

Performance Analysis Of A Solar Dryer With Silica Gel Integration For Outlet Air Dehumidification

Suhaimi Misha ^{1,2*}, Eslam Ahmed Hashem ¹, Mohd Afzanizam Mohd Rosli ^{1,2}, Fatimah Al Zahrah Mohd Saat ^{1,2}, Nor Faizah Haminudin ^{1,2}, Fudhail Abdul Munir ³

¹ Faculty of Mechanical Technology and Engineering, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, Durian Tunggal, Melaka, 76100, Malaysia

² Centre for Advanced Research on Energy, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, Durian Tunggal, Melaka, 76100, Malaysia

³ Mechanical Engineering Department, Faculty of Engineering, Universiti Teknologi Petronas, 32610 Seri Iskandar, Perak, Malaysia

suhaimitisha@utem.edu.my, eslam735119@gmail.com, afzanizam@utem.edu.my, fatimah@utem.edu.my, faizah@utem.edu.my, fudhail.munir@utp.edu.my

*Corresponding Author: suhaimitisha@utem.edu.my

Abstract— This paper presents an experimental study on the integration of silica gel as a desiccant bed in a two-chamber solar dryer to improve outlet air conditions for reuse in drying applications. The system comprises a flat-plate solar air collector (forced convection via four fans-powered by solar PV), Drying Chamber 1 (DC1), a packed bed of silica gel for dehumidification, and Drying Chamber 2 (DC2). Mee wantan was used as the test product under low solar radiation conditions (average 452 W/m²). Seven measurement points were instrumented with temperature and humidity sensors, and solar irradiance was recorded using a pyranometer. Results show that the average outlet air temperature from DC1 increased from 37.88 °C to 39.29 °C after passing through the silica gel bed, while the average relative humidity decreased from 59.75% to 55.07%, indicating enhanced drying potential in DC2. The final product moisture content reached 21% in DC1 and 23% in DC2, with the small difference attributable to the improved air properties dehumidification and the short experimental window due to rain. The silica gel bed exhibited an approximate mass increase of 11 g, confirming the adsorption of moisture from the air by the silica gel. The regeneration by solar heating is proposed for continuous operation. The study demonstrates a practical, hygienic approach to reduce ambient dependency in solar drying and supports hybrid desiccant solar dryer designs for food processing.

Keywords— Solar drying, silica gel, desiccant, hybrid dryer, food drying, renewable energy

1. INTRODUCTION

Open sun drying is widely practiced but suffers from contamination, variable quality, and dependence on weather. Indirect and mixed-mode solar dryers improve control and hygiene but the outlet air often has elevated humidity after moisture uptake from the product, lowering its drying potential for subsequent stages. To address this, desiccant integration can condition the outlet air by adsorbing moisture, thereby reducing relative humidity and, due to latent heat release, slightly increasing air temperature. This work investigates a two-chamber solar dryer in which the air exiting Drying Chamber 1 is polished by a silica gel bed before entering Drying Chamber 2.

Solar-energy drying systems have been extensively reviewed, highlighting classifications into passive and active designs and the practical advantages of solar dryers over open sun drying in improving product quality and hygiene [1,2]. Handbook references consolidate principles for dryer selection and operation, including solar drying of food products [3]. Recent reviews and chapters further emphasize performance evaluation and taxonomy of solar dryers, as well as the need for dehumidification strategies to manage latent loads [4–6]. Solid desiccants such as silica gel can be regenerated at relatively low temperatures available from solar collectors, making them suitable for integrated dryer designs; experimental studies on silica gel adsorption and

regeneration demonstrate stable dehumidification performance under solar-driven conditions [7–10].

In experiments that rely heavily on controlled environment such as solar drying systems the reliability and accuracy of data collection determine the validity of the results. IoT technology enhances this reliability by automating data acquisition, minimizing human error, and allowing remote supervision of system behavior. This capability not only improves operational efficiency but also ensures that the experiment progresses smoothly despite external constraints, such as limited physical access or fluctuating environmental conditions. The successful execution of such experiments therefore depends greatly on the strategic deployment of IoT components and sensors, which together form the backbone of a robust, data-driven monitoring and control framework

II. METHODOLOGY

System configuration: The dryer consists of (i) a flat-plate solar air collector with glazing and black absorber; (ii) four inlet fans powered by solar PV to ensure forced convection; (iii) Drying Chamber 1 (DC1); (iv) a packed bed of silica gel (desiccant) connected downstream of DC1; and (v) Drying Chamber 2 (DC2). Solar irradiance was measured using a pyranometer. Temperature and relative humidity sensors were installed at seven locations: environment (Point 1), collector inlet (Point 2), DC1 outlet (Point 4), DC2 inlet (Point 5), and DC2 outlet (Point 7); Points 3 and 6 inside chambers were not analyzed due to non-uniformity of temperature in the drying chamber. The position of each sensors and the illustration of experimental setup as shown in Figure 1. Data acquisition was performed with logging to a computer. The actual photo as shown in Figure 2. The silica gel is covered with a stainless steel plate to prevent direct exposure to solar radiation. This arrangement is intended to maximize the silica gel's ability to absorb moisture from DC1. Based on theory, desiccant materials perform moisture absorption more effectively when temperature is low.

The solar drying system integrates a photovoltaic (PV) system with battery storage to power not only the speed-controlled fan but also an Internet of Things (IoT) system used for monitoring and control. Two PV solar panels, with a total capacity of approximately 100 watts, generate the required electrical energy. The energy generated is stored in a 12-volt, 100 Ah LiFePO₄ battery, ensuring a reliable power supply during periods of solar outages. The system also includes a charge controller to prevent overcharging and battery damage and preserving the lifespan.

The system provides continuous power to the fans that control the airflow, as well as IoT components that monitor the temperature, humidity and airflow in the drying chamber. The photovoltaic (PV)-powered IoT system enables real-time data collection and remote monitoring, improving control and efficiency of the drying process. Sensors connected to the IoT platform measure important parameters, such as temperature, humidity and airflow, and this data can be accessed remotely to optimize drying conditions and ensure product quality. Solar-powered IoT systems eliminate the need for external energy sources, making the drying process more sustainable and autonomous. This integration of renewable energy and smart technology encompasses a modern approach to solar drying, improving energy efficiency and process control, while enabling timely intervention through remote monitoring and alerts.

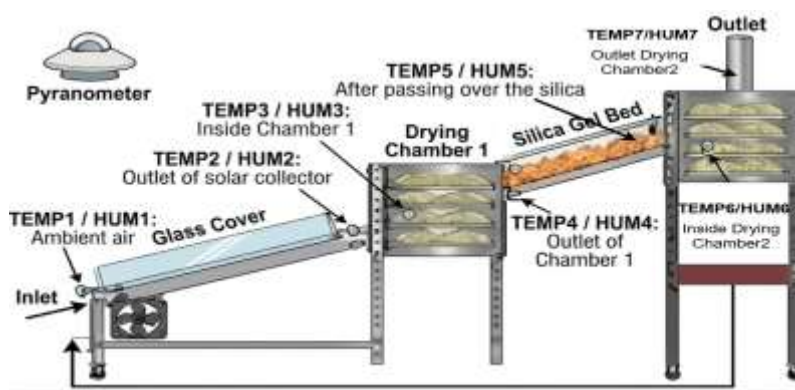


Fig. 1 Experimental setup and position of sensors



Fig. 2 Photo of solar dryer system

Product: Mee wantan, typically dried under open sun, was selected to demonstrate hygienic drying. The picture of the product as shown in Figure 3. Experimental conditions: Average solar radiation during the trial was approximately 452 W/m^2 ; the experiment ended at 16:45 due to rainfall. Initially, the products were weighed manually every 15 minutes. The interval was later increased to 30 minutes from 10:45 a.m. to 11:45 a.m. Since the reduction in mass became very small, the weighing interval was further increased to 1 hour, starting from 11:45 a.m. until 4:45 p.m. To measure the mass, the tray and product had to be removed from the drying chamber. Opening the chamber door during this process caused heat loss, which reduced the temperature inside the dryer. Therefore, to minimize heat loss, the weighing interval was extended to 1 hour.



Fig. 3 Mee wantan

III. RESULTS AND DISCUSSION

The final moisture contents were approximately 21% (DC1) and 23% (DC2) as shown in Figure 4. The small 2% difference reflects the improved air properties after dehumidification and the reduction of drying duration. The temperature and humidity were measured at specific points: environment (1), inlet (2) and outlet (4) of DC 1, and inlet (5) and outlet (7) of DC 2, as illustrated in Figures 5 and 6. Data from points 3 and 6 are excluded because they represent random, non-uniform conditions within the drying chambers

According to Table 1, the average outlet air temperature at point (4) is 37.88 °C, which increases to 39.29 °C after passing through the desiccant at point (6). Similarly, the average air humidity at point (4) is 59.75%, and it decreases to 55.07% after moisture from the wet air is absorbed by the silica gel at point (6). The average temperature and humidity measurements show conditioning of the air by the silica gel bed, with temperature rising and relative humidity falling between Points 4 (DC1 outlet) and 5 (DC2 inlet). Without the use of silica gel, the outlet air from DC1 is unsuitable for drying because its temperature is nearly the same as the ambient temperature and its humidity is high.

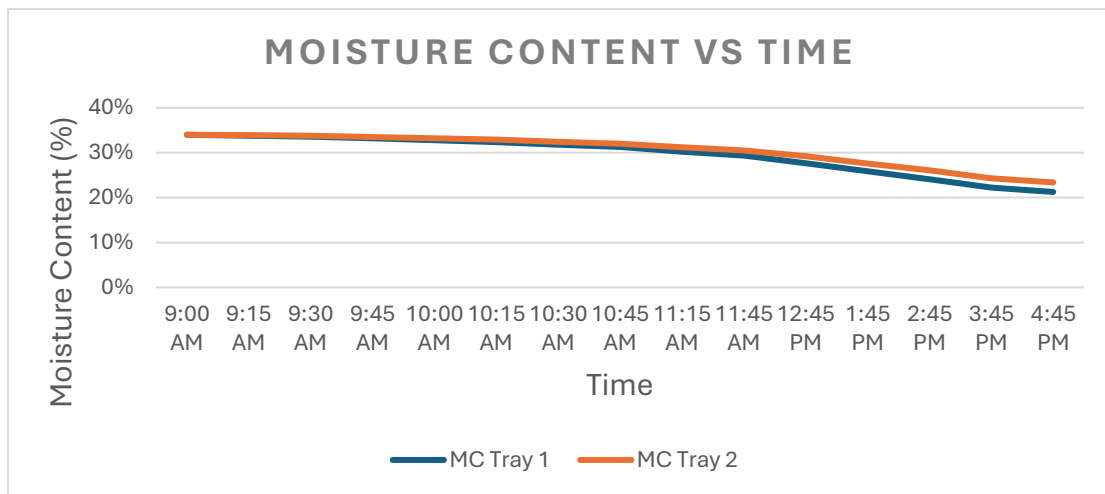


Fig. 4 Drying kinetic

The adsorption of water vapour by silica gel reduces the humidity ratio and it increasing the potential for further drying in DC2. The slight temperature rise (1.41 °C average) is consistent with latent heat release during adsorption and reduced evaporative cooling. This indicates that the silica gel functions to absorb moisture from the humid air after it carries moisture from drying chamber 1. As shown in Table 2, the mass of the silica gel increased by 11 g. When saturated, the silica gel must be regenerated to remove the absorbed moisture.

However, the experiment was stopped at 4:45 due to rain. Regeneration can be achieved by separating drying chambers 1 and 2 and exposing the silica gel to solar radiation when there is no product in drying chamber 2. The concept of regeneration involves allowing natural airflow through points 4 and 5 while the silica gel is directly exposed to solar radiation by removing the cover on top of the desiccant. Solar radiation passes through the glass and heats the desiccant. This process was not implemented in this project because the increase in silica gel mass was minimal.

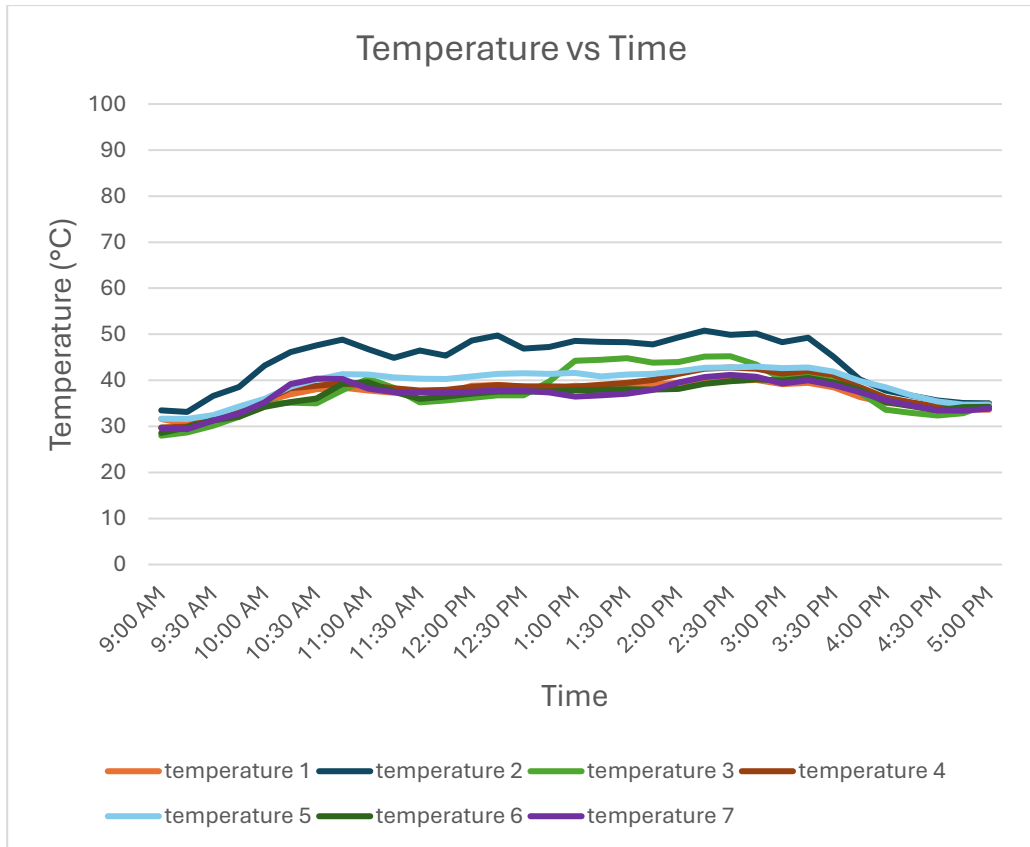


Fig. 5 Temperature at each point

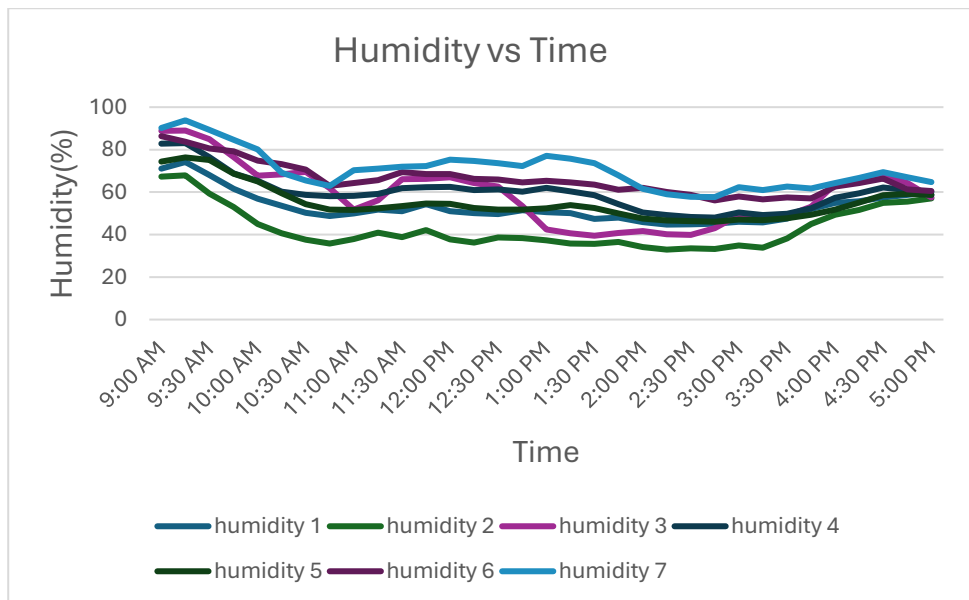


Fig. 6 Humidity at each point

TABLE 1 AVERAGE TEMPERATURE AND HUMIDITY

Points	Temperature	Humidity
1	37.01	52.99

2	44.23	42.94
4	37.88	59.75
5	39.29	55.07
7	36.84	70.52

TABLE III MASS OF SILICA GEL

Parameter	Before	After	Loss
Mass (g)	1453	1464	11

IV. CONCLUSIONS

The integration of a silica gel bed between two solar drying chambers proved effective in conditioning the outlet air by reducing its relative humidity and slightly increasing its temperature, thereby improving the drying potential for subsequent stages. This approach addresses a common limitation in solar drying systems, where air exiting the first chamber often becomes saturated with moisture, reducing its effectiveness for further drying. The experimental results demonstrated a humidity reduction from 59.75% to 55.07% and a temperature increase from 37.88 °C to 39.29 °C after passing through the desiccant bed, confirming the adsorption capability of silica gel. Additionally, the silica gel mass increased by 11 g, indicating moisture uptake during the process.

Although the experiment was constrained by a short duration due to rainfall, the findings validate the concept of hybrid solar drying with desiccant integration as a practical and hygienic solution for food processing. The proposed regeneration strategy using solar radiation ensures sustainability and low operational cost, making the system suitable for rural and small-scale applications. Future work should focus on optimizing the desiccant bed design, improving regeneration efficiency, and conducting long-term performance evaluations under varying climatic conditions. Furthermore, energy and exergy analyses, coupled with economic assessments, will provide deeper insights into the viability of this system compared to conventional and hybrid dryers. Overall, this study contributes to advancing renewable energy-based drying technologies and supports the development of efficient, weather-independent solar drying systems for agricultural and food products.

Based on the integrated operation of the photovoltaic-powered IoT platform, it can be concluded that the IoT system and its associated sensors successfully recorded all necessary parameter including temperature, humidity, and airflow throughout the drying process. The continuous, reliable power supply from the PV panels and battery storage enabled uninterrupted monitoring, real-time data acquisition, and remote access. This ensured that all required data for the experiment was captured accurately and consistently, supporting effective analysis and validation of the solar drying system's performance.

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REFERENCES

- [1] A. Sharma, C. R. Chen, and N. V. Lan, "Solar-energy drying systems: A review," *Renewable and Sustainable Energy Reviews*, vol. 13, pp. 1185–1210, 2009.
- [2] O. V. Ekechukwu and B. Norton, "Review of solar-energy drying systems II: An overview of solar drying technology," *Energy Conversion and Management*, vol. 40, pp. 615–655, 1999.
- [3] A. S. Mujumdar (Ed.), *Handbook of Industrial Drying*, 3rd ed., Boca Raton, FL: CRC Press, 2006.
- [4] B. Norton, "Solar Drying," in *Harnessing Solar Heat*, *Lecture Notes in Energy*, vol. 18, Springer, 2013.
- [5] A. A. El-Sebaili and S. M. Shalaby, "Solar drying of agricultural products: A review," *Renewable and Sustainable Energy Reviews*, vol. 16, pp. 37–43, 2012.
- [6] Jebaraj S. and M. Y. Khan, "A review on solar dryers to evaluate the performance and drying characteristics for agricultural products," *Renewable Energy and Sustainable Development*, vol. 11, no. 1, pp. 1–16, 2025.
- [7] M. Kumar and A. Yadav, "Comparative study of solar-powered water production from atmospheric air using different desiccant materials," *International Journal of Sustainable Engineering*, 2016.
- [8] A. Kumar and A. Yadav, "Experimental investigation of solar driven desiccant air conditioning system based on silica gel coated heat exchanger," *International Journal of Refrigeration*, 2016.
- [9] Y. Zhao, Y. Dai, and J. Zhang, "Experimental study on solar driven dehumidification system with silica gel coated heat exchanger in winter," *Proc. ISES Solar World Congress*, 2017.
- [10] A. Zouaoui, L. Zili-Ghedira, and S. Ben Nasrallah, "Experimental Investigation of Air Dehumidification and Regeneration Operations Using Packed Bed of Silica Gel Particles," *International Journal of Heat and Technology*, vol. 34, no. 1, pp. 103–109, 2016.