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DEVELOPMENT OF SOLAR DRYER

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ABSTRACT
Preservation of agricultural products is one of the main problems faced by many countries. Large quantities of fruits and vegetables get spoilt due to poor infrastructure and storage facilities. By the method of Solar Drying, we can also preserve the nutritional values of the product. Solar Photovoltaic Panels are another application of solar energy which work on the principle of Solar Photovoltaics to generate electricity. By the method of Solar Drying, we can preserve the nutritional values of the product by reducing its moisture content. Solar Photovoltaic Panels which are used for generating electricity start to lose their overall efficiency when the temperature of the Solar Panel starts increasing beyond 25ºC [1]. Overall efficiency of solar panels falls by 0.27% to 0.77% when panel temperature starts increasing by 1ºC [2]. In this paper, we have discussed a method of forced convection by air to cool the overheated solar panel by passing air under the panel with the help of DC fans. To utilize the waste heat coming out of the solar panel we used the outlet hot air for drying spinach. Hence combining the concepts of Solar PV and Solar Thermal to increase the power produced by the solar panel and dry agro products.

Keywords: Dryer, Solar Cells, Efficiency, Forced Convection Drying, Solar Thermal, Agroproduct drying

INTRODUCTION
Solar energy means the energy that is harnessed from the sun. This energy from the sun captured by the earth's surface is close to 1.8 x 10^{11} MW [3] which is very large amount of energy as compared to the actual consumption rate of energy resources on earth. Hence, solar energy has a capability to supply present and future energy needs, which makes it one of the most promising energy sources. Energy from the sun can be directly used in the form of photovoltaic and thermal conversions. Solar Photo voltaic Cells work on the principle of Photo voltaic conversions and is capable of converting Solar Energy of the sun directly into electricity. There are different types of Solar Cells available in market among which Monocrystalline Cells are most efficient among silicon cells [4]. The efficiency of these ranges from 15 to 20 % [15]. It's counterpart Polycrystalline cells are more affordable than monocrystalline; however, they are less efficient due to less silicone purity. As polycrystalline cells have very low heat tolerance, they are less efficient in high temperature areas. Efficiency of polycrystalline cells varies from 13% to 16%[15]. Factors like temperature, solar shadings, orientation and inclination of solar panel can affect the overall efficiency of a solar panel. Orientation and inclination are important factors that must be considered while setting up a solar panel, so that the panel works at its maximum efficiency. Orientation of solar panel is dependent on country. As India lies in Northern Hemisphere, solar panel must be oriented towards south. Inclination of panel with respect to horizontal depends upon the latitude of the location. One of the major disadvantages of Solar PV cells is that they start to lose its overall efficiency when the panel temperature gets heated up beyond 25ºC [1]. There are multiple ways of reducing the panel temperature by using air as a coolant or water as a coolant. The advantage of using air as a coolant is this system is that, air wont freeze at low temperatures like water, corrosion and leakage problems are also less severe for such a system [3]. We have used air generated by DC fans powered by the Solar Panel itself to increase the efficiency of Solar Panel [5]. Solar Dryers work on the principle of solar thermal conversions, where a collector plate is used to trap the heat energy of the sun. By use a solar panel as a collector plate in the dryer arrangement here it is possible to reduce the space and cost involved in setting up individual Solar and PV and thermal systems, improve the overall productivity and efficiency of the system. The hot air which is obtained as byproduct of the solar panel cooling process can be used to dry vegetables which can be kept in a dryer cabinet directly connected to Solar Panel. Advantage of drying in a closed structure by forced convection is that the dried product will be protected from impurities and insects, shelf life of the product is enhanced, a good quality dried product is obtained which does not lose its color after drying.

Introduction

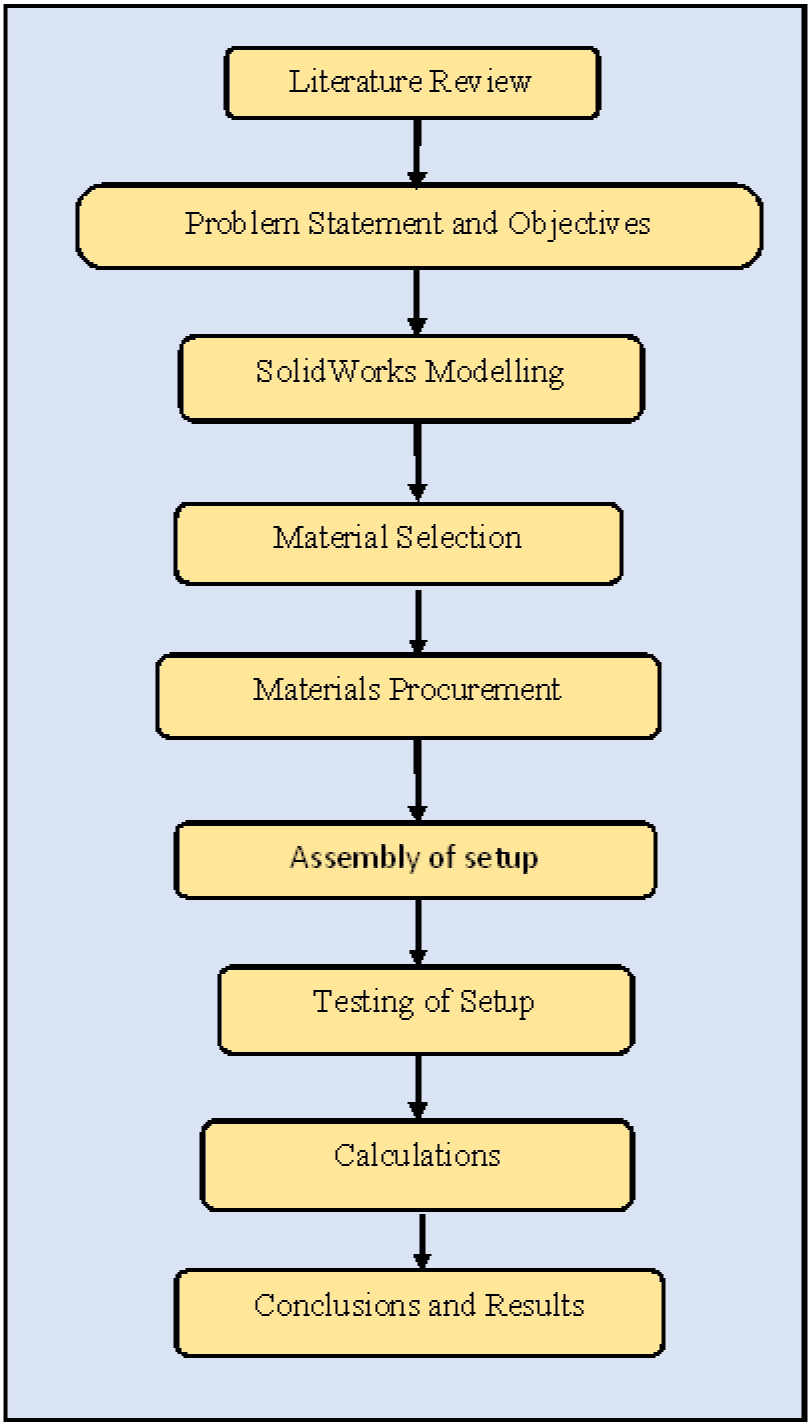

Fig. 1: Methodology Flowchart

Measuring Devices

Thermocouple. Four K-type thermocouples were used by us to measure temperature at a regular time interval. The procedure followed for calibration of thermocouples is as follows:

- First a 1000 ml glass beaker filled with water was taken. The water inside the beaker was boiled till 100ºC as shown in figure below.
- During the whole process beaker was insulated at top with the help of ASAWA Smart PIR Panel.
- Two holes were made in the insulation. One to insert a mercury thermometer and the other to insert a thermocouple
- The end at other side of thermocouple was connected to a indicator which displays temperature.
- Thermometer and temperature indicator readings were recorded and compared.

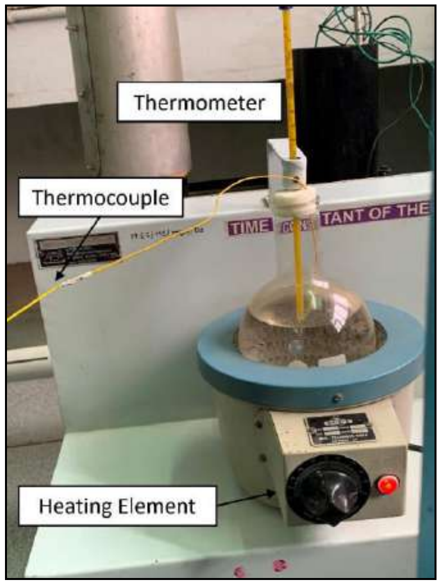

Fig. 2: Calibration Setup of Thermocouple

Pyranometer. Pyranometer is an instrument which is used to measure solar radiation flux in W/m^2, it measures the global solar radiation falling on a horizontal surface over a hemispherical field of view. The pyranometer was calibrated by multiplying 400 to the output radiation voltage generated by the pyranometer.

Fig. 3: Dynalab Pyranometer

Components of Setup

Solar Panel. Solar panel for our experiment is made by arranging 12 monocrystalline solar cells in the form of series and parallel on a multiwalled polycarbonate sheet of 10 mm thickness and connecting the cells with the help of tabbing wire. The top surface of solar cells is covered with a polycarbonate sheet to prevent dust accumulation. Function of multiwalled polycarbonate sheet is to incorporate air flow below the solar cells. K Type Thermocouple wires were used to measure the temperature of solar cells. An insulation made of ASAWA Smart PIR Panel was attached below the solar panel to avoid heat losses.

Fig. 4: Solar Panel mounted on stand

Solar Panel Stand. A solar panel stand was made to support the solar panel which was mounted on it. As we had tested the panel in the Panvel location (18.9894°N, 73.1175°E), the panel inclination was formulated as 35° with horizontal [6, 7, 21, 22].

Dryer Cabinet. Dryer Cabinet of dimension 46 x 46 x 46 cm was made out of ASAWA Smart PIR Panel. A slot was provided on front side of dryer cabinet for insertion of Solar Panel. A facility of door was provided on the rear side of dryer cabinet for insertion and removal of drying trays. Two DC fans were fitted on top of dryer cabinet to incorporate forced convection of air inside dryer cabinet.

Fig 5: Dryer Cabinet

Fig. 6: DC Fabs connection on Dryer Cabinet

Dryer Trays. Dryer trays of dimensions 36 X 26 cm was made to dry spinach inside dryer box. The tray was made of stainless-steel mesh bordered on all four sides by ASAWA Smart PIR Panel.

Fig. 7: Dryer Trays used to dry Spinach

Dryer Stand. Dryer stand was made of plywood in order to hold the dryer box. The height of the stand was 90 cm from the base

Fig. 8: Plywood Dryer Stand

Cost Analysis of Setup

Table 1: Cost Analysis of Components

Sr.No.	Cost analysis of all components	
	Material	***Cost (In Rupees)***
1	PIR Insulation Panel	Rs 800
2	Stainless Steel Wire	Rs 500
3	Acrylic sheet	Rs 500
4	Polycarbonate sheet	Rs 400
5	DC fans	Rs 300
6	Solar Cells	Rs 1440
7	Thermocouple wires	Rs 1880
8	Miscellaneous costs	Rs 1260
Total Cost		Rs 7000

Assembly of Setup

The following steps were followed by us to complete the assembly of the setup:

1. For testing we mounted the solar panel on stand, for the whole timeframe we aligned the panel towards south direction.
2. Solar panel was inserted inside the dryer box to complete our assembly.
3. For first reading thermocouple wires were used to measure the temperature of solar panel without the dryer box.
4. Power generated by solar panel was used to run the DC fans.
5. For second reading dryer box was attached to solar panel, temperature of panel inlet, solar panel, outlet of panel, dryer box was measured with the help of thermocouples.
6. Average temperature of solar panel was compared for both cases
7. Drying of spinach in the drying cabinet was done during the third test.

Fig. 9: Assembly of Experimental setup

Testing of Setup

Without DC fans. Figure shows thermocouples connected to solar panel to measure solar panel temperature for 1st reading. They are connected at three distinct points of solar panel.

Fig. 10: Experimental setup for 1st Reading

With DC fans. Figure shows thermocouples connected to inlet of solar panel (T0), solar panel (T1), outlet of solar panel (T2), dryer box (T3) to measure their respective temperatures for second reading.

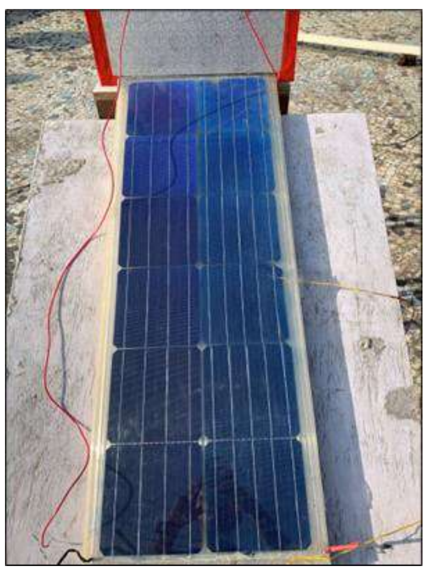

Fig. 11: Experimental setup for 2 Reading

DAQ and LABVIEW Software. Fig.12 shows the other end of thermocouples connected to a temperature sensing module. With the help of DAQ, we can get thermocouple readings with the help of LABVIEW software. Solar radiation readings were also obtained with the help of this software.

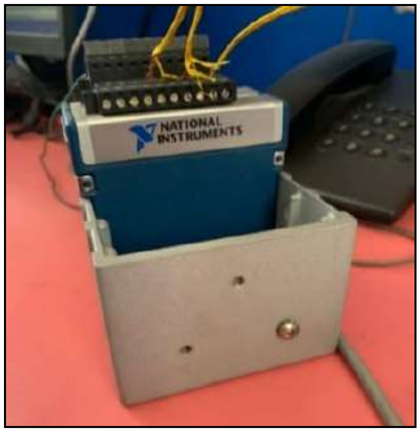

Fig. 12: Thermocouple Connected to DAQ

Calculations

Mass flow rate of air (m) and Volumetric flow rate of air (V).

$Q = m*C_p*(T_2-T_1)$ (1)

$A_s*I_g = m*C_p*(T_2-T_1)$ (2)

Where T1, T2 , As, Ig represent the temperature at the inlet and the outlet of solar panel, Area of the solar panel, Solar radiation respectively

Note: Ig (W/m2), T1 and T2 (K) values taken from figure 12 and 14 respectively for 10:30 am

0.2920×400 = m×1.00578×(333.585-308.837)

116.8=m×24.891

74.211 = m×6.195×1000 (Converting Kilojoules into Joules)

m = 4.692 g/s

$m = 4.692*10^{-3}$ kg/s

Volumetric flow rate = Mass flow rate /Density of Air (3)

*V = 4.692*10-3/1.127*

$V = 0.00416\ m^3/s$

V=0.00416×2118.88 [cfm conversion]

V = 8.81 cfm

Hence minimum 8.81 cfm of flow rate from dc fan is required to reduce the temperature of solar panel

Efficiency of Solar Panel.

Efficiency = (Isc × Vsc ×FF)/Solar Radiation×Area of Solar Panel×100 [8] (4)

FF= Im × Vm / Isc × Vsc (5)

Where FF is Fill Factor, higher the Fill factor more efficient is our solar panel.

Isc, Vsc are short circuit Current and Voltage Im, Vm are maximum current and Voltage [23]

Without DC fans.
Solar Radiation = 590 W/m^2 (12:30 noon)

Im= 7.28

Vm= 4.93

Isc= 8.07

Vsc= 6.63

Fill Factor = 0.670792 (From Eq. 5)

Efficiency = 17.380 % (From Eq. 4)

With DC fans.
Solar Radiation = 454.589 W/m^2 (12:30 noon)

Im= 7.32

Vm= 5.88

Isc= 8.165

Vsc= 7.48

Fill Factor = 0.7047 (From Eq. 5)

Efficiency = 27.05% (From Eq. 4)

Power required to run DC Fans.
$P_{fan1} = V_{fan1} * I_{fan1}$ (6)

= 24 * 0.05

= 1.2 W

$P_{fan2} = P_{fan1} = 1.2$ W

$P_{fans} = P_{fan1} + P_{fan2}$ (7)

= 1.2 + 1.2

= 2.4 W

Final Moisture Content of Spinach.
$W_{fSpinach} = (W_{iSpinach} * (100-M_{iSpinach}))/((100-M_{fSpinach}))$ (8)

$12 = (100\times(100-90))/((100-M_{fSpinach}))$

$M_{fSpinach}$=16.666%

EXPERIMENTAL RESULTS

Solar Radiation Plots.

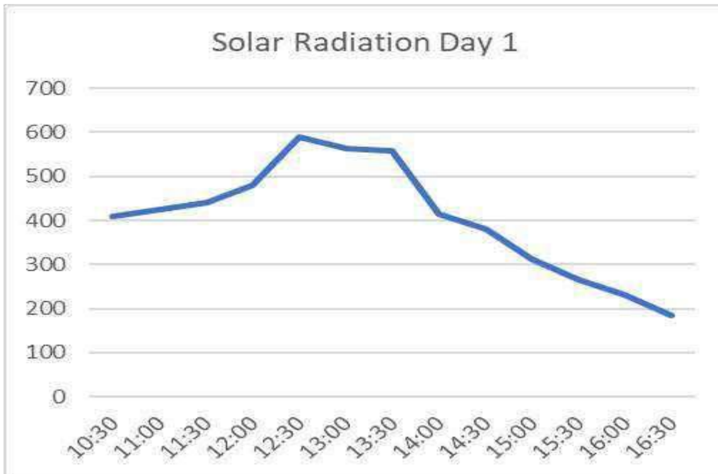

Fig. 13: Solar Radiation Graph for Day 1

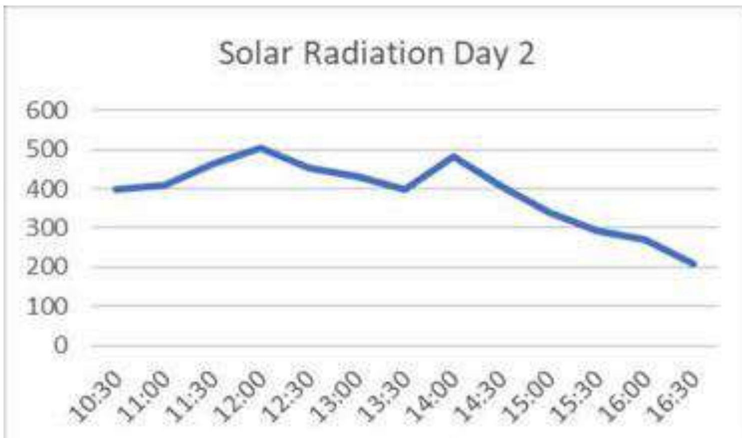

Fig. 14: Solar Radiation graph for Day 2

Thermocouple Calibration. With the help of calibration readings of thermocouples graphs were plotted. X axis shows standard temperature measured with thermometer and y axis shows temperature measured with the help of temperature indicator.

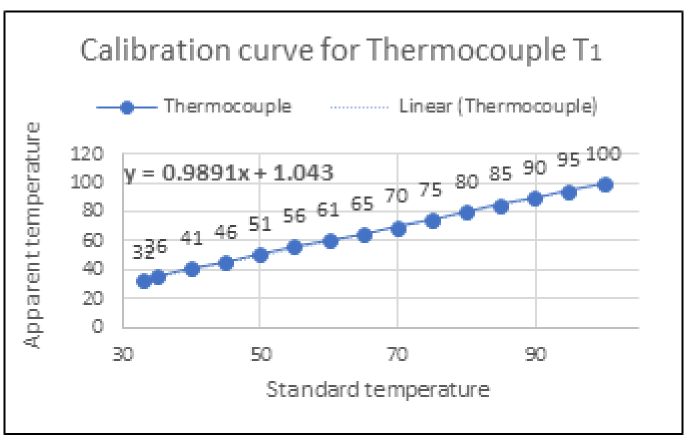

Fig. 15: Calibration Curve for Thermocouple 1

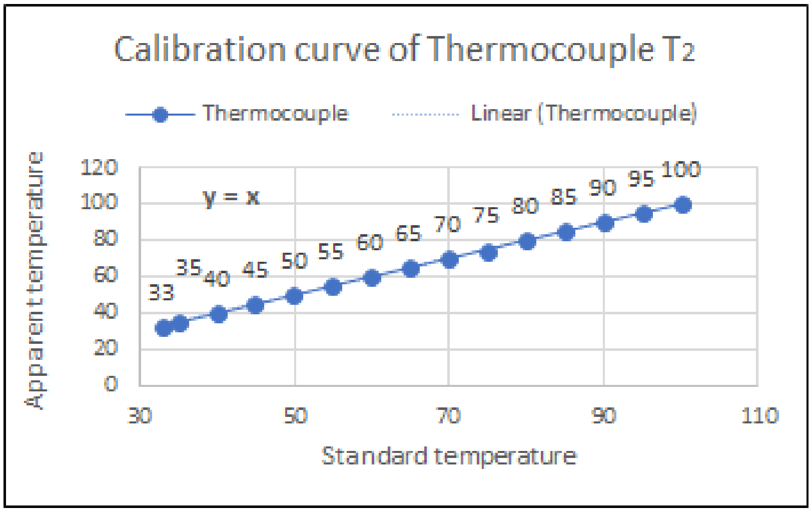

Fig. 16: Calibration Curve for Thermocouple 2

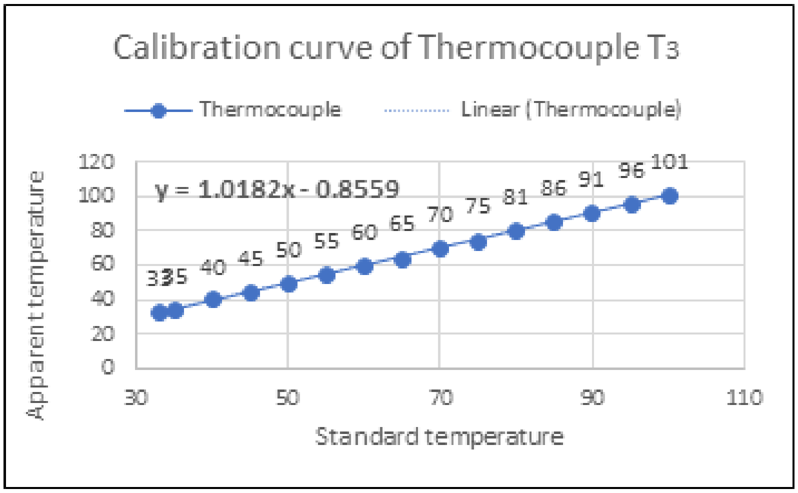

Fig. 17: Calibration Curve for Thermocouple 3

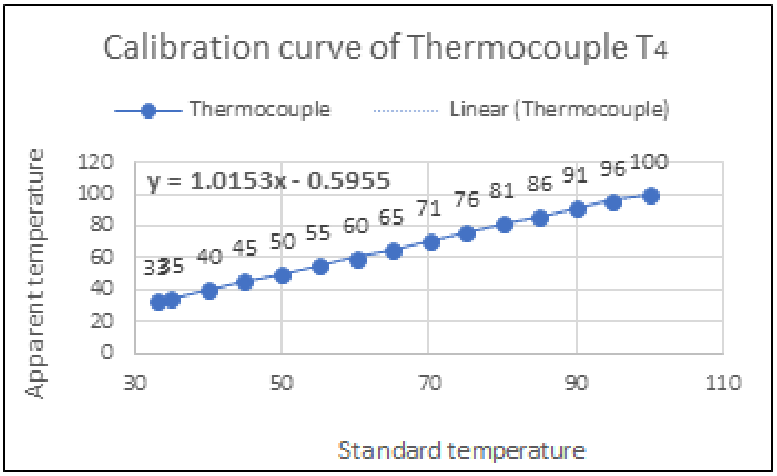

Fig. 18: Calibration Curve for Thermocouple 4

Temperature Graph. Figures 19 and 20 shows a graph of temperature versus time. X axis represents time, y axis represents temperature. In fig.19 8.9 T1, T2, T3 represents the temperature of solar panel at lower, middle and upper section, the graph shows the variation of these temperatures with time. In fig.20 T0 represents the inlet of solar panel, T1 represents on solar panel, T2 represents outlet of solar panel, T3 represents dryer cabinet. From figures 19 and 20 we can conclude that temperature of solar panel reduced by 1.51ºC in case of forced convection.

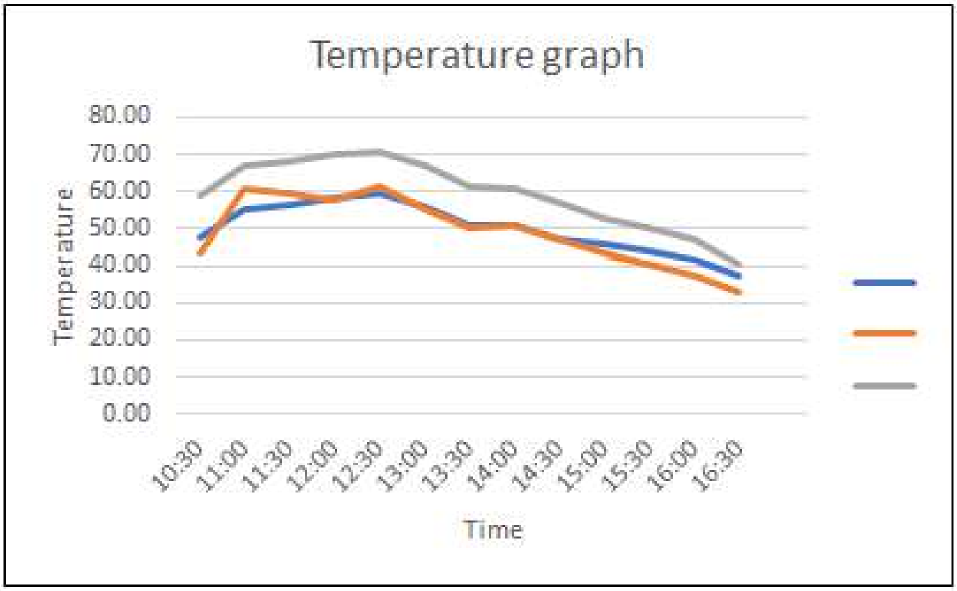

Fig. 19: Temperature Graph for Day 1

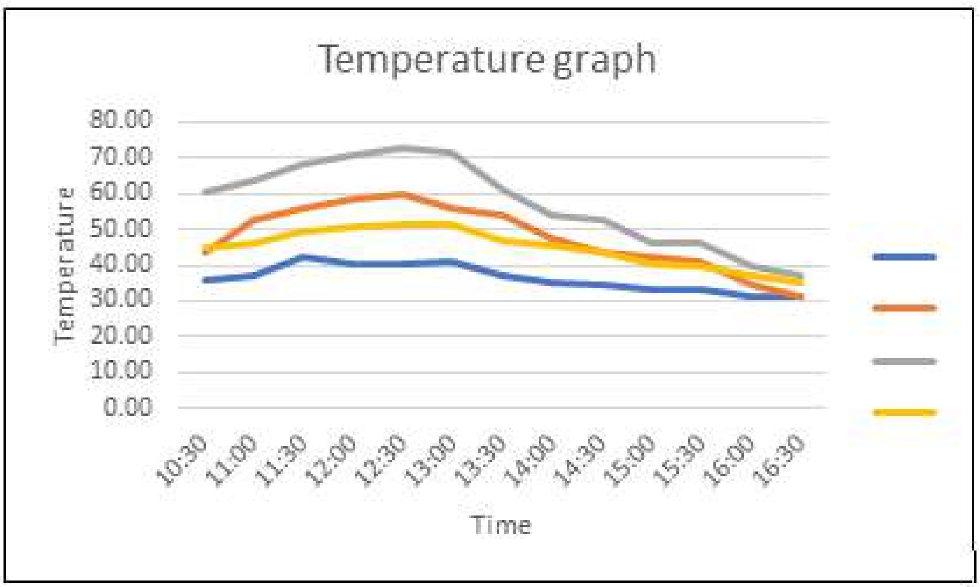

Fig. 20: Temperature Graph for Day 2

Graph showing variation of efficiency with time. Fig. 21 shows the variation of efficiency versus time for both cases without the use of DC fans and with the use of DC fans. As efficiency is directly proportional to power generation, we can conclude from the graphs below that the solar panel generated more power in the case of forced convection with the help of DC fans

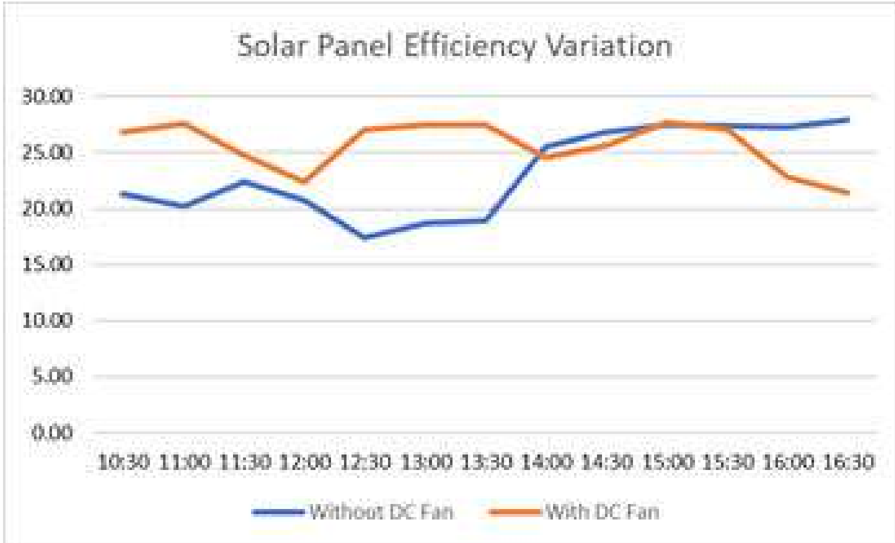

Fig. 21: Graph showing variation of panel efficiency without and with DC fans

Drying Results

Initially we took about 100g of spinach for drying in solar dryer for a period of 6 hours. Weight of spinach after drying was analysed to find out amount of moisture content reduced by our dryer in 6 hours. Final weight of spinach after drying was 12 g. After experimental calculation the moisture content of spinach after 6 hours of drying was formulated as 16.66 %. Further we also compared sun dried spinach with spinach dried in our dryer, we could infer that the sun-dried spinach lost its colour and got overdried after 4 hours while the spinach in dryer retained its colour even after drying process was complete.

Fig. 22: Open Sun drying of Spinach

Fig. 23: Drying of Spinach in Solar Dryer

CONCLUSION AND FUTURE SCOPE

1. Solar panel temperature reduced by 1.51°C when DC fan used for circulating air inside the solar panel.
2. Average Efficiency of solar panel increased from 23.219% to 25.617% in case of forced convection of air.
3. Good quality dried product was obtained after drying spinach in dryer cabinet, the final product having a moisture content of 16.66% retained its green colour With this experimental setup future scope can be

1. Efficiency of solar panel can be increased more by increasing the number of DC fans in the setup.
2. Thermostat can be used to maintain the desired temperature inside solar panel for longer amount of time
3. We can incorporate a fan box arrangement at bottom of solar panel for better circulation of air.

REFERENCES

[1] Muhammad, F., Raza., M.W., Khan, S. & Ahmed, A. (2017). Low Efficiency of the Photovoltaic Cells: Causes and Impacts. International Journal of Scientific & Engineering Research, 8(11), 1201-1207.

[2] Thong, L.W., Murugan, S., Ng, P.K., & S., C.C. (2016, November 18-19). Analysis of Photovoltaic Panel Temperature Effects on its Efficiency [Conference Presentation]. 2nd International Conference on Electrical Engineering and Electronics Communication System, Ho Chi Minh, Vietnam.

[3] Sukhatme, S. P., & Nayak, J. K. (2009). Solar Energy: Principles of Thermal Collection and Storage (3rd ed., pp. 71-107). McGraw-Hill Education (India).

[4] Biermeier, D. (2023, October 9). Best solar panels for homes of October 2023. Forbes. https://www.forbes.com/home-improvement/solar/best-solar-panels/

[5] Amelia, A. R., Irwan, Y. M., Irwanto, M., Leow, W. Z., Gomesh, N., Safwati, I., & Anuar, M. A. M. (2016). Cooling on photovoltaic panel using forced air convection induced by DC Fan. International Journal of Electrical and Computer Engineering, 6(2), 526. https://doi.org/10.11591/ijece.v6i2.9118

[6] Ajao, K. R., Ambali, R. M., & Mahmoud, M. O. (2013). Determination of the optimal tilt angle for solar photovoltaic panel in Ilorin, Nigeria. Journal of Engineering Science and Technology Review, 6(1), 87–90. https://doi.org/10.25103/jestr.061.17

[7] Yunus Khan, T. M., Soudagar, M. Elahi., Kanchan, M., Afzal, A., Banapurmath, Nagaraj. R., Akram, N., Mane, S. D., & Shahapurkar, K. (2019). Optimum location and influence of tilt angle on performance of solar PV panels. Journal of Thermal Analysis and Calorimetry, 141(1), 511–532. https://doi.org/10.1007/s10973-019-09089-5

[8] Kumbhar, C. (2023, March 21). How is solar panel efficiency measured? - technical articles. EEPower. https://eepower.com/technical-articles/how-is-solar-panel-efficiency-measured

[9] Hossain, M. Z., Hossain, M. A., Awal, A., Md., Alam, M., Md., & Rabbani, M. (2015). Design and Development of Solar Dryer for Chilli Drying. International Journal of Research (IJR), 2(1), 63-78.

[10] Baradey, Y., Hawlader, M. N. A., Ismail, A. F., Hrairi, M., & Rapi, M. I. (2016). Solar Drying of Fruits and Vegetables. International Journal of Recent Development in Engineering and Technology, 5(1).

[11] Kumar, L., Kumar, M., & Kumar, P. (2017). Drying behavior of spinach under various drying conditions. International Journal of Applied Research, 3(1), 815-819.

[12] Shaikh, Mohd. R. (2017). A review paper on electricity generation from Solar Energy. International Journal for Research in Applied Science and Engineering Technology, V(IX), 1884–1889. https://doi.org/10.22214/ijraset.2017.9272

[13] Kilanko, O., Ilori, T. A., Leramo, R. O., Babalola, P. O., Eluwa, S. E., Onyenma, F. A., Ameh, N. I., Onwordi, P. N., Aworinde, A. K., & Fajobi, M. A. (2019). Design and performance evaluation of a solar dryer. Journal of Physics: Conference Series, 1378(3), 032001. https://doi.org/10.1088/1742-6596/1378/3/032001

[14] Kumar, A., Singh, K. U., Singh, M. K., Kushwaha, A. K., Kumar, A., & Mahato, S. (2022). Design and fabrication of solar dryer system for food preservation of vegetables or fruit. Journal of Food Quality, 2022, 1–14. https://doi.org/10.1155/2022/6564933

[15] Wallender, L. (2023, August 31). Monocrystalline vs polycrystalline solar panels: What’s the difference? Forbes. https://www.forbes.com/home-improvement/solar/monocrystalline-vs-polycrystalline-solar-panels/

[16] Ahmed, A. M., & Hassan Danook, S. (2018). Efficiency improvement for solar cells panels by cooling. 2018 2nd International Conference for Engineering, Technology and Sciences of Al-Kitab (ICETS). https://doi.org/10.1109/icets.2018.8724625

[17] Singh, A., Pandey, M., & Gour, A. (2018). Experimental analysis of solar photo voltaic panel with air cooling system to maintain its efficiency. International Journal of Creative Research Thoughts, 6(2), 715-726.

[18] Sultan, T. N., Farhan, M. S., & Salim ALRikabi, H. TH. (2021). Using cooling system for increasing the efficiency of solar cell. Journal of Physics: Conference Series, 1973(1), 012129. https://doi.org/10.1088/1742-6596/1973/1/012129

[19] Suresh, M., Palanisamy, P., & Senthil, K. (2019). Drying of mint leaves in forced convection solar dryer. Thermal Science, 23(6 Part B), 3941–3949. https://doi.org/10.2298/tsci171230303s

[20] Chouikhi, H., & Amer, B. M. (2023). Performance evaluation of an indirect-mode forced convection solar dryer equipped with a PV/t air collector for drying tomato slices. Sustainability, 15(6), 5070. https://doi.org/10.3390/su15065070

[21] Birol, F. (2023, May 16). What should be the best angle for a solar panel? does direction matter?. Solar Square Blog. https://www.solarsquare.in/blog/what-should-be-the-best-angle-for-a-solar-panel-does-direction-matter/

[22] Liu, H., Xu, X., Meng, Y., Yu, D., Liu, H., & Shi, K. (2018). A research for the influence of tilt angles of the solar panel on Photovoltaic Power Generation. 2018 International Conference on Smart Grid and Clean Energy Technologies (ICSGCE). https://doi.org/10.1109/icsgce.2018.8556655

[23] Mollick, AR. (2020). Why it's crucial to understand the fill factor of solar cell? How it's affecting the efficiency of PV cells. EcoWowLife. https://ecowowlife.com/fill-factor-of-solar-cell/.

[24] Hegde, V. N., Hosur, V. S., Rathod, S. K., Harsoor, P. A., & Narayana, K. B. (2015). Design, fabrication and performance evaluation of Solar Dryer for banana. Energy, Sustainability and Society, 5(1). https://doi.org/10.1186/s13705-015-0052-x

[25] Ferhat, R., Siabdallah, N., Lahbari, M., & Fahloul, D. (2019). Convective solar drying of spinach leaves. MOJ Food Processing & Technology, 7(1), 22–25. https://doi.org/10.15406/mojfpt.2019.07.00214