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Development of a Temperature Food Dehydrator for Sustainable Food Preservation

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Abstract: The dehydration of perishable goods remains a critical focus in research and development. Notably, the production processes tailored for small and medium-sized enterprises hold significant importance in this landscape. Such initiatives contribute to the establishment of efficient methodologies for food preservation, enabling improved monitoring and development of dehydration techniques. This Endeavor calls for comprehensive engineering studies. Therefore, the aim of this research was to conceptualize and construct a device specifically designed for consistent vegetable dehydration. Our investigations explored the potential of various machines, highlighting the advantages of utilizing a direct food dehydrator. The findings demonstrate that the production method for the developed direct food drying de hydrator surpasses traditional approaches, which often struggle with maintaining a uniform temperature throughout the drying process.
Keywords: Dehydration, uniform temperature, small and medium scale industries productions.

I. INTRODUCTION

Drying has been used as a preservation method since ancient times. It involves techniques such as solar drying, heated ovens, relative humidity (RH) control, and more. The process of dehydration can be complex, requiring careful regulation of conditions to achieve high-quality results [1], [2]. The importance of controlled dehydration has grown significantly, as unregulated or uneven conditions can damage food products and lower their quality [3]. A uniform temperature dehydrator is particularly beneficial for businesses, as it ensures consistent drying conditions. The primary objective of this process is to reduce moisture content to levels that facilitate safe storage or further processing, especially for export-quality products. High-quality, efficient dehydration devices are essential for meeting these standards [4], [5]. A direct food dehydrator is perhaps one of the most ad vantages appliances. It saves vegetables from much degradation, and makes large-scale drying possible, saves time, reduces costs, and thus it enhances both health and economic factors by optimizing the utilization of time, energy, and resources. Most industries today continue to use obsolete or labour-intensive techniques for dehydration. Modern uniform temperature dehydrators have the potential to make the process more productive, diminish the cost of production, and improve the quality of the product. This technology could change the food dehydration industry for better efficiency and profitability relative to the traditional methods available today in the market.

II. MOTIVATION

The overpopulation phenomenon will pose a significant threat to food supplies worldwide, with possible shortcomings by the year 2050. In the solution of this critical issue, means of food preservation, such as dehydration are critical [2], [3]. The application of solar dryers, as one of them, are highly sustainable and environment friendly, using clean and renewable energy sources. The reduction in greenhouse gas emissions results, hence, promoting environmental conservation and sustainability [1], [5]. Besides, solar dryers add value to agricultural produce and improve access to markets thereby empowering local economies. Through this technology, one earns income and improves livelihood; hence, it is very practical in solving food insecurity challenges while bringing about economic as well as environmental benefits.

III.PROBLEM STATEMENT

Studies have shown that it is possible to reduce moisture content of food from 10% to 20% that really suppresses the growth of bacteria, yeast, Molds and enzymes hence keeping its taste and nutrition quality intact [3], [6]. Drying and preservation of food constitute some of the earliest application of solar energy. The traditional method, which is still common worldwide, involves open sun drying where fruits, vegetables, cereals, grains, and tobacco crops are spread on the ground and are turned frequently until they have been adequately dried for storage without risking them [2], [4]. However, there is a problem in open sun drying. This includes great space requirements, increased exposure time, and high chance of contamination. The said downsides require a developed alternative technology that could provide high quality product output with low wastage rates. This has motivated the manufacturing of different types of drying tools, such as solar dryers, electric dryers, wood-fuelled dryers, and oil-fired dryers. Notwithstanding their effectiveness, the high costs of oil and electricity, besides their unavailability in rural areas of many developing countries, have made some techniques less attractive. Therefore, there has been a greater focus on the development of solar dryers, which is a cost-effective, efficient, and sustainable method of food preservation. [1], [5].

IV. LITERATURE REVIEW

A. Project 1

The standard parameters for the experimental drying tests involved an air temperature set at 30ºC, a relative humidity level of 15%, and an airflow rate of 0.0903 kg/s. Additionally, the daily global solar radiation measured on a horizontal surface was approximately 232 W/m², with a drying duration of 10 hours each day. During the experimental drying tests, standard conditions were established, featuring an air temperature of 30ºC and a relative humidity level of 15%. The airflow rate was maintained at 0.0903 kg/s, while the daily global solar radiation hitting a horizontal surface was approximately 232 W/m². The drying process was conducted for a total of 10 hours each day.

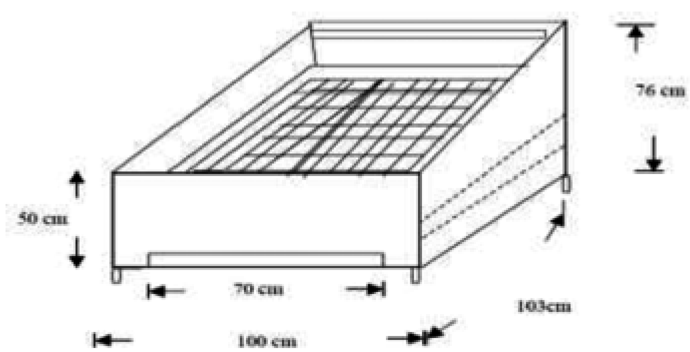

Fig 1. Box Type Solar Dryer

B. Project 2

A cylindrical and hollow architecture of the drying system using solar energy was designed, and the effectiveness of the thermal drying system was analysed, as shown in Fig 2. The system consists of a solar collector plate with a length and width of 1.10 m, a cylindrical drying chamber, and a fan that dehydrates 70 kg of leguminous crops. Performance test of the solar air collector was conducted at three airflow rates. At radiation intensity of 750 W/m² and an airflow rate of 0.0401 kg/s, the highest outlet temperature of the solar collector reached 71.4°C. The lowest temperature measured was 40.0°C at an airflow rate of 0.0675 kg/s and a radiation intensity of 460 W/m². The highest mean thermal efficiency was at the solar air collector 25.64%, where this occurred at the airflow rate of 0.0675 kg/s. On the other hand, the minimum average thermal efficiency was 18.63% at an airflow rate of 0.0405 kg/s. At 70% moisture content at beans, when the airflow rate is at 0.0405 kg/s the final moisture content is brought to 14%. The moisture content was decreased to 14% at airflow velocities of 0.0540 kg/s and 0.0765 kg/s, respectively.

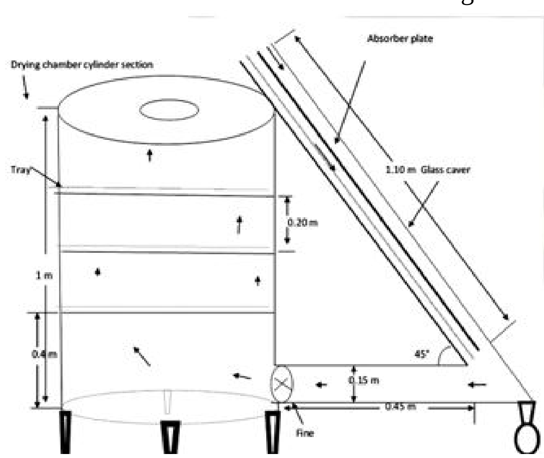

Fig. 2. Sun based drying framework

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C. Project 3

This research project constructed a sun dryer whose intermittent drying operation of the cocoa beans hinged upon thermal energy storage, as portrayed in Fig 3. A technique of convective heating with direct radiation was used where a device modulated an airflow rate across the beans. The solar collector area consisted of an open-top wooden box, 1100 x 1000 x 200 mm in size, made from 10 mm thick plywood. In the experimental setup, it was possible to reduce the moisture content of cocoa beans from 53.4% to 3.6% over a 72-hour intermittent drying process under ambient conditions with temperatures ranging from 25°C to 30°C and relative humidity between 58% and 98%. The free convective drying reached the final moisture content at 3.56%. Forced convective drying attained the moisture contents at 9.09% and 7.11% with the airflow rates at 1.02 and 1.32 m³/min, respectively.

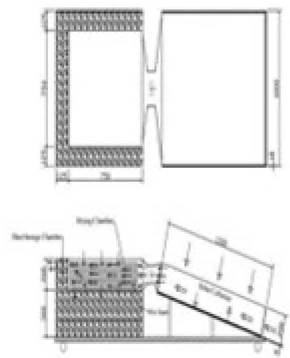

Fig. 3. Sun based Drying

D. Project 4

A forced convection solar dryer was fabricated and tested for drying copra under Indian climatic conditions as depicted in Fig 4. During the experiment, the maximum solar radiation encountered was 932 W/m². The average relative humidity was around 68% and the average drying air temperature at the inlet of the dryer was 43°C, and the highest recorded temperature attained was 63°C. The relative humidity was observed to increase highly at almost 90%. However, it dropped off slightly to nearly 34% after the drying period. There was a significant drop of about 51.8% moisture content within the coconut to 7.8% of the bottom plate and 9.7% of the top plate after the duration of 82 hours. The moisture content of the product decreased to 33% and 20% during the first two days of drying cycle. In conclusion, the forced convection solar dryer was found suitable for small scale copra production of good quality copra; it can yield about 75% of high-quality copra. The average thermal efficiency of the solar air heater was estimated to be around 24%.

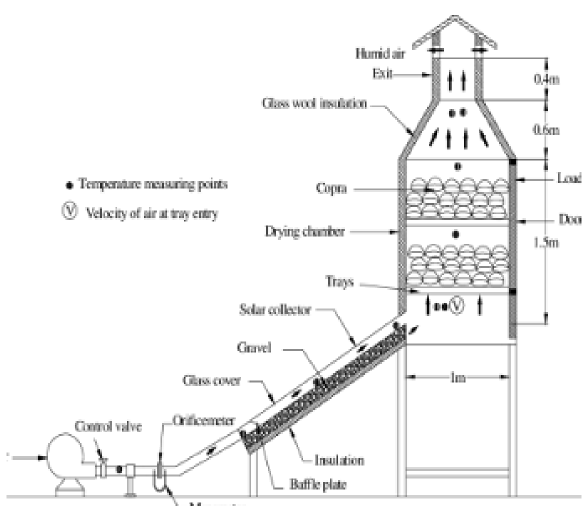

Fig. 4. Constrained Convection Sun based Drying

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E. Project 5

Outlined Multiplied Pass Sun oriented Dryer (DPSD) for drying ruddy chili in central Vietnam as appeared in Fig.5 and compared with cabinet dryer (CD) and conventional open sun drying. They found that normal drying temperatures were 60ºC, 52ºC and 35.8ºC and comparing relative mugginess 34, 45 and 62 rate for DPSD, CD and open discuss sun drying, separately. The damp substance of new ruddy chili was nearly comparative amid all drying tests while the starting values were 9.18,9.17and 9.30 rate for DPSD, CD and open-air sun drying, separately. Where the ultimate dampness substance in case of DPSD 0.05 percentage was come to after 23 h, 0.09 rate after 29h for CD and 0.18 rate after 36 h in case of open sun drying (barring evenings).

F. Project 6

N.S. Rathore and N.L. Panwar conducted the study of a hemi-cylindrical walk-in type solar tunnel dryer for large-scale grape drying, as in Fig 6. It was designed to process 320 kg of grapes. Maximum permissible temperature inside the dryer was 65°C with average solar radiation of 2.3 MJ/m²/h during the drying period of 10 hours. Specific heat of the air was taken as 1.012 kJ/kg/°C. Using this tunnel dryer, they were able to reduce the moisture content of the grapes from 85% to 16% in a 7-day period with an efficiency of 30%.

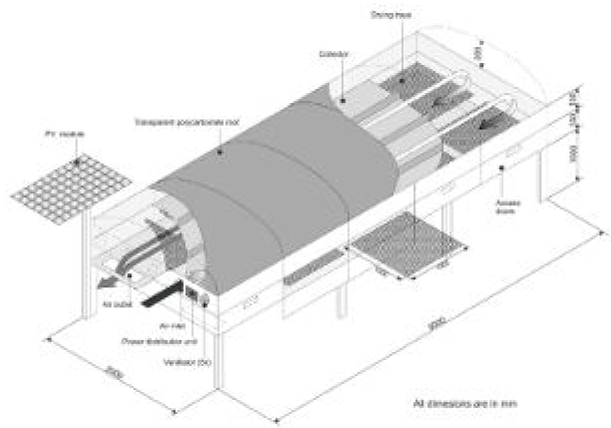

Fig. 5. Outlined Multiplied Pass Sun oriented Dryer

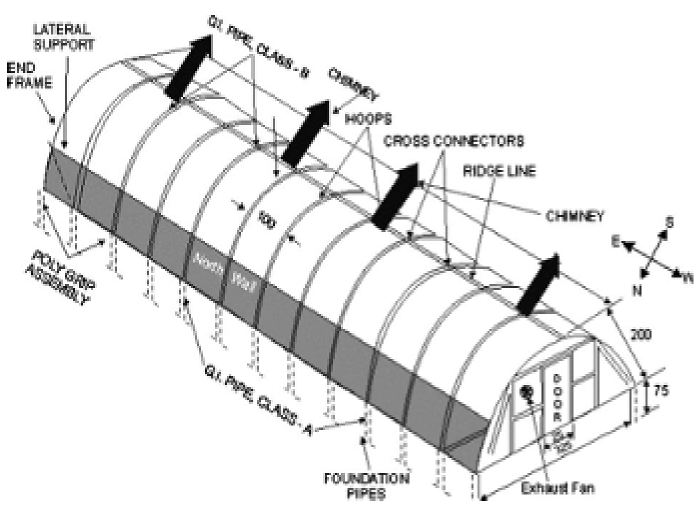

Fig. 6. Burrow Dryer

V. PROPOSED SOLUTION

In application, the solar dehydrator uses solar energy to remove moisture from food products, thereby providing a practical and sustainable method of food preservation [1], [3]. By using solar power, this dehydrator has successfully eliminated reliance on electricity or conventional fuels, thereby resulting in significant energy savings and a reduced carbon footprint throughout the food preservation process [5]. In practical applications, our solar dehydrator has proved to be flexible as it can successfully preserve different food products, including fruits, vegetables, herbs, and meats, all of which are preserved with nutritional value, flavour, and appearance intact [6], [7]. The structural design of our solar dehydrator has incorporated key features like a drying chamber, strategically placed airflow vents, transparent glass, and trays or racks that support the food items firmly in place. This functional design allows sunlight penetration while efficiently retaining heat, thus improving the drying conditions [2], [4]. Through empirical testing and application, our solar dehydrator effectively uses natural convection. As solar energy penetrates the dehydrator, it raises the internal air temperature, causing the air to rise spontaneously and exit through the ventilation openings. This evaluated airflow mechanism promotes effective moisture removal from the food, thus ensuring a more rapid drying procedure [1], [5].

VI. METHODOLOGY

A. Research and Planning

We conducted extensive research on the principles of solar drying, thoroughly studying the existing solar dehydrator designs and best practices in the field [1], [3]. In doing so, we gained valuable insight into the factors that in- fluence the drying process, such as temperature, humidity, and airflow [4], [6]. We identified the specific requirements and objectives of our project, considering factors such as target food items, desired capacity, local climate conditions, and the needs of our intended users.

B. Design and Prototyping

Based on the extensive results of our research, we developed a rather complex design blueprint for our solar dehydrator. We carefully considered various parameters, including the dimensions and design of the drying chamber, the ventilation system for airflow, the transparent cover or panel, the design of trays or racks, and the control systems for temperature and airflow regulation. We had developed prototypes and 3D models validating and refining our design concept so we could then modify and perfect before moving ahead with our work.

C. Material Selection and Procurement

We ensured that we identified all the necessary materials to construct our solar dehydrator. For this, we considered several important fac tors, including durability, thermal insulation properties, transparency, and ease of assembly [2], [5]. We ensured that the material sources were reliable and confirmed their compliance with our stipulated requirements and quality standards. This careful selection and sourcing process ensured that our solar dehydrator was assembled using high-quality materials, able to withstand outdoor conditions but also to enhance effective drying. With the successful implementation of the research and planning phase and the design and prototyping stage, we were able to develop a well-thought solar dehydrator design that was aligned with our project requirements. In addition, the detailed selection and acquisition of materials ensured the proper use of the right and reliable components in the fabrication of our solar dehydrator.

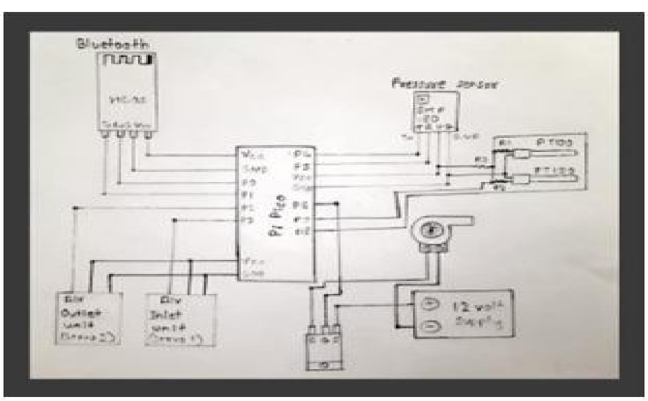

Fig. 7. Block Diagram

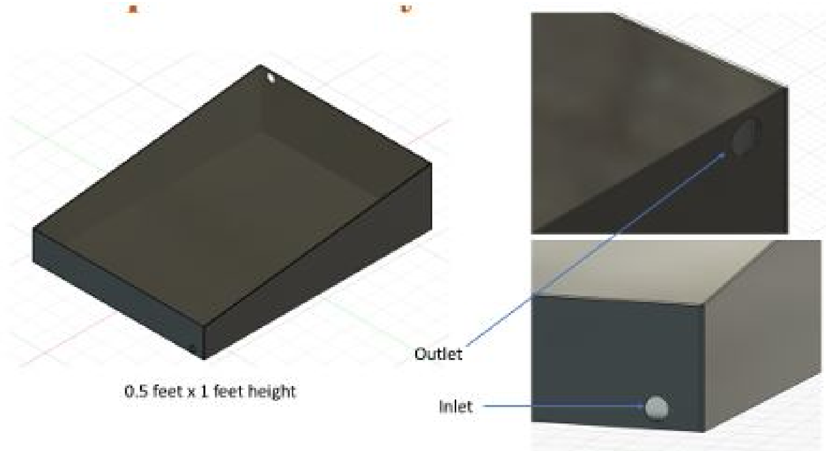

Fig. 8. 3D Model in Autodesk Fusion

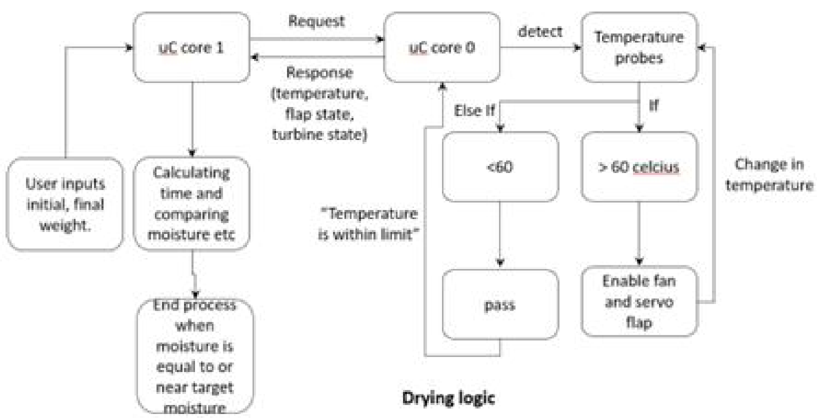

Fig. 9. Program Logic for drying

Fig.10. Dehydrator: Side view

D. Mechanical Drawing

Fig 7 shows the block diagram and Fig 8 shows the 3D model that was designed in Autodesk fusion 3D design software. It shows the inlet and outlet for airflow.

E. Approach

Fig. 9 shows how the program logic has been developed for the drying process of the food product. This program logic works inside the Raspberry Pi Pico microcontroller as mentioned in below section.

Fig. 11. Dehydrator: Top view

Fig. 12. Dehydrator: Front view

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VII. HARDWARE AND SOFTWARE REQUIREMENTS

Below mentioned is the list of hardware components used for this research project:

1) Li-ion battery
2) Wires 16AWG
3) DC Exhaust Fan (12V 3A)
4) Servo motors
5) Raspberry Pi Pico
6) HC-05 Bluetooth module
7) PT100
8) Push button latching switch
9) Active buzzer
10) Glass sheet
11) Aluminium Sheet
12) Silicone sealant

The programming software used is Thonny IDE and the programming language used is micro python. The Code runs in Pi Pico and with reference to Fig 7, we can see how the Pi Pico microcontroller will interact with the sensors and outputs in order to control the environment inside the dehydrator.

VIII. CIRCUIT

Fig 10 features all the components which are mounted on the PCB. The capacitors are being used to stabilize the input voltage and supply it to different components onboard.

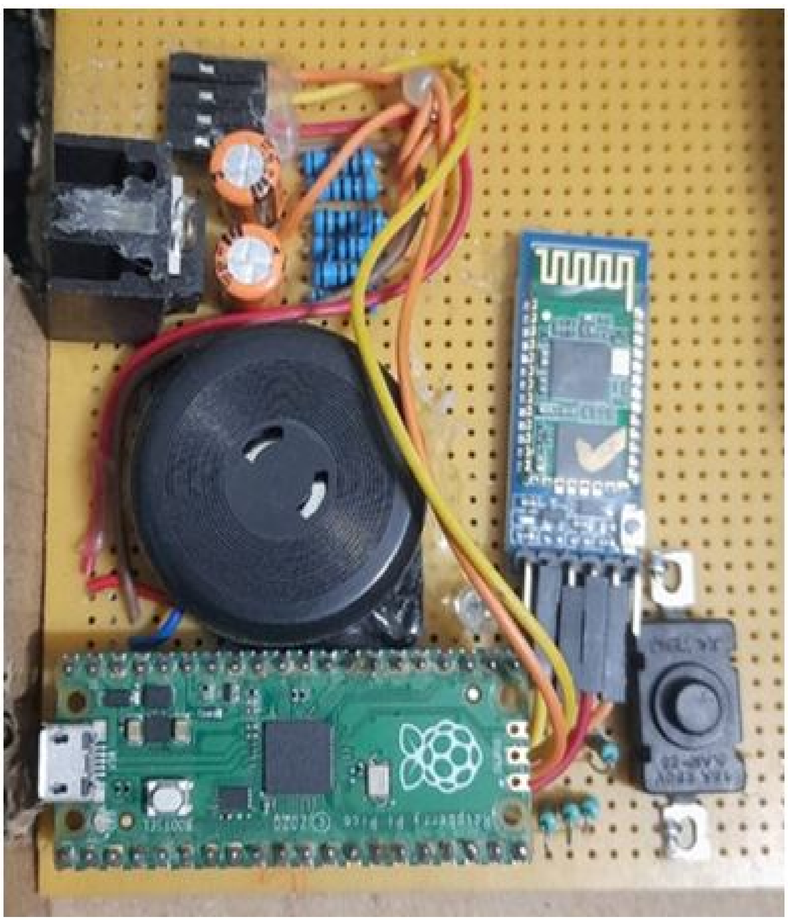

Fig. 13. Electronics mounted on PCB

IX. RESULTS AND DISCUSSION

Fig. 14. Application Home Page

Fig. 14 features the home page of the developed application. This app connects to the HC-05 Bluetooth module. We press the" connect button which pops up the connection window where we can see all nearby Bluetooth devices as shown in Fig. 15

Fig. 15. Bluetooth connections Page

After connecting to the app and choosing our desired food product and pressing "Begin drying", the chamber begins to heat up, during our testing we achieved a maximum temperature of 85.2 Degree Celsius and a maintained temperature of 85 Degree Celsius, which aligns with recommended drying temperatures for various food products [3], [6]. Fig. 16 shows the maximum achieved and maintained temperature inside the drying chamber.

Fig. 16. Maximum achieved temperature in chamber

X. CONCLUSION

In summary, the heating chamber designed for the solar dehydration system for the project has been shown to fulfill critically the objectives of optimization for efficiency in drying, energy savings, and quality product. Utilizing energy from the sun, it accomplished the required heat input that could extract moisture while minimally relying on nonconventional energy sources and reducing the environmental footprints.

The precise control of temperature inside the chamber ensured that the targeted range was constantly maintained throughout the drying process, a consideration that was critical in ensuring the nutritional content, flavour, colour, and texture of the products were preserved [6], [7]. Secondly, the economic efficiency of the heating chamber is remarkable because its application of solar energy greatly minimized the cost of energy, and thus, the drying process became economically viable. Its initial cost was justified by its long-term effectiveness and sustainability.

In summary, the importance of the heating chamber in the solar dehydrator system is an aspect that made the effective system. It harnessed solar energy effectively ensured the control of temperature conditions and improved the economic features of the project. This implementation shows good promise for solar heating technology in sustained dehydration processes while maintaining products quality.

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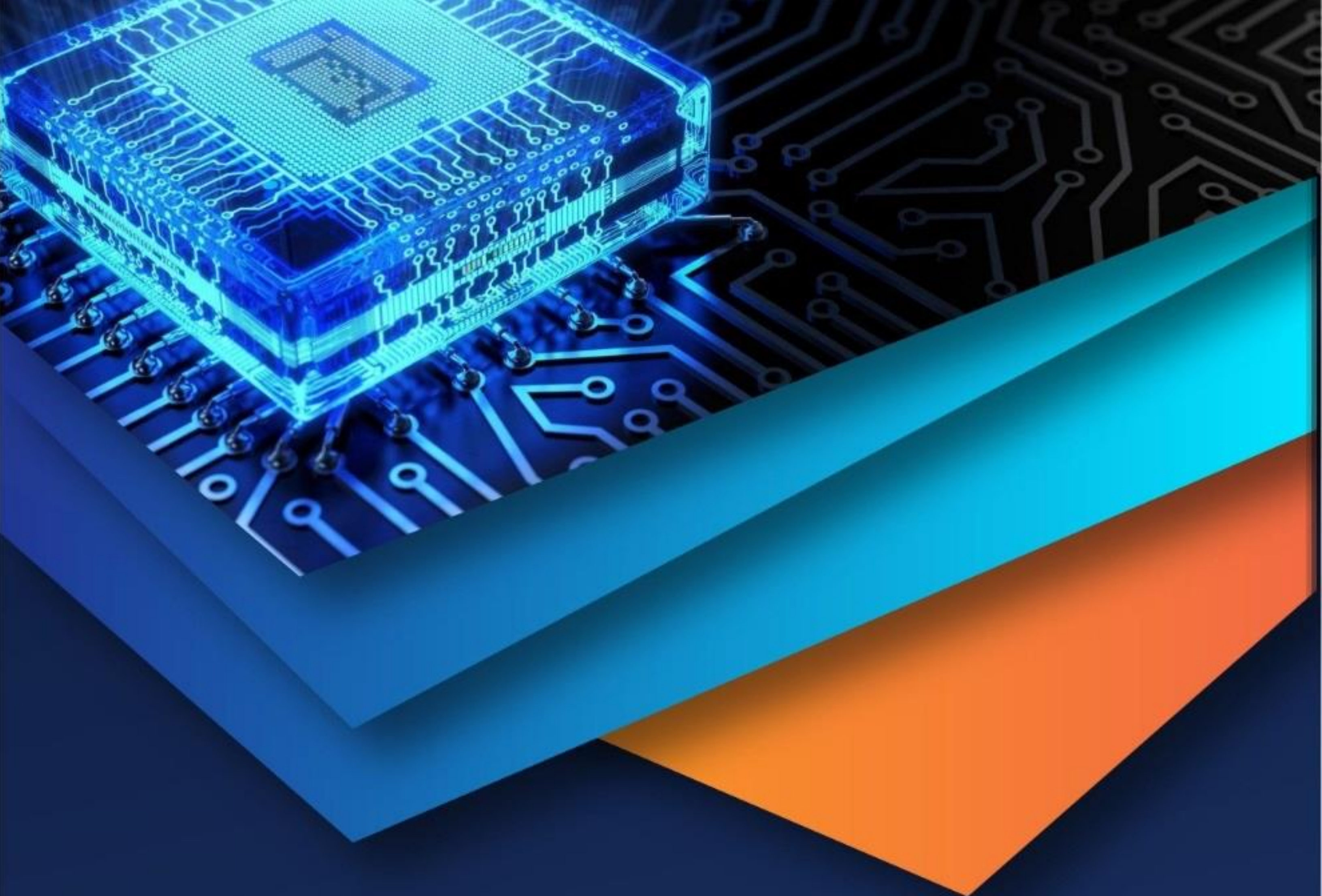

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