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Comprehensive Analysis of Thermal Performance of Solar Hot Case Based on Solar Power Energy

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Abstract: Solar energy is becoming increasingly popular as a renewable energy source, especially with advancements in solar photovoltaic (PV) technology. However, the efficiency of PV systems is affected by various factors, including temperature. This study explores the practicality of a box-style solar hot case driven by PV energy to address deforestation and cooking challenges in rural areas. The solar hot case, designed with efficient insulation using aluminium foil, maintains desired temperatures during the day, making it suitable for keeping food warm. A stainless-steel glass with hot water inside the cabin was tested, revealing the cabin and water temperatures' dynamic relationship over time. The findings highlight the importance of maintaining lower operating temperatures for PV modules to achieve peak efficiency and demonstrate the potential of PV-powered solar hot case in addressing heating challenges in rural areas.

Keywords: Energy, Renewable energy source, solar photovoltaic (PV) technology, Efficiency, PV systems

I. INTRODUCTION

Solar energy stands as one of the most promising and compelling renewable energy sources presently available. With the continuous advancements in solar photovoltaic (PV) technology, its global adoption for clean electricity generation is on the rise. However, certain challenges persist concerning the efficiency and reliability of solar PV systems, necessitating focused attention and resolution. One crucial factor influencing the performance of solar PV systems is temperature. When exposed to sunlight, solar cells tend to experience a significant reduction in power conversion efficiency due to increased heat. Consequently, maintaining lower operating temperatures becomes imperative to ensure PV modules operate at their optimal efficiency.

In rural and forested areas, approximately half of the population relies on wood for cooking [1]. Alarmingly, over two-thirds of the world's population, amounting to two billion individuals, faces a scarcity of wood, according to the United Nations (UN) [2]. This predicament exacerbates deforestation, leading to elevated greenhouse gas levels [3]. To address the pressing issue of deforestation, box-style solar cookers have been recommended for adoption, particularly in regions like Africa [4–9]. Nonetheless, the effectiveness of these cookers faces constraints, such as a limited maximum cooking temperature of 140°C [5–9], thermal efficiencies below 54% [10–11], cooking times exceeding 120 minutes [12], usage outside of homes [1, 10], and the requirement for intervention during cooking to track the sun's position [1]. Consequently, numerous efforts have been made in the literature to harness photovoltaic energy in these cookers, aiming to enhance the performance of box ovens [10, 13–18]. In these endeavours, photovoltaic (PV) panels are employed to charge solar batteries, subsequently utilized for heating thermal resistances [13–14].

This research delves into the feasibility of a box-style solar cooker fuelled by PV energy, supported by initial experimental findings illustrating its functionality. A comprehensive exploration of the cooker's construction is followed by an assessment of crucial operational parameters on a typical sunny day. These parameters include the electric heater Pel's power, the temperature of the heating resistor Tr, the interior temperature of the cooker, the boiling time for a liter of water, the heating power Po, and the thermal efficiency.

II. LITERATURE REVIEW

The suggested solar cookers operate directly to the Outside the residences, the sun's beams. Users must intervene with this technology to provide their positions and orientations during cooking. The most popular solar ovens and cookers are:

1) *Box Type:* The construction of this particular type of cooker involves pyramid reflectors situated on both the inside and outside of the flat panels, effectively focusing solar energy into the insulated cooking chamber.[12] As a result of the greenhouse effect, the concentrated heat from the sun's rays elevates the temperature within the cooking chamber and effectively heats the black container holding the food to be cooked. After 4 hours of operation, the highest recorded oven temperature ranges from 140 °C without load to 98.6 °C with a full load[12], under an illumination of 858.11W/m^2 and an ambient temperature of 37.9 °C. It is important to note that the overall thermal efficiency of this cooker does not exceed 54%.[11] Additionally, it is worth mentioning that this type of oven is intended for use outside of residences and requires careful handling during its operation.

2) *Parabolic Type:* The primary mode of operation of this type of cooker involves the concentration and focusing of solar rays through the utilization of parabolic reflectors positioned at the bottom of the container.[19] When accurately oriented, this cooker is capable of achieving elevated cooking temperatures ranging from 200°C to 300°C[18] and demonstrating thermal efficiencies within the range of 43.45% to 77% [19–22]. However, this type of cooker is not without its drawbacks, which include a high price point, larger physical dimensions, unpredictable temperature control, and potential burn risks to users (e.g., hands, eyes) as well as to the food being cooked. Consequently, caution and careful handling are necessary while using this cooker.
3) *Reflective Type Panel:* This type of cooker comprises multiple flat panels or reflecting parabolic panels and encases a dark container within a plastic bag. The cooker is capable of achieving firing temperatures ranging from 100°C to 200°C [18], with thermal efficiencies approximately around 26.6% [23]. These performance values are observed under specific conditions, such as an illumination level of 850 W/m^2 and an ambient temperature of 20°C. The usage of this cooker demands considerable caution and prudence on the part of users, similar to the parabolic cooker, due to potential challenges associated with unpredictable temperature control, precise orientation toward the sun, and the risk of burns.

The performance of box solar furnaces is now being improved by solar cooker designers incorporating photovoltaic (PV) electricity. The work done relates to the solar-powered heating of the heating components batteries with a 24 V and 45 Ah capacity, by the PV solar panels [13]. using batteries increases the expense of cooking and upkeep costs. Despite using solar power, performances are quite constrained. under 950 W/m^2 of lighting Assuming a 20 °C ambient temperature, a battery-powered The cooker's internal temperatures and the ambient not to surpass 124 °C when heating a resistor [14].Additionally, the thermal efficiency for 0.385g of water does not go above 43.6%.

III. STRUCTURE OF SOLAR HOT CASE WITH PHOTOVOLTAIC ENERGY

1) The system comprises photovoltaic (PV) panels with a maximum power output of 100 W, generating electricity in response to the solar irradiance throughout the duration of a sunny day. These panels are strategically installed on the roof of HBTU, Mechanical Engineering Department, with a south-facing orientation and positioned at a fixed 26-degree inclination to maximize solar exposure. For enhanced electrical energy generation, the incorporation of dual-axis sun followers is an option, leading to an increase of 15 to 20% in energy production. However, it should be noted that this improvement comes at the cost of a 20 to 30% increase in the overall system cost, with no significant impact on the cabin temperature.
2) The solar hot case is constructed using plywood, providing a total area of 929.03 cm^2. The hot case takes the shape of a cuboid, with all sides measuring 30.48 cm in length. To optimize its performance, the interior of the case is lined with aluminium sheets, serving the dual purpose of reflecting and containing the solar energy within the box. The plywood utilized in the construction is designed with mica on both sides, functioning as an insulator to minimize heat loss and effectively trap the radiation within the box, thus facilitating the warming of food and maintaining the box's internal temperature. Specifically, the experimental setup box has an inner length and width of 27.88 cm each, along with an inner height of 24 cm.
3) An alloy called Ni-Cr, used in resistance heating, is composed of 80% Ni and 20% Cr. The Ni-Cr is heated mainly by the joule heating of resistive (ohmic) materials. When current passes through the Ni-Cr, heating, or the generation of heat, occurs. Ni-Cr wire heats up at a rather rapid pace. When compared to alternative heating sources like thermoelectric devices and other heating wires, Ni-Cr is too cheap to be useful in this experiment. The Ni-Cr wire is inserted into the box by gripping both ends with a copper clip and extending through a ceramic tube in order to link with the cable powered by a 100-watt solar photovoltaic panel.

A. *Electrical Characterization of Photovoltaic Panels*

The specifications pertain to a solar panel with a maximum power output of 100 watts. It operates at an open circuit voltage of 21.9 volts, meaning there is no current flow through the panel. In contrast, its short circuit current is measured at 6.12 amperes, indicating the maximum current it can deliver when the terminals are directly connected.

The solar panel's maximum power voltage is 17.96 volts, and at this voltage, it produces a maximum power current of 5.57 amperes. These numbers show the ideal working circumstances under which the panel can produce its greatest amount of electricity. In order to guarantee the safe and effective operation of the solar panel inside a solar power system, it is crucial to abide by the stipulated maximum system voltage of 600 volts.

The maximum power output of this solar panel is 100 watts thus it needs to be used safely, which necessitates careful consideration of voltage and current levels to maximize its performance. Below is a graph showing how power output changes over time.

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B. Solar hot Case Characteristics

The solar hot case is a box-shaped container with good heat retention capabilities. Its estimated 6.3-kilogram weight makes it reasonably light and portable. The case's inside dimensions are somewhat less than its exterior ones, measuring 27.88x27.88x24 cubic centimetres as opposed to 30.48x30.48x30.48 cubic centimetres. Aluminium foil is used in the solar hot case's construction to provide excellent insulation. The solar hot case is designed to offer exceptional insulation, and it does so by utilizing aluminium foil. Due to the case's great heat retention provided by this insulation, hot things may be kept warm for a prolonged amount of time. The solar hot case has a volume of about 28,316.847 cubic centimetres, which is more than enough room to store a variety of objects while keeping them at the right temperature. This kind of container is very beneficial for drinks and other temperature-sensitive commodities since it keeps them warm and fresh. Due to its lightweight box-like construction, good insulation with aluminium foil, and ample room to hold various objects, the solar hot case is a useful and effective method of sustaining desired temperatures during the day. Figure depicted the solar hot case from all four view angles.

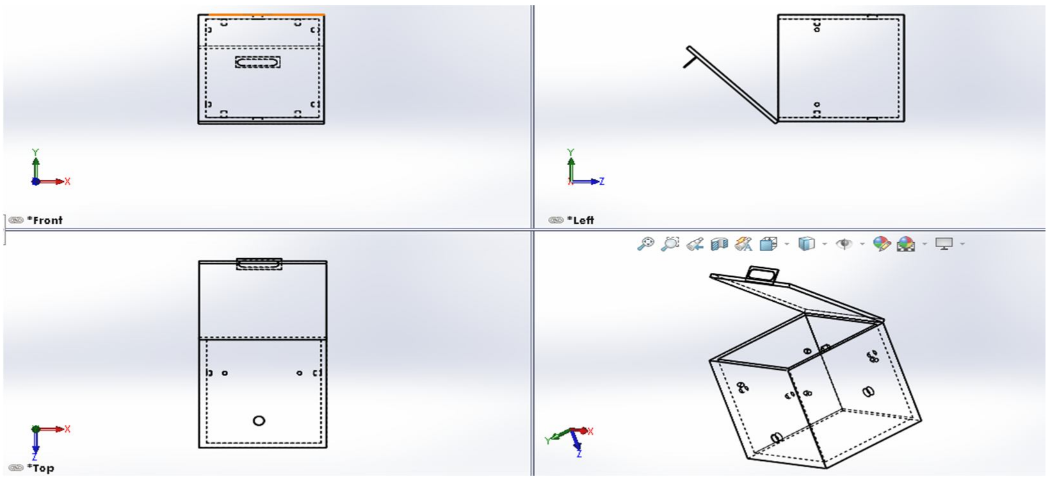

Fig.1 Solar hot case all views

C. Resisting wire Specifications

The criteria listed provide a wire's specs. The wire has a 2.4-ohm electrical resistance at normal temperature. For a complete knowledge of how the wire behaves in electrical circuits, this resistance value is essential. The wire can also absorb and release heat when temperatures change thanks to its 450 joules per kilogram per degree Celsius specific heat. The wire's capacity to efficiently conduct heat is demonstrated by its thermal conductivity, which is 11.3 watts per meter per degree Celsius. Due to its thermal characteristics, it may be used in a variety of applications where heat dissipation is crucial. The wire's thickness or diameter, which affects its ability to conduct current and electrical resistance, was classified as 32 gauge. Its total resistance at room temperature ranges from (1.0 to 1.5) 10-6 ohms with a wire length of 30.48 centimetres. It is desirable to reduce power losses during electrical transmission within this low resistance band. The wire's total electrical and thermal performance was also aided by the discovery that its cross-sectional area was 0.032429 square meters. The wire's characteristics, including its gauge, length, cross-sectional area, specific heat capacity, and thermal conductivity, are crucial elements to take into account in this experiment for a variety of electrical and thermal uses. It is an important part of our prototype experiment due to its low resistance and effective thermal characteristics.

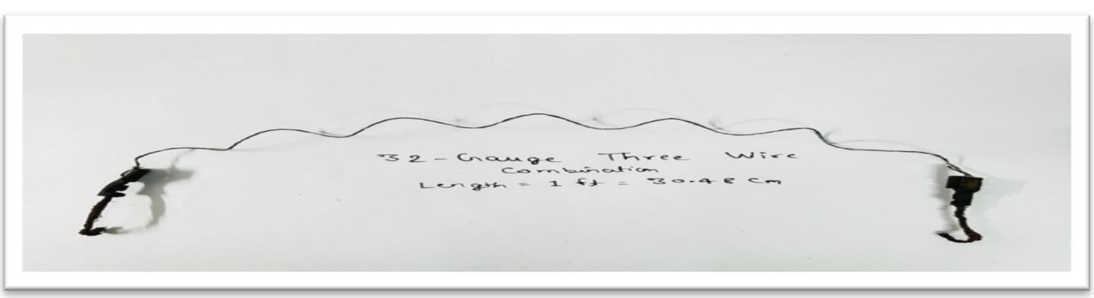

Fig.2 32-gauge Ni-Cr wire

IV. RESULT AND DISCUSSION

We can see the following patterns in Fig. 3(A):

1) The cabin temperature typically rises during the morning and early afternoon, reaching its peak around 1:00 PM. It then begins to steadily decline after that.
2) Like the cabin temperature, the water temperature rises during the morning and early afternoon, although it seems to climb more gradually.
3) Both T_{cabin} and T_{water} show a decreasing trend in the late afternoon, as the day progresses toward evening. These patterns suggest that a variety of elements, including the environment's weather, exposure to sunshine, and the heating systems in the cabin and the water, affect the temperature of the interior and the water. According to the findings, the cabin temperature reacts to irradiation changes more quickly than the water temperature. To reach more detailed findings and find particular patterns or connections between the two temperatures with regard to time, further investigation and data would be required.

From Fig. 3(B) The following patterns may be identified based on the data:

a) Placing a stainless-steel glass with hot water inside the cabin causes the cabin's temperature (T_{cabin}) to increase initially, reaching its highest point around noon (12:00 PM).
b) After the peak at noon, T_{cabin} starts to decrease gradually in the afternoon.
c) The water temperature (T_{water}) shows some fluctuations but generally decreases throughout the day but between 12:00 pm to 14:00 pm almost remain constant between 61°C to 62°C .
d) There seems to be a thermal exchange between the cabin and the water, causing the cabin temperature to increase initially due to the hot water and then decrease as the water loses heat to the environment.
e) The cabin's temperature responds more rapidly to changes in the water temperature during the morning and early afternoon.

It's vital to remember that additional elements, such as the size of the stainless-steel glass, the hot water's beginning temperature, and the insulation of the cabin, may also have an impact on the temperature trends that are being recorded. To get more firm findings and comprehend the dynamics of the thermal exchange between the cabin and the hot water, further investigation and data points would be required.

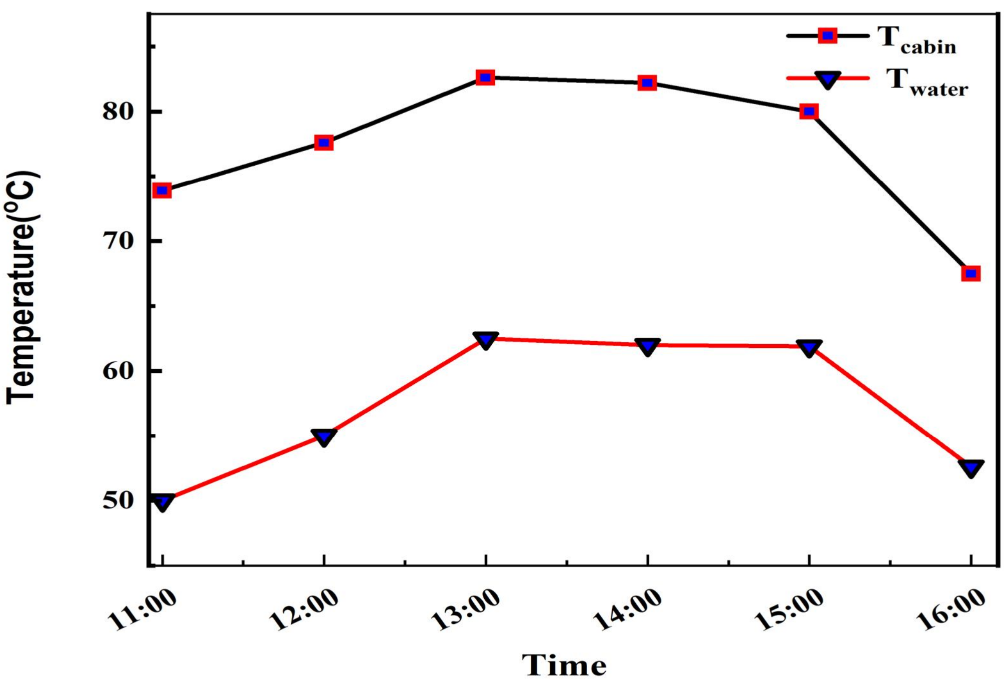

Fig.3(A) Time-dependent Temperature Variation of Water and Cabin

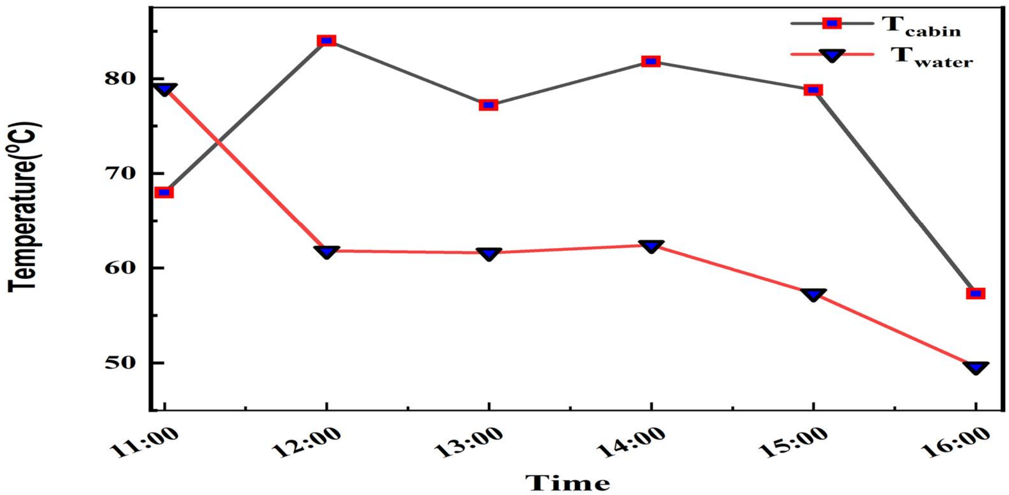

Fig.3 (B) Time-dependent Temperature Variation of Hot water and Cabin

V. CONCLUSION

The experimental findings underscored the viability and efficacy of a box-style solar cooker energized by photovoltaic (PV) energy. The solar hot case, distinguished by its commendable insulation attributes, demonstrated proficiency in sustaining optimal temperatures over daylight hours, thereby furnishing a pragmatic resolution for the conservation and preparation of foodstuffs in rural environs. The introduction of a heated stainless-steel glass within the enclosure elicited a discernible thermal interplay between the cabin and water temperatures, resulting in an initial elevation in the cabin's thermal state followed by a gradual descent. The investigation underscores the importance of sustaining reduced operational temperatures within photovoltaic (PV) systems to optimize their efficacy. In its entirety, this study offers valuable perspectives into the potential utility of PV-driven solar ovens as sustainable remedies for culinary complexities and deforestation prevalent in rural and wooded areas. Ongoing research endeavours and refinements in PV technology hold the potential to augment the efficiency and availability of such solar ovens, facilitating their integration to confront worldwide energy and ecological predicaments.

VI. ACKNOWLEDGEMENTS

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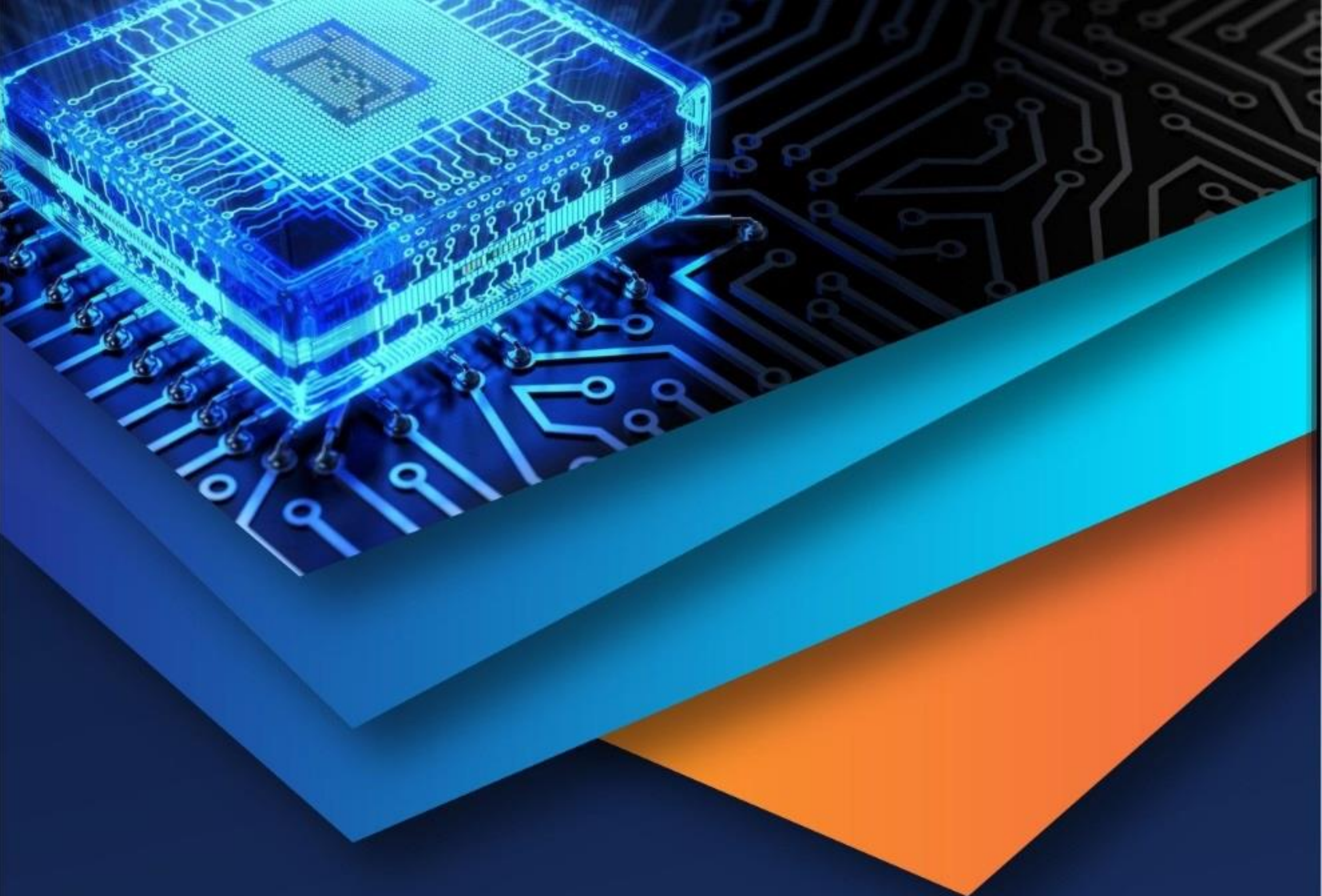

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