DEVELOPMENT OF A THERMAL MODEL OF A SOLAR POWERED VAPOUR ABSORPTION REFRIGERATION SUPPORTED GREENHOUSE FOR STRAWBERRY CULTIVATION

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Abstract

In this paper, a novel scheme of a solar powered vapour absorption refrigeration supported greenhouse with indirect evaporative cooler has been proposed. The main objective of this work is to create a favorable microclimatic condition for strawberry cultivation inside the greenhouse for a country with sub-tropical climatic conditions like India when the ambient temperature and humidity are high. The maximum yield of strawberry is achieved for a temperature ranging between 15-25 °C with a relative humidity varying from 55 to 65%. It is quite impossible to achieve a favorable temperature range for strawberry cultivation in the greenhouse under such condition by using the existing greenhouse cooling techniques. A double effect parallel flow LiBr-H2O absorption cooling system along with an IDEC powered through solar energy has been used. A thermal model for the greenhouse has been developed and analyzed for the climatic condition of Kolkata, India. The study reveals that the proposed system can very well maintain a conducive climate for the growth of target plantation for the given location.

Keywords: Greenhouse Cultivation; Double effect VAR system; Solar Thermal; Indirect evaporative cooler

1. Introduction

Greenhouse is an enclosed structure made of any transparent material inside which the climatic conditions can be regulated artificially for the optimum growth of flora. The primary objective of a greenhouse is to maintain a favourable microclimate for optimizing the plant growth. Other than the temperature control, it is also necessary to maintain an optimum relative humidity inside a greenhouse to achieve the maximum growth of flora. An effective greenhouse should be designed to achieve high cooling efficiency, low cost of investment, low operation and maintenance costs, and also the design should provide an even temperature profile along the greenhouse [1]. In subtropical countries like India, hot and humid climatic conditions prevail for the most part of a calendar year. High temperature is detrimental for the cultivation of high value plantation like Strawberry (Fragaria Ananassa) which thrives at a temperature between 15 and 20 °C with the maximum viable temperature being 25 °C [2]. This is the main reason that the leading producer of strawberries (USA, Spain, Turkey, Mexico) are not located in the hot and humid tropical and sub-tropical part of the world. Apart from temperature, one of the major factors for strawberry cultivation is humidity. The yield of Strawberry is maximum when the air vapour pressure deficit (V.P.D) is between 200-1000pa. The plants suffer from diseases with high ranges of humidity level (V.P.D<200pa) and when the humidity level is low (V.P.D>100pa) plants suffer from water stress. So, for the greenhouses located in subtropical regions like India, the major objective is to reduce the inside temperature as well as control of the humidity for cultivation of strawberries.

Several research and development works have been done on the different traditional greenhouse cooling systems. However, it may be noted that the traditional methods of greenhouse cooling (i.e. fan-pad cooling, evaporative cooling, and desiccant cooling) fail to maintain a conducive microclimate for strawberry cultivation inside greenhouse for the plains of sub-tropical or tropical region. The integration of a VAR
system along with a greenhouse can be a viable solution for the cultivation of plantation which requires a low temperature with decent humidity levels. The technology of greenhouse cultivation is also highly relevant to the rural development of a country. For the developing countries like India the availability of power on a sustainable basis in the rural areas is a big challenge. In case of VAR system there is a scope of utilization of low-grade energy as input. The load on the VAR system will be extremely high if it is alone used to cool the greenhouse. Pre-cooling process can reduce the air temperature resulting in the decrease in load of the VAR system. The indirect dew point cooling technology which is also known as M-cycle cooling technology can cool the air below the WBT without adding any moisture, which is the main reason for which this technology is very much effective for the hot and humid environmental conditions. Technically in the dew point evaporative cooler the temperature of the product air can be approached nearly to the DPT of the air [3]. For the hot and humid climatic conditions, only IDEC cooling is not sufficient to provide adequate amount of cooling air in the conditioned space [4]. Delfani et al.[5] experimentally investigated the performance of an IDEC to pre-cool the air for a conventional cooling system. Cui et al. [6] in his research numerically modeled an IDEC as a pre-cooling unit for hot and humid climatic condition and stated that a huge amount of energy can be saved by using IDEC as a cooling unit. Chauhan and Rajput [7] proposed an air conditioning system which comprises DPEC and VCR system. The results showed that the load on the cooling coil decreased by about 61% at 46°C and 6g/Kg sp. humidity, when DPEC is used along with a VCR system. The results obtained thus showed, that up to 55% electrical energy can be saved by using IDEC. In this work N-PVT-CPC collector is used to supply energy to the whole system, this collector system is self-sustained for VAR system [8].

There is very little literature available on greenhouse cooling using VAR system [9]. No work has been found on greenhouse cooling which is based on a combination of VAR system and indirect evaporative cooler.

### Nomenclature

| Acronym | Description |
|---------|-------------|
| IDEC | Indirect Evaporative Cooler |
| DPEC | Dew point Evaporative Cooler |
| WBT | Wet bulb temperature |
| DBT | Dry bulb temperature |
| DPT | Dew Point temperature |
| VPD | Vapour Pressure Deficit |
| VAR | Vapour Absorption Refrigeration |
| VCR | Vapour Compression Refrigeration |
| PVT | Photovoltaic |
| CPC | Compound parabolic concentrator |
| α | Absorptivity |
| T₀ | Temperature inside greenhouse (°C) |
| λE | Canopy Transpiration |
| G₀ | Total Radiation on greenhouse (W/ m²) |
| τ | Roof transmittance |
| Γ | roof area of Greenhouse(m²) |
| γ | Psychrometric constant (Pa K⁻¹) |
| K₄ | Heat transfer Coeff. (Wm⁻² K⁻¹) |
| v | Volume of air flow(m³/s) |
| HIX | Sensible Heat exchange for ventilation (W/m²) |
| K₅ | Heat transfer coff. Of greenhouse and ambient |
| K₆ | Sensible heat transfer coefficient (W/m²K) |
| K₇ | Latent heat transfer coefficient (W/m²°C) |
| Tₕ | Temperature inside greenhouse (°C) |
| Tₕ | Temperature of the supply air(°C) |
| Δe | Vapour pressure deficit (Pa) |

### 2. System Description

The schematic of the proposed system is given in figure 1. In the proposed system, the ambient air is drawn from outside and sensibly cooled in an IDEC, where the air exchanges heat with working air channel. In this process no moisture is added to the air, so the specific humidity of the air remains same only, the DBT of the air decreases. After getting cooled from the IDEC, the product air is allowed to blow across the evaporator of a double effect parallel flow Li-Br VAR system. There the temperature of the air is reduced to a sufficiently low value and the cooled air is then supplied to an east-west oriented Quonset greenhouse. An array of N-PVT-CPC collector is used to produce water at a temperature of 120°C, which is stored in an insulated storage tank. The hot water is supplied in the high-pressure generator for the water vapor generation from the weak solution. The electricity produced from the photovoltaic collector is supplied to the grid. The grid electricity is used for running the various auxiliary devices such as pumps, cooling fan of the system.
3. Thermal Model Development

The following assumptions have been made to develop the thermal model

(1) The condition inside the greenhouse is assumed as steady state and density of air and water vapour are also assumed to be constant.

(2) Heat storage of the greenhouse-soil system is neglected.

(3) The evapo-condensation phenomenon on the greenhouse cover is neglected.

(4) The supply air to the greenhouse and return air mass flow rate are assumed to be the same.

(5) The initial conditions of the greenhouse are assumed to be same as ambient condition.

![Schematic Diagram of the proposed system](image)

Energy balance equation within the greenhouse can be expressed as [10]

\[ \alpha G_{\delta}t - \lambda E - HX - K_s (T_{gb} - T_a) - Q_m = 0 \] (1)
Qm is the heat storage or retrieval rate of greenhouse soil system. The value of Qm is very less and thus it can be neglected. G0 is the solar radiation per unit area.

The latent heat load due to canopy transpiration (λE) can be written as [10]

\[ \lambda E = K_s \Delta e \]  

Where \( \Delta e = e_{gh} - e_s \) (pa)

\( e_{gh}, e_s \) are the vapour pressure of greenhouse and the supply air.

Temperature of the greenhouse can be written as [11]

\[ T_{gh} = \left[ \alpha G_0 \tau - \lambda E + K_h T_s + K_s T_g \right] \left( K_s + K_h \right) \]  

The water vapour pressure (Dgh) deficit inside the greenhouse can be expressed as:

\[ D_{gh} = \left[ e^* (T_{gh}) - e^* (T_s) \right] - \left[ e^* (T_{gh}) - e^* (T_s) \right] + \left[ e^* (T_s) - e_s \right] \]  

The total sensible cooling load on the greenhouse can be given by

\[ Q_{SHT} = A \cdot G_0 - Q_s - Q_d - Q_r \]

4. Results and Discussions:

In this study the performance of the cooling system has been studied numerically. The inputs and the constants which are used for this study are given in Table 1.

| Table 1: Inputs and Constrains for the study |
|---------------------------------------------|
| Temp. of supply air (T_s) | 15°C | Heat transfer Coeff. (K_s) | 4.5 Wm⁻² K⁻¹ [13] |
| RH of the supply air | 60% | Roof area of Greenhouse (A) | 58.92 m² |
| Sp. heat of the air (C_p) | 1005 J kg⁻¹ K⁻¹ | Psychrometric constant (\( \gamma \)) | 72.08 Pa K⁻¹ |
| Roof Transmittance (\( \tau \)) | 0.8 [12] | Heat of vaporization of water | 2260 KJ/Kg |
| Absorptivity (\( \alpha \)) | 0.7 [12] | Day of the year | June 15 |
| Volume of air flow | 2.04 m³/s | IDEC efficiency (\( \epsilon \)) | 0.8 |
Figure 4 shows the variation of temperature of greenhouse with the variation of relative humidity of the process air. It is observed from the figure that the temperature of the greenhouse decreases with the decrement of relative humidity of the process air. Because as the relative humidity of the supply air increases the ability of the supply air to take the heat from greenhouse air will decrease. Maximum temperature of the greenhouse is 26°C for which a conducive microclimate for strawberry cultivation can be maintained.

Figure 5 shows the variation of vapour pressure deficit with the variation of relative humidity of the process air. It is seen from the figure that the V.P.D of the greenhouse increases with the decrement of relative humidity of the process air. As the relative humidity of air at a fixed temperature increases, the vapour content of the air is also increases, so when the process air with high RH mixes with greenhouse air it will unable to lowered the V.P.D of the greenhouse air. It is seen from the figure 5 that for both 85% and 70% RH of the air the V.P.D inside the greenhouse is suitable for strawberry cultivation.
5. Conclusion
The present paper discusses a novel scheme of a solar powered VAR supported greenhouse for cultivation of Strawberry for the sub-tropical climatic conditions prevailing in the plains of India. A thermal model of the greenhouse is developed and analyzed for a representative day in Summer (June 15) when both the ambient temperature and relative humidity levels are very high. Following points are revealed from the study:
(1) For a representative day of summer (June15) when the outside temperature is very high this proposed system will able to maintain a suitable temperature for strawberry cultivation inside the greenhouse when the temperature and RH of the air is 15°C and 70% respectively.
(2) Two different condition of supply air is specified in this work in both the cases the V.P.D inside the greenhouse is suitable for strawberry cultivation.

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