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Fabrication and Thermal Analysis of Nano-structured Heat Transfer Medium and Novel Conical-shaped Solar Greenhouse Device

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ABSTRACT

The solar device that acts on the principle of greenhouse effect is a solar greenhouse device and it is a feasible option for photothermal applications. Its optical characteristics, thermal properties, and thermal performances are to be improved for its effective utilization in application sectors. From these perspectives, the initial part of the present research was devoted to preparing, characterizing, and evaluating the nano-based heat transfer medium. The central part of the present research was devoted to fabricating the novel conical-shaped solar greenhouse device integrated with the nano-based heat transfer medium; the final part was devoted to experimentally evaluating the thermal performances of the fabricated solar greenhouse device. In the present research work, the carbon nanotube and nano-tungsten carbide-coated heat transfer medium and novel solar greenhouse device were developed and they were experimentally analyzed. The characterization studies showed that the chemical constituents in the coating affecting the heat transfer medium were in nano-sizes. The thermal studies showed that the maximum temperature enhancement on heat transfer medium with nano-coating was in the range of 49.0 to 76.2 °C. The performance study showed that the maximum drying efficiency of the conical-shaped solar greenhouse device varied from 63.9 to 66.7% for drying the leaves of medicinal plants. The novelty of the present work was not only the preparation of a nanostructured heat transfer medium but also the fabrication and utilization of a novel solar greenhouse device. Since the physical characteristics of the components and devices were found to be satisfactory, it could be concluded that the components and conical-shaped greenhouse devices would effectively be utilized in energy-intensive sectors.

Keywords: Nano-structured heat transfer medium; Conical-shaped greenhouse; Thermal enhancements; Efficiency.

1. INTRODUCTION

Using a greenhouse device is a feasible method for dehydration and drying any product in a clean and controlled environment (Tiwari, 2003). It has a greenhouse structure along with other integral components and it works on the principle of greenhouse effect for the removal of moisture contents from a variety of products (Thomas *et al.* 2016). It is essential to improve the efficiency of the conventionally used solar greenhouse device by modifying the size, shape, and design of its transmitter. It is also essential to improve the efficiency of the conventionally used solar greenhouse device by modifying the size, shape, and coating of the heat transfer medium and hence the present investigation (Vivekanandan *et al.* 2021). Vasantha and Jeba (2017) researched nano-graphite and CuO-based absorbers and evaluated the performance of solar air heating collectors integrated with the same nano-graphite and CuO-based absorber. The research outcomes showed that the maximum temperature of working fluid and thermal performance of the solar collector were 59.4 °C and 68.0%, respectively (Vasantha and Jeba, 2017). Jeya and Jeba (2021) researched nanocarbon and chromium oxide-coated fins and also solar collectors with nanostructured materials. The research outcomes showed that the temperature of nanocarbon and chromium oxide-coated fins inside the solar collector ranged between 98.3 and 128.6 °C (Jeya and Jeba, 2021). Vivekanandan et al. conducted research on six shapes of solar greenhouse devices in no-load conditions to identify the ideal shape of the device. The research outcomes showed that the inside temperature was in descending order from maximum to minimum in the shapes of Quonset, Tropical, Pyramid, Parabola, Modified Quonset, and igloo-shaped greenhouse devices during the summer season (Vivekanandan *et al*. 2021). Fatih *et al*. (2022) conducted research on the utilization of graphene nano-platelet-embedded black paint in active greenhouse devices. The research results showed that the thermal efficiency of the solar absorber was 24.4% which caused a reduction in drying time of 75 minutes. It could be concluded that the efficiency of greenhouse devices would be improved due to the usage of graphene-embedded paint (Fatih *et al*. 2022). Kumar and Prakash (2023) researched the thermal performance of a hybrid solar greenhouse device. The results showed that the maximum crop and ground temperatures were 67.1 °C and 79.1 °C, with the drying and thermal efficiencies of 20.52% and 54.53%, respectively. It could be concluded that the moderate temperature inside the solar device would be used for drying crops as well as sustaining the environmental balance (Kumar and Prakash, 2023). By considering the research gaps in these reviews, the present research work has been carried out with objectives such as (i) preparation of nano-carbon and tungsten carbide-coated solar heat transfer medium, (ii) characterization of the nanocomposite coatings deposited on the solar heat transfer medium, (iii) evaluation of thermal durability and thermal enhancement on the prepared solar heat transfer medium, (iv) construction of solar greenhouse device integrated with the prepared solar heat transfer medium and (v) experimental evaluation of the performances of the conical solar greenhouse device integrated with nanocomposite-coated heat transfer medium. In continuation, the standard chemicals, materials, and components were used for the fabrication of a conical-shaped solar greenhouse device. The standard methodology, test methods, and test setups were used for the testing of integral components and conical-shaped solar greenhouse devices. The research results have been documented in this research paper for the benefit of manufacturers, researchers, and end users worldwide.

2. MATERIALS AND METHODS

2.1 Preparation and Characterization of Nanocomposite-coated Heat Transfer Medium

The commercially procured carbon nanotube and nano-tungsten carbide were mixed in 70:30 mass proportions. They were subsequently mixed in solar emulsion that has been commonly used for black coating on central components of solar greenhouse devices. The mixed carbon nanotube and tungsten carbide were stirred thoroughly in the solar emulsion by using the mechanical stirrer.

The zinc aluminum alloy metal plate was pre-cleaned and it was spray-coated with the carbon nanotube and tungsten carbide mixed absorptive solution. The spray rate was fixed as 10 ml/ minute with compressed air as carrier gas (Jeya and Jeba, 2021). The distance between the spray head and the zinc aluminum alloy plate was kept at 15 cm during the spray coating on the metal plate. The developed coating on the zinc metal plate was checked visually and the observations were noted.

The nano-sized constituents of the resultant solar emulsion were characterized through XRD, UV-Vis, SEM, and EDAX techniques. The XRD analysis was carried out by using a Powder X-ray diffractometer (X' Pert Pro - P Analytic with 15 kVA UPS support ID SSD160 detector and Cu-Kα radiation at the wavelength range of 1.541 A°). While the scan parameter had the coupled two theta values, the start and end times of the XRD analysis were 10.000 and 99.992 with a step size of 0.020. The UV-Visible analysis was carried out by using a UV-Vis-NIR Spectrophotometer with Thermofisher Evaluation 220, in the range of 190-1100 nm. The SEM with EDAX analysis was carried out by using ZEISS EVO-18 SEM-equipped BRUKER-X Flash-6130.

By the generated XRD diffractograms, the crystallite size in the coating on heat transfer medium was calculated by using the Debye–Scherrer formula: $D = k\lambda/\beta\cos\theta$, where D is crystallite size, K is the correction factor, λ is the wavelength of the X-ray used, β is the FWHM of the observed peaks, and θ is the diffraction angle. By the generated UV absorptance graph, the optical absorbance of the nanocomposite was calculated. By the generated SEM images with the EDAX spectrum, the morphology of the coating on heat transfer medium was studied and the various elements present in the nanocomposite were identified.

2.2 Optical and Thermal Studies on Integral Components of Greenhouse Device

The transmitting medium is the primary component of any solar device. It transmits the incident solar radiation through it and the transmitted radiation heats the heat transfer medium. The level of transmitted radiation not only affects the level of heating up of the transfer medium but also the overall performance of the solar greenhouse device. So, it is essential to study the optical transmittance of the transmitting medium through the prescribed optical transmitter test procedures (BIS, 2005). To study the optical characteristics of the transmitting medium, the polycarbonate sheet was fixed on a test stand in outdoor conditions. The level of solar radiation above and below the sample of polycarbonate sheet was measured. The ratio of transmitted and incident solar radiation was taken and the transmittance of polycarbonate sheet was calculated. It is to be noted that the transmittance experiments were conducted at and near solar noon on clear sunny days to minimize the effect of diffused components of solar radiation (BIS, 2005).

Solar heat transfer medium is the central component of any solar greenhouse device. It is heated up due to the transmitted radiation. In addition, it is heated up due to the greenhouse effect that is built up inside the collector. The level of heating up of the heat transfer medium not only influences the heat transfer to the working fluid but also the overall performance of the greenhouse device. Hence, it is essential to study the durability and characteristics of the heat transfer medium through the prescribed thermal tests. To study the thermal durability of the heat transfer medium, the prepared heat transfer medium of size 15 cm x 15 cm was heated in an oven temperature of 175 °C for two hours (BIS, 2005).

After heating, the heat transfer medium was taken out from the oven and they were cooled at room temperature. The peeling of coating, fading of coating, and filtering of coating, if any, in the heat transfer medium were noticed. It was found that there was no peeling of coating on the heat transfer medium. It was also found that there was neither fading nor filtering of the coating on the heat transfer medium (BIS, 2005).

To study the thermal characteristics of the developed heat transfer medium, the improved nanocomposite-coated heat transfer medium was integrated with a conical solar greenhouse device. The fabricated greenhouse was kept outdoors for the measurement of temperature on heat transfer medium in varied meteorological conditions. During experimentation, the temperature of the heat transfer medium along with the influencing parameters such as incident solar radiation, ambient temperature, and wind speed were measured. It would be worth mentioning here that the sample was free from fall of dust, shadows, and other integrating materials during the experimental period (John and William, 2013).

2.3 Performance Evaluation of Greenhouse Device

The polycarbonate sheets with good optical transmittance were commercially procured. They were properly cut in different sizes, shapes, and designs. The pieces of polycarbonate sheets were integrated to form a conical-shaped greenhouse. The developed greenhouse was integrated not only with the heat transfer medium but also with the supporting structure that was made with bars of adequate mechanical strength, appropriate thermal durability, and corrosion resistance. It was ensured that there was no fluid leakage from the developed conical greenhouse device. It was also ensured that there was no heat loss from the developed conical greenhouse device to the surroundings.

In the present research, the leaves of the medicinal plant were collected and cleaned. The cleaned leaves were spread over a heat transfer medium in the solar greenhouse device before three hours of solar noon (Pantira *et al.* 2019). They were kept in the same heat transfer medium of the solar greenhouse device after three hours of solar noon. The weights of the leaves were measured before and after experimentation in a solar greenhouse device. The amount of moisture removed from the product was measured on a weight basis. The influencing meteorological parameters were periodically noted and they have been tabulated (Pantira *et al.* 2019).

The moisture removal rate was calculated by,

$$\mathrm{M_R} = \mathrm{m_i} - \mathrm{m_f}/\mathrm{t_d} \qquad \ldots (1)$$

where, $\mathrm{M_R}$ is the mass removal rate, $\mathrm{m_i}$ is the initial weight of the sample before drying, $\mathrm{m_f}$ is the final weight of the sample after drying and $\mathrm{t_d}$ is the drying tenure.

The solar energy input to the device ($\mathrm{Q_{solar}}$) is,

$$\mathrm{Q_{solar}} = \mathrm{A_{device}} \int \mathrm{I(t)\,dt} \quad \ldots (2)$$

where, $\mathrm{Q_{solar}}$ is solar energy input to device (in J), $\mathrm{A_{dryer}}$ is area of device (m^2), I is the incident solar radiation and t is the drying tenure (in s) and it is to be noted that the integral limits extend from 0 to t.

The energy required for vaporization ($\mathrm{Q_{device}}$) can be calculated by the equation that has the parameters such as the amount of moisture removal and latent heat of vaporization.

$$\mathrm{Q_{device}} = \mathrm{m_r} \times \mathrm{L_g} \qquad \ldots (3)$$

where, $\mathrm{Q_{solar}}$ is the energy required for vaporization (in J), $\mathrm{m_r}$ is the amount of moisture removed (in kg) and $\mathrm{L_g}$ is the latent heat of vaporization (in $\mathrm{J/kg}$).

The drying efficiency of a solar greenhouse device can be calculated by the equation that incorporates the input and output energies of the solar device.

$$\eta = \mathrm{Q_{device}} / \mathrm{Q_{solar}} \qquad \ldots (4)$$

where, η is the drying efficiency (in %) of the greenhouse devices.

3. RESULTS AND DISCUSSION

The technical specifications and monitored values in loaded and no-load conditions have been presented from Table 1 to Table 5. The photographs of the circular heat transfer medium have been presented in Figures 1 and 2. The characterization outcomes concerning EDAX, XRD, SEM, and UV-Vis have been presented in Figures 3 and 4. The photographs of the developed conical-shaped greenhouse device are presented in Figures 5 to 7. As the preliminary study of the present investigation, the nano-structured heat transfer medium and greenhouse device were tested for three days in field conditions and the test results have been presented in Figures 8 to 10 respectively. As the final study of the present investigation, the greenhouse device was tested to estimate the drying efficiency of three different medicinal plants in field conditions and the hourly weight reduction of these medicinal plants in the greenhouse device has been presented in Fig. 11.

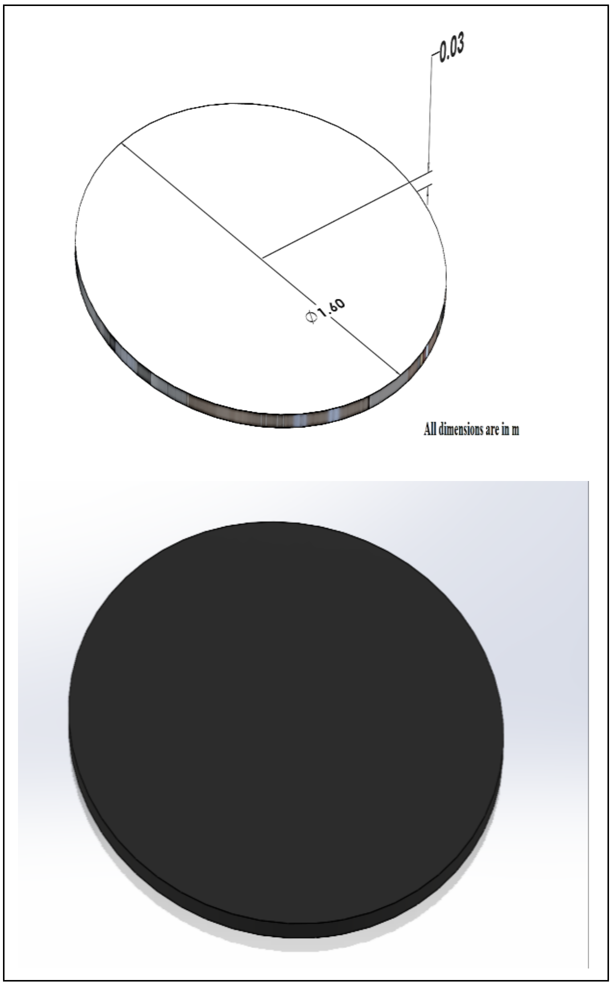

Fig. 1: Design of solar heat transfer medium used in the solar heating device

Fig. 2: Prepared carbon nanotube and nano-tungsten carbide-coated heat transfer medium used in the solar greenhouse device

As far as the preparation of nano-carbon and tungsten carbide-coated solar heat transfer medium was concerned, the carbon nanotube, nano-tungsten carbide, and solar emulsion were mixed in suitable mass proportions and the absorptive solution was prepared. It was spray-coated on a circular-shaped metal plate with side baffles around the plate. This nanocomposite-coated heat transfer medium was integrated with a conical structure by using galvanized aluminum rods. It is worth mentioning here that the prepared solar greenhouse device would have the advantages of having simplicity in design, easiness in fabrication, and elevated performance.

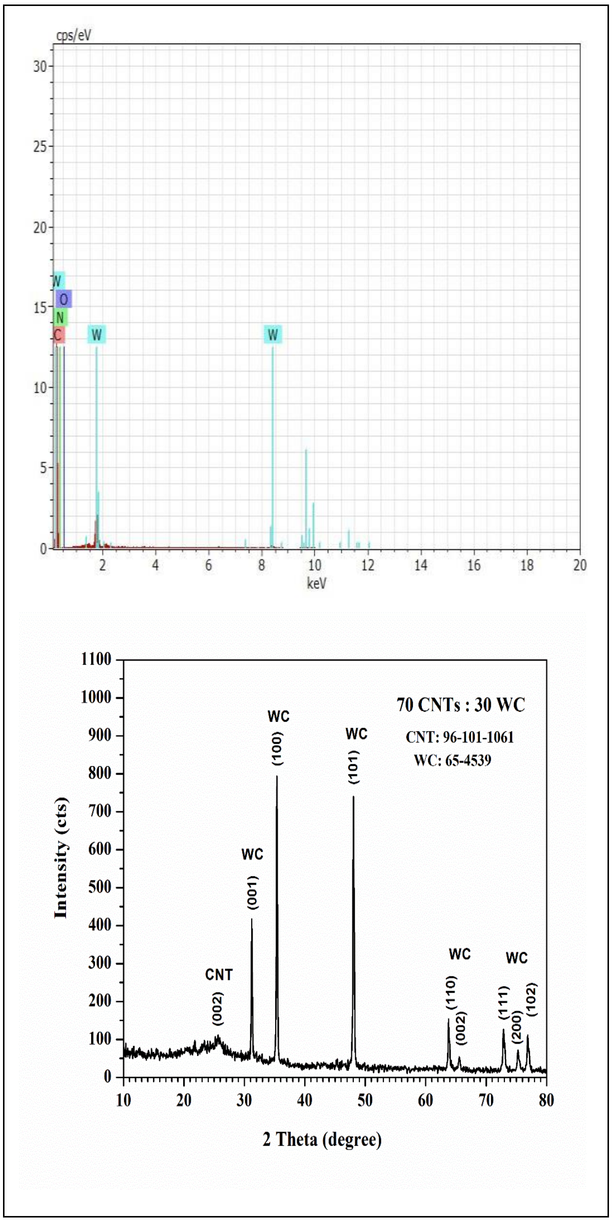

Fig. 3: EDAX and XRD Diffractogram spectra

As far as the characterization of the carbon nanotube and tungsten carbide-coated solar heat transfer medium was concerned, the constituents of nanocomposite coating on solar heat transfer medium were characterized through EDAX, XRD, SEM, and UV-Vis. The EDAX results showed that the nanocomposite powder contained carbon (C), oxygen (O), and tungsten (W) elements with 96.02, 1.25, and 0.80% respectively. The XRD characterization results showed that the crystallite sizes of carbon nanotube and tungsten carbide were 14.4 nm and 44.27 nm respectively. The SEM characterization results showed that there was the presence of crystallized carbon nanotube and tungsten carbide nanoparticles and they were in usual shapes. The SEM characterization results also showed that there was uniformity with minimal voids in the coatings deposited on the heat transfer medium. The UV-Vis results showed that the optical absorptance was maximum at the wavelength of 600 to 800 nm. It is noteworthy here that some of these characterization results showed that the designed and fabricated heat transfer medium had enhanced optical properties. As there were enhanced optical properties, the prepared solar greenhouse device would be effectively used for drying applications.

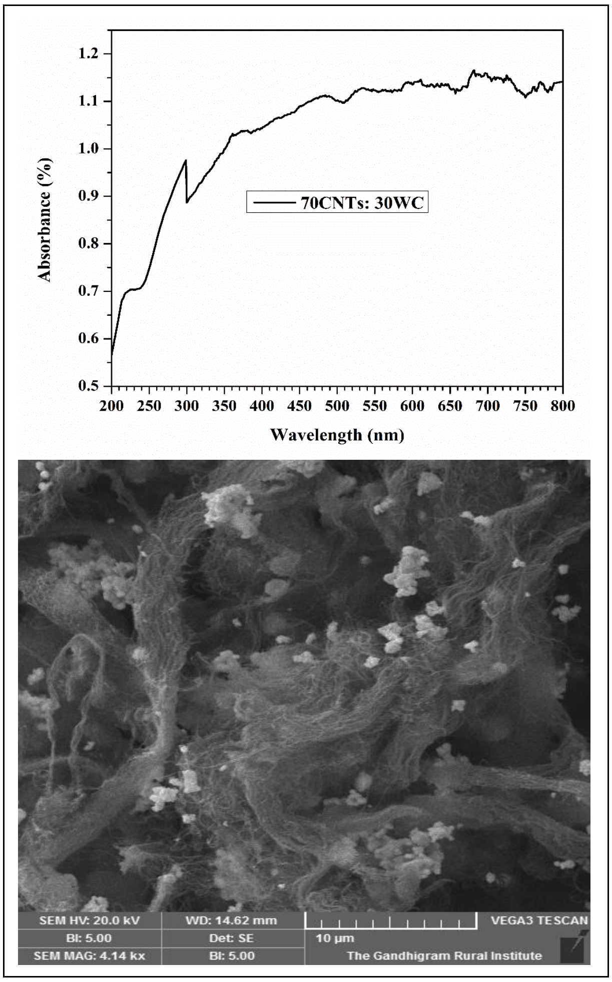

Fig. 4: UV- Visible spectrum and SEM image

Besides the characterization studies, the optical transmittance of the polycarbonate sheet was experimentally estimated to be 92%. As there was elevated optical transmittance, there would be an enhanced level of transmitted radiation inside the solar greenhouse device. This process would enhance the optical absorptances in heat transfer media and hence the efficiency of the fabricated device that would be effectively used for drying applications.

Table 1. Specifications of integral components

Components	Specifications
Transmitting medium	
Thickness	0.006 m
Transmittance	92%
Area	6.03 m^2
Heat transfer medium	
Material	Zinc-aluminium alloy plate
Thickness	0.03 m
Coating	Carbon nanotube and nano-tungsten carbide
Surface area	2.01 m^2

As far as the performances of the circular-shaped heat transfer medium were concerned, it was kept during sunshine hours in outdoor conditions for extensive field experimentation on the developed heat transfer medium. The temperature on the heat transfer medium was measured on a half-an-hour basis along with the influencing parameters such as the level of solar radiation, ambient temperature, and wind speed. The experimental results showed that the temperature on the circular heat transfer medium varied from 49.0 to 76.2 °C. The temperature on the heat transfer medium could be ascribed to the material constituents of nano-coating on the metal plate, materials of the base plate, and physical characteristics of the coating on the zinc aluminium alloy metal plate. It could also be ascribed to influencing parameters such as increased level of incident solar radiation, decreased level of ambient temperature, and lessened level of wind speed. As the heat transfer medium had elevated temperatures in field conditions, they would effectively be used in the greenhouse devices.

As far as the construction of the conical greenhouse device was concerned, it was constructed in such a way that there would be variations concerning the shape, size, and materials of the components of the solar greenhouse device.

In the case of the shape of the solar greenhouse device, it was specifically designed in a conical structure and it was subsequently fabricated in such a way that the solar radiation would fall on this solar greenhouse device in a perpendicular direction throughout the sunshine hours. This process would enhance the level of incident and transmitted solar radiation on greenhouse devices and hence would enhance the thermal efficiency of the device.

Table 2. Specifications of conical-shaped greenhouse device

Components	Specifications
Material of transmitter	Polycarbonate sheet
Material of heat transfer medium	Zinc-aluminium alloy plate
Material of supporting structure	Iron rod
Volume	1.07 m^3
Number of supporting rods	4
Slant height of supporting rod	1.6 m

Table 3. Monitored values in testing the conical-shaped solar greenhouse device in no-load conditions

Time (h)	Solar radiation (Wm^{-2})	Ambient temperature (°C)	Wind speed (ms^{-1})	Temperature profile (°C)		
				Tray temperature	Lower part temperature	Upper part temperature
09.00	453.4	33.6	0.8	49.0	47.7	46.3
10.00	526.7	34.2	0.9	56.8	52.9	51.4
11.00	643.2	35.4	1.2	68.6	64.5	62.0
12.00	690.3	35.0	1.4	74.6	70.5	64.9
13.00	720.3	36.1	1.1	76.2	72.0	67.7
14.00	720.4	35.9	1.0	74.6	70.1	66.6
15.00	615.6	34.5	0.9	70.2	65.3	63.1

Table 4. Monitored values in testing the conical-shaped solar greenhouse device in load conditions

Time (h)	Solar radiation (Wm^{-2})	Ambient temperature (°C)	Wind speed (ms^{-1})	Temperature profile (°C)		
				Tray temperature	Lower part temperature	Upper part temperature
09.00	472.5	32.5	0.9	48.4	45.4	43.5
10.00	547.9	35.1	1.5	54.8	51.6	49.0
11.00	639.6	36.3	1.1	68.2	63.9	59.6
12.00	698.9	35.8	1.3	70.5	65.1	61.3
13.00	734.5	37.9	1.4	71.7	66.8	63.2
14.00	718.9	36.4	0.8	65.1	61.5	58.9
15.00	634.8	30.3	0.9	59.6	54.9	52.4

Table 5. Thermal profile of greenhouse device

Solar radiation $ends(Wm^{-2})$	Maximum temperatures in greenhouse device (°C)					
	In no-load conditions			In loaded conditions		
	Tray temperature	Lower part temperature	Upper part temperature	Tray temperature	Lower part temperature	Upper part temperature
Below 500	49.0	47.7	46.3	48.4	45.4	43.5
500 to 700	74.6	70.5	64.9	68.2	65.1	61.3
Above 700	76.2	72.0	67.7	71.7	66.8	63.2

In connection with the sizes of the solar greenhouse device, the thickness, diameter, and area of the circular heat transfer media were fixed to be 0.03 m, 1.8 m, and 6.03 m^2 respectively. At the same time, the volume of the conical-shaped structure was fixed to be 1.07 m^3. The sizes of the transmitter, heat transfer medium, and greenhouse device were fixed to have desirable optical properties, thermal durability and portability of these pilot scale devices.

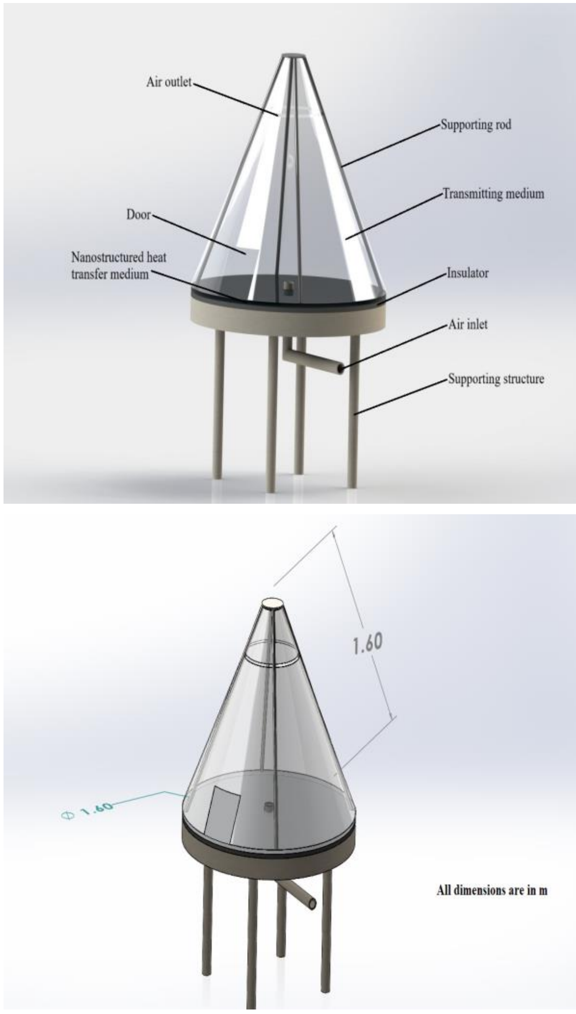

Fig. 5: Design of conical-shaped solar greenhouse device

Regarding the materials of the components of the solar greenhouse device, the polycarbonate sheet was used as a transmitter and the nanocomposite-coated zinc aluminum alloy plates were used as integrals of the heat transfer medium. The iron alloy rods were used as supporting structures in this greenhouse device. The materials of the components were selected to have cost effectiveness, adequate flexibility, appropriate mechanical strength, acceptable thermal durability, and corrosion resistance.

As far as the generation of the thermal profile of the conical-shaped solar greenhouse device (integrated with nanocomposite-coated heat transfer medium) was concerned, the developed conical greenhouse device was kept during sunshine hours in outdoor conditions for extensive field experimentation on the developed device. The temperatures in the heat transfer medium, the lower part of the greenhouse, and the upper part of the greenhouse were recorded in no-load and load conditions during the experiment. In the case of the no-load condition, the temperature enhancement in the upper part, lower part, and heat transfer medium was 21.4, 24.3, and 27.2°C respectively. As far as the load condition was concerned, the temperature enhancement in the upper part, lower part, and heat transfer medium was 19.7, 21.4, and 23.3°C respectively. As there were sufficient thermal enhancements inside the greenhouse device, it could be effectively used in the application sectors.

The constructed greenhouse device was tested in field conditions. The leaves of the medicinal plants were kept in the devices and they were effectively dried. The thermal performance of the greenhouse device for drying the leaves of medicinal plants was experimentally evaluated. The developed conical greenhouse device was kept in the field to assess not only its thermal characteristics during sunshine hours but also to evaluate its thermal performances in drying medicinal plant leaves.

Fig. 6: Developed solar greenhouse device with heat transfer medium

Fig. 7: Testing of solar greenhouse device

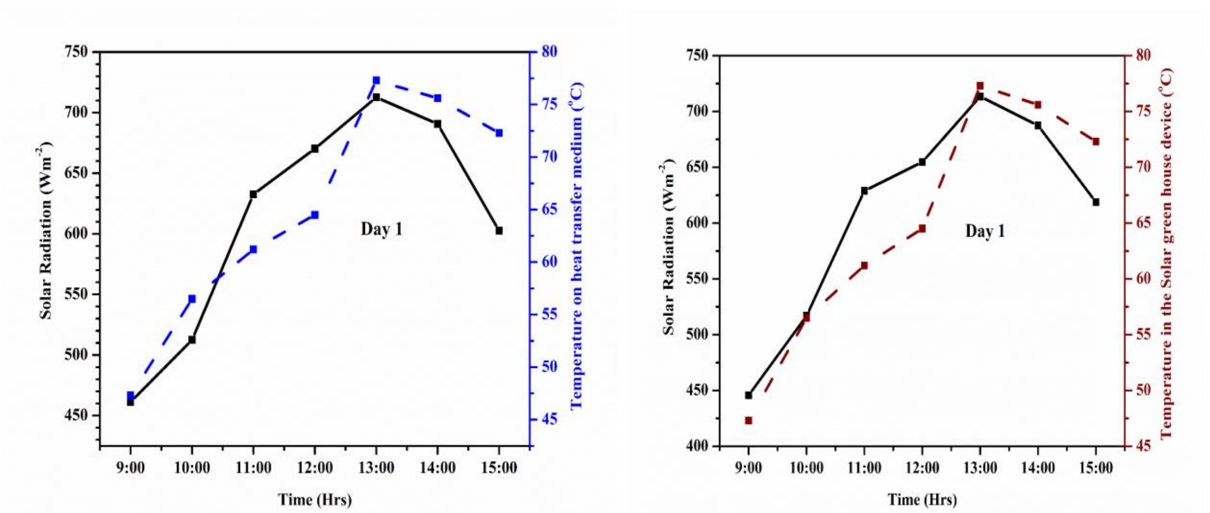

Fig. 8: Thermal enhancement in component and device on Day 1

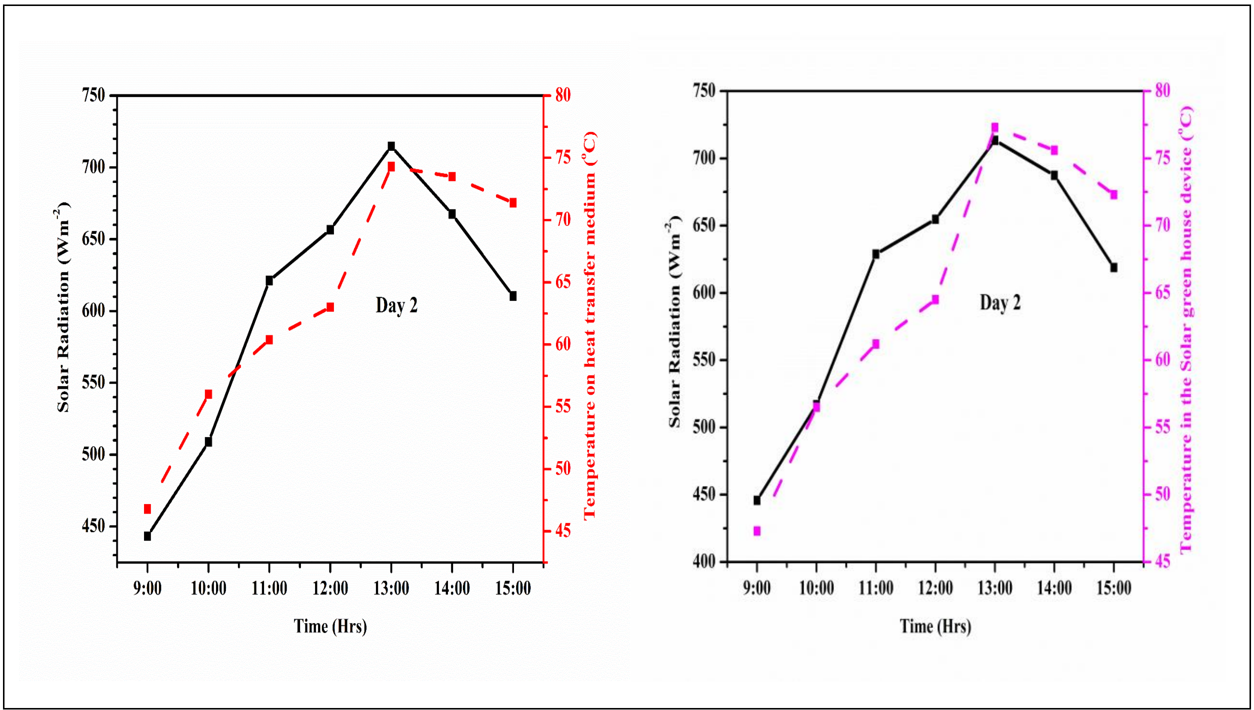

Fig. 9: Thermal enhancement in component and device on Day 2

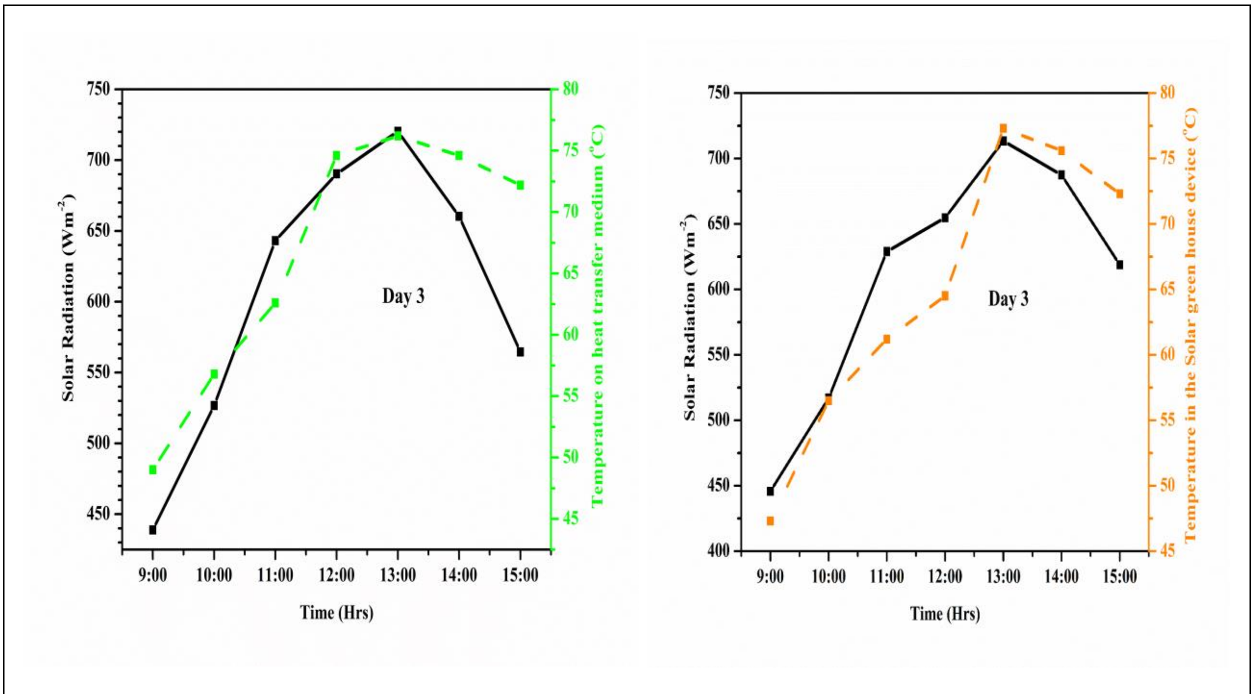

Fig. 10: Thermal enhancement in component and device on Day 3

The research reviews showed that the *Ocimum tenuiflorum* dried leaves have been used for the treatment of bronchitis, bronchial asthma, malaria, diarrhea, dysentery, and skin diseases. The research reviews also showed that the *Azadirachta indica* dried leaves have been used for the treatment of tooth plaque, blood sugar, and ulcers in the digestive tract, and Coriander sativum dried leaves have been used for the treatment of nausea, diarrhea, intestinal gas, constipation, and irritable bowel syndrome (Geetha *et al.* 2019). Hence, these medicinal plants were chosen for their drying in this present research investigation.

The leaves of medicinal plants were collected and they were properly cleaned. The cleaned leaves were spread over the heat transfer medium three hours before solar noon in the greenhouse device. The dried plant leaves were taken out from the greenhouse device after the stipulated period of drying at the solar noon. The weights of the medicinal plant leaves were measured before and after experimentation in this solar greenhouse device. The influencing parameters such as incident solar radiation, ambient temperature, and temperature inside the greenhouse device were periodically noted. The amount of moisture removed from the plant product was measured on a weight basis and the moisture removal rate was calculated (Pantira *et al.* 2019). The experimental results showed that the weights of leaves of medicinal plants such as *Ocimum tenuiflorum*, *Azadirachta indica*, and *Coriander sativum* were reduced from 605 to 171.2 g, 800.5 to 212.8 g and 723.5 to 190.5 g during the experimental period of one day.

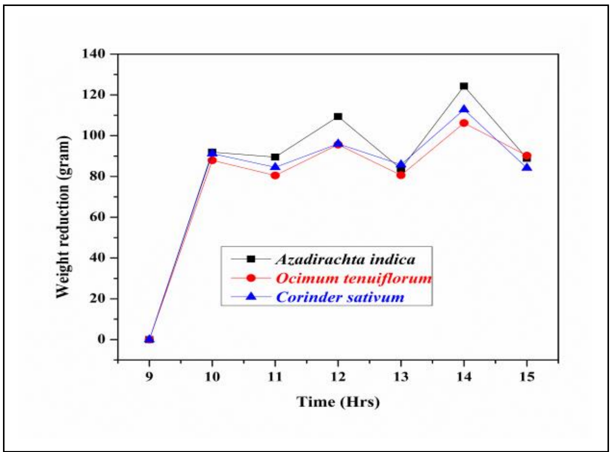

Fig. 11: Hourly weight reduction in medicinal plants

Three major observations on the thermal characteristics and performance of solar greenhouse devices were noted in this field study. The first observation was the temperature of the lower part was always higher than that of the upper part of the greenhouse device. This could be correlated to more heat transfer from the heat transfer medium to the lower part of the greenhouse due to its immediate humidity. This could also be correlated to the less heat transfer from the heat transfer medium to the upper part of the greenhouse due to its distant humidity. The second observation was the temperature of the heat transfer medium in no-load conditions was always higher than that of that in load conditions. This could be correlated to the direct exposure of the transmitted radiation on a heat transfer medium in no-load conditions. This could also be correlated to the direct exposure of transmitted radiation on the products to be dried which were spread over the heat transfer medium in load conditions. The third observation was that the performance of the conical-shaped solar greenhouse device varied from 63.9 to 66.7%. The enhanced temperatures and thermal performance could be correlated to the thickness of the polycarbonate sheet, the transmittance of the polycarbonate sheet, and the shape of the polycarbonate sheet. These enhanced temperatures and performance could also be correlated to the thickness of the heat transfer medium, the optical absorptance of the coating on the heat transfer medium, and the thermal conductivity of the heat transfer medium. These enhanced temperatures and performance could also be correlated not only to the chemical constituents such as CNTs (Carbon nanotubes) and nano-WC (nano-tungsten carbide) with high thermal conductivities, rapid heat distribution, and thermal stability but also to the nanostructured medium with increased effective surface area for heat absorption. These enhanced temperatures and performance could also be correlated to the level of transmitted radiation inside the greenhouse, the level of convective heat transfer from the tray to the air, and the level of moisture content of the air during the drying process.

4. CONCLUSION

In the previous research, the conventional heat transfer media were utilized. But, in the present work, the nanostructured heat transfer medium was newly developed and it was utilized in the greenhouse device. In addition, in the review works, the different shapes of solar greenhouse structures, such as parabolical, pyramidal, and trapezoidal structures, were utilized; but, in the present work, a novel conical-shaped structure was newly developed and utilized in a solar greenhouse device. Owing to these novelties in the present research, the leaves of the medicinal plants were effectively dried in the conical-shaped greenhouse device.

The optical property of polycarbonate sheets concerning transmittance was quantified to be 92%. The thermal property of the heat transfer medium concerning thermal enhancement was quantified to be in the range of 49.0 to 76.2 °C. The thermal property of solar greenhouse devices with special reference to drying performance was quantified to be in the range of 63.9 to 66.7%.

As the optical and thermal characteristics of solar components in solar conical greenhouse devices were found to be satisfactory, it could be concluded that the solar components such as polycarbonate cover and nanocomposite-coated heat transfer medium would be utilized in solar conical-shaped greenhouse devices. As the thermal enhancements and thermal performances of solar greenhouse devices were found to be substantial, it could also be concluded that the conical-shaped solar greenhouse dehydration or drying system is suitable for drying selected agricultural products in application sectors.

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CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest.

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