comparing the difference of these temperature data between the two greenhouse models, a contrast diagram as shown in Fig.3 (point 1-5-3 was set on north roof of NO.1 greenhouse, point 2-5-3 was set on north roof of NO.2 greenhouse, see Fig.2) was drawn. In order to show temperature conditions indoor and outdoor of two greenhouse models, one set-point in each model was selected to compare with the set-point (point SW-2) outside the greenhouse models as shown in Fig.4.

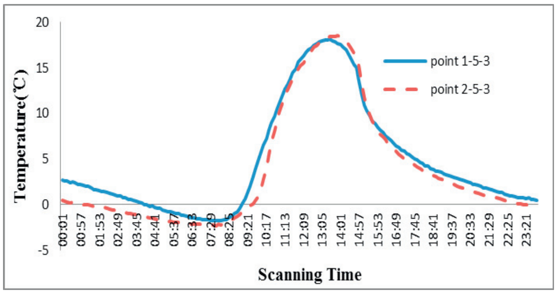

Fig.3. Comparison of point 1-5-3 and point 2-5-3

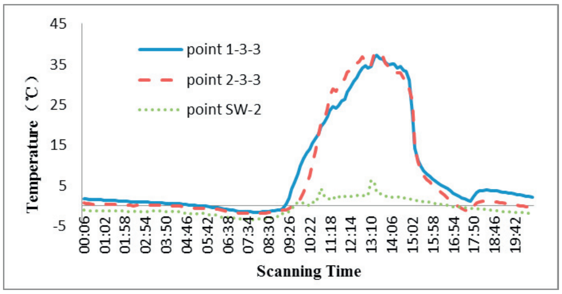

Fig.4. Comparison of point SW-2、point 1-3-3 and point 2-3-3

As shown in Fig.3, The temperature fluctuations of No. 2 greenhouse were -2.3 ~ 18.6 ℃, the temperature fluctuations of No. 1 greenhouse were -1.7 ~ 18.1 ℃, and less than No. 2 greenhouse by 1.1 ℃. Temperature of two greenhouses reached the highest value at about 13:00 and reduced the minimum value at about 7:00. Compared with No. 2 greenhouse, the temperature of No. 1 greenhouse was lower about 0.75 ℃ on average and maximum lower about 1.7 ℃ during the daytime from 13:00 to 15:30, but would be increased an average of 1.1 ℃ at night from 18:00 to 7:00.

In addition, as shown in Fig.4, the tendencies of up and down of temperature both in two greenhouse models were substantially the same. And due to the heat storage effect of PCM, by contrast, the temperature fluctuations of NO.1 greenhouse contained with PCM was smaller. During the daytime, when the temperature reached the phase change temperature of 18 ℃, butyl stearate began to phase change and absorb heat, so the temperature of NO.1 greenhouse would not be too high; at night, temperature of two greenhouse dropped very quickly, but thanks to the heat release of PCM, the temperature of NO.1 greenhouse was higher than that of NO.2 greenhouse about 1~2 ℃, and higher than the temperature of outdoor about 2~5 ℃.

4. Conclusions and Suggestions

In general, some conclusions can be acquired from the research as following:

- Temperatures in both greenhouse models were higher than that outside the models, but greenhouse fixed with PCM would increase the minimum temperature and lower the maximum temperature to make the fluctuations of temperature smaller.
- According to the comparison of temperature of set-points in both greenhouse models, butyl stearate as a kind of PCMs worked well on heat preservation. It can help reduce the fluctuations of indoor temperature about 1 ~ 2 ℃, lower the maximum temperature about 1 ~ 2 ℃ during the daytime, and increase the minimum temperature about 1 ~ 3 ℃ at night.
- In this experiment, PCM stored in cylindrical stainless steel bottles was feasible and practicable, and we can use some tubes as a device to store PCM in future research to promote the applying potential of PCM in the field of greenhouse.

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