iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH
IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 3 Issue: III Month of publication: March 2015

DOI:

International Journal for Research in Applied Science & Engineering Technology (IJRASET)

Drying of Chili Using Solar Cabinet Dryer & Analysis with Results of Various Parameters

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Abstract— ***Solar Energy will going to be 5th generation main energy sources with its easy availability and scarcity of non-renewable energy sources. With increasing demand of energy sources to harness our daily needs and scarcity of coal and petroleum products it will be a better option to depend upon more reliable renewable energy sources. Various research works are going on solar energy but it still many more to be done to fully depend upon its utilization. Objective of the present study was to carry out detail experimentation and then analyze solar cabinet dryer. The loading capacity of the dryer was about 2kg of fresh product per batch. The dryer is of both natural and force mode type based solar cabinet dryer. The experiments were carried on both natural and force mode by using chili as the raw product. Various readings related to temperature and humidity at the desired points were measured with the help of thermocouples and hygrometer respectively, also air flow rate and solar intensity were measured with the help of anemometer and pyrometer. These experiments were carried in ITER, SOA UNIV Bhubaneswar (India), in this various parameters related to solar dryer was not only calculated but also natural and force mode was compared in terms of drying rate. The data are presented in terms of tables and graphs. It was found that the drying of chili in natural mode would take around 50-56 hrs and drying in force mode will take about 10-21 hrs depending on whether we are using heater as an external source of heat or not. It will take around 105 hrs in open drying of chili. The chili was reduced from the initial moisture content of 86.5(wb) to 7.3(wb).***
Keywords— ***Solar Drier, Solar Collector, Pyrometer, Anemometer, Thermocouples and Hygrometer***

I. INTRODUCTION

The future of solar energy is very bright, as the non-renewable resources of energy are in extinct. One day when all the resources may go on extinct then we have to rely upon our renewable resources. In India there is a huge scope of solar power/energy, as the solar radiations we are getting are greater than what China and Japan like countries are getting; but the fact is that much more research related to solar is going on in these countries. Actually, Japan and China are in the top zone of solar equipment producing countries. Solar dryer is among one of the equipments or we can say a machine which is used for drying purpose, it can be either in natural mode or in forced mode. People are actually not very confident in using solar dryer because of its initial cost, but they are not thinking about its pay back periods and its effectiveness as compared to open drying. Actually we have to do a lot of research work related to solar energy, inspite of its abundantly availability and one of the oldest sources of energy to mankind it had not been given enough attention for its development. Almost all the old civilizations from Egypt to Inca have built solar temples and solar operated monuments to trace the position of stars and to set the flow of wind in their desired directions. If you have noticed then you could have seen that there is a network of energy points of pyramids of all civilizations over the globe, perhaps it may be used in for communication. Hossain and Bala[1] had dried chili using solar tunnel drier and showed the effectiveness of dryer than open drying, also they showed that there was a considerable reduction in drying time. Ceylan and Ergun[2] had studied the relation between the psychrometry working upon the thermo-dynamic analysis of humid air and drying at a timber dryer. The thin layer silk cocoon drying was studied by Singh[3] in a forced convection[21-22] type of solar dryer, the drying air temperature varied from 50 to 75 C and the cotton was dried from the initial moisture content[17-18-19] of about 60-12(wb). Akintunde[4] studied the four layer drying models. The page model was found to best describe the drying behavior of chili pepper for sun and solar drying. The kinetics of heat pump drying of cocoa beans was investigated by C.L Hii et al.[5]. Chowdhury et al. studied the exergy and energy analysis of jackfruit leather in solar tunnel dryer. The various drying curve characteristics of tomato were studied by Manna et al.[6]. please contact us via e-mail.

II. METHODOLOGY

A. Experimental setup and approach

The solar dryer we had used in our experiment is of cabinet type solar dryer. The design of the solar dryer is based on the climatic conditions of the place, nature of the product and the quantity of the product to be dried. The indirect type of the solar dryer was designed and constructed and then it was coupled with already available solar collector. The dimension of the solar collector is 1.55 by 1.09 m. The dryer is of 0.6m height from the ground, the inlet ambient air enters through the inlet of the collector of square cross-section having dimension of 12cm by 12cm. After that the inlet air is heated up with the help of solar air collector and the outlet is connected to the solar dryer inlet, where the hot heated-up air carries out the moisture content of the product to be dried and the extra moisture carried by the air is then thrown by the outlet of the drier. The electric blower used here have a capacity of 379W, as already mentioned the capacity of the drier is of 2kg of raw product. Matt black paint is used on the absorber plate to increase the absorptivity to solar radiation. The collectors were oriented due south at an angle of '. More details on the solar air collector can be found out from Wankhade et al.[6] where they had discussed the drying characteristics of Okra slices. A 1000W auxiliary heater was constructed from a galvanized steel sheet with a square cross-section area that had a slide length of 0.27m; heating filament was wrapped on ceramic isolators. A constant variable resistance is provided to control the output power required to provide the selected air inlet temperature to the drying chamber. The power is calculated from the reading of the voltage provided by the variac and the amperage read by a digital multimeter (type ID-1000, range: 0-30 A and accuracy 0.75).An aluminum drying chamber, which had the dimension of 1.05 0.5 0.9m (length $\times width \times heig$) was insulated from the outside by a 30-mm aluminum coated rock wool sheet. 8 numbers of trays are inserted in the dryer. The drying of the materials involve the migration of water from the inner of the material to its surface, and then removal of the water from the surface; which in turns requires an equivalent of latent heat of evaporation of water. The equilibrium equation that presents the heat required is supplied by the solar air collector is given by Equation (1):

$$m_w h_{fg} = m_a C_P (T_{oc} - T_{tc})$$

The collector should deliver a quantity of heat which equals to Equation (2):

$$Q = HR(\overline{\tau a}) t A_{c\eta c}$$

The values of m_a and A_c are selected as desired by the drying conditions. The quantity of moisture removed from the raw product is calculated from the following relation referred to as Equation (3):

$$m_w = \frac{m_i(M_i - M_f)}{(1 - M_f)}$$

The efficiency of the air collector may be calculated from the following relation as shown in Equation (4):

$$\eta_c = \frac{Q_U}{HR.A_c}$$

The following relation referred to as Equation (5) shows the efficiency of the dryer:

$$\eta_d = \frac{P.h_{fg}}{(HR.A_c + W)t}$$

For heater the efficiency is calculated as follows as shown by Equation (6):

$$\eta_h = \frac{\dot{m}.C_p.\Delta T}{I.V}$$

The efficiency of the drying system is calculated by multiplying the efficiencies of the individual components of the system. Several tests were carried on using the flow rates 0.0378, 0.05619, 0.0689, and 0.0793m^3/sec. Calibrated thermocouples are used to measure the temperatures at the desired points for each interval of time. The temperature measurements were taken at the inlet to the collector, outlet to the collector, inlet to the dryer, outlet to the dryer, dryer inlet temperature, absorber plate temperature. Equal quantities of product were taken both for natural and forced convection, and for drying the product was uniformly spread over the 8 shelves of the dryer. The sample of dried product were taken and weighted with the help of weight balance, then the sample was dried with the help of oven and again its weight was measured with the help of the same weight balance after the sample was completely dried off. The weight balance used here is of type PE-3600, range0-500g and accuracy $\pm$1.5%. The relation whom we had used to calculate the moisture content is shown by Equation (7) [8-9-10-11]:

$$M = \frac{w_s - w_d}{w_s}.100$$

B. Design approach

We had tried to represent the design and drying analysis of the solar dryer.

1) *Thermal analysis*: The performance characteristic of the collector [7] and solar dryer is described by the energy balance that indicates the conversion of incident solar energy into useful energy gain and various losses.[6].

The air properties that are considered here are taken for the average temperature of the of the dryer cabinet: $\rho = 1.1324 kg/m^3$, $C_p = 1.0066 kJ/kg°C$,$\mu = 1.9036 \times 10^{-5}$kg/m.s, ν=16.9616$\times 10^{-6} m^2$/s, k=0.02719W/m.°C, Pr=0.70524; these properties are used to calculate the thermal characteristics and performance of the system. Grashof Number, Gr is given by the Equation (8).

$$Gr = \frac{g\beta L^3 \Delta T}{\nu^2}$$

Where $\nu=\mu/\rho$, $\beta=1/T$, $\Delta T=T_c - T_a$, $T=(T_c + T_a)/2$. L depends on the section of the cabinet under analysis.
The heat transfer coefficient is represented by the Equation (9).

$$h = \frac{kNu}{L}$$

Where the following Nusselt numbers Nu were used depending on the section or area of the cabinet under consideration.
For horizontal plate:
Above heated plate, Equation (10 a & b) conforms:

$$\textbf{Nu}=0.54 Ra_L^{1/4} \text{ for } 10^4 \le Rc_L \le 10^9$$

$$\textbf{Nu}=0.15 Ra_L^{1/3} \text{ for } 10^7 \le Ra_L \le 10^{11}$$

Below heated plate, Equation (11) conforms:

$$\textbf{Nu}=0.274 Ra_L^{1/3} \text{ for } 10^5 \le Ra_L \le 10^{10}$$

For vertical heated plate, Equation (12) signifies:

$$\textbf{Nu}=0.68+\frac{0.67 Ra_L^{1/4}}{\left(1+(0.492/Pr)^{9/16}\right)^{4/9}} \text{ for } Ra_L < 10^9$$

Where $Ra_L = Gr \times Pr$.
Here the analysis is not shown in details, because the heat transfer is more important and is calculated from the above Nusselt Number. In all the cases air in the environment is assumed to be stagnant; that is the reason why the heat transfer coefficient outside the dryer is taken to be zero.

2) *Collector analysis [16]:* The properties of air which had been used is already discussed before. Heat absorbed by radiation in the collector is predicted by Equation (13) $Q_{rad,in}$:

$$Q_{rad,in} = \propto A_C I,$$

Where $\propto$the absorptivity of the metal is, $A_C$is the surface area of the collector. I is the total incident solar radiation [20] and is expressed as by Equation (14):

$$\text{I}= \frac{\text{hourly radiation}}{\text{solar radiation}} \times \text{solar irradiation}$$

Heat loss by convection and conduction through the base of the collector$Q_{cb,loss}$ is given by Equation (15):

$$Q_{cb,loss} = \frac{\Delta T_{cb}}{\Sigma R_{cb}}$$

Where Δ T_{cb} is the temperature difference between the collector and the environment.$\Sigma R_{cb} = \frac{1}{h_{cb} A_{cb}} + \frac{x}{k A_{cb}}$ is the thermal resistance offered by the wall and the film at the inside of the collector taking the heat transfer coefficient at the outside of the wall as zero (still air). A_{cb} is the base area of the collector.

Useful heat in the collector Q_u is given by Equation (16):

$$Q_u=\dot{m}C_p(T_c - T_a)= Q_{rad,in} - Q_{cb,loss}$$

Collector Efficiency $\eta_c$is given by Equation (17)

$$\eta_c=\frac{Q_u}{Q_{rad,in}} \times 100\%$$

3) *Cabinet analysis:* The analysis for drying cabinet was evaluated for the properties of air at the bulk temperature. Heat absorbed by the radiation in the cabinet $Q_{rad,in}$is given by the Equation (18):

$$Q_{rad,in} = \alpha A_d I$$

Heat transfer through the walls of the collector body $Q_{gc,in}$is given by the Equation (19):

$$Q_{gc,in} = \frac{\Delta T_{gc}}{\Sigma R_{gc}}$$

Where ΔT_{gc} is $\Delta T_{ca} + T_d$ and $\Sigma R_{gc} = {}^1/_{h_{gc} A_{gc}} + {}^1/_{k\, h_{gc} A_{gc}}$ is the heat transfer coefficient at the inside wall of the cabinet and $A_{gc}$is the area of the portion of the vertical wall separating the collector and the cabinet case.

Heat radiated to the environment by the cabinet $Q_{rad,out}$ is given by the Equation (20):

$$Q_{rad,out} = \mathcal{E}_{in} \sigma A_d (T_d^4 - T_a^4)$$

Where $\mathcal{E}_{in}$ is the emissivity of the metal, $\boldsymbol{\sigma}$=5.699$\times 10^{-8}$W/$m^2.K^4$ is the Stefan-Boltzmann constant and $A_d$is the total surface area of the cabinet through which heat is exchanged by radiation with the environment.

Heat Transfer from the cabinet through the side wall Q_{vc} is given by the Equation (21):

$$Q_{tc} = \frac{\Delta T_{da}}{\Sigma R_{tc}}$$

Where $\Delta T_{du} = T_d - T_u$ and $\Sigma R_{tc} = {}^{1}/_{h_{tc} A_{tc}} + {}^{x}/_{k A_{tc}}$.Here A_{tc} is the area through which heat is transferred from the lower side of the cabinet to the ambient & h_{tc} is the heat transfer coefficient on the inside of the box about the desired area.

Heat transfer from the cabinet through the bottom wall Q_{bc} is given by Equation (22) :

$$Q_{bc} = \frac{\Delta T_{da}}{\Sigma R_{bc}}$$

Where $\Delta T_{da} = T_d - T_a$ and $\Sigma R_{bc} = {}^{1}/_{h_{bc} A_{bc}} + {}^{x}/_{k A_{bc}}$. Here A_{bc} is the area through which heat is transferred from the base wall of the cabinet to the ambient & h_{bc} is the heat transfer coefficient at the top surface of the base wall inside the cabinet around the desired area. Total heat through the walls of the cabinet box Q_{loss} is given by the equation (23):

$$Q_{loss} = Q_{vc} + Q_{tc} + Q_{bc} + Q_{rad,out}$$

Useful heat in the cabinet is given by the equation (24):

$$Q_u = \dot{m} C_p (T_c - T_d) = Q_{rad,in} + Q_{gc,in} - Q_{loss}$$

Solar Dryer Efficiency is given by Equation (25):

$$\eta_s = \frac{Q_u}{Q_{rad,in} + Q_{gc,in}} \times 100\%$$

III.RESULTS AND DISCUSSION

A. Moisture content

Fig. 1 and 2 shows the time variation of moisture content for different airflow rates for solar(using blower) and mixed drying(using blower and heater) of chili respectively in comparison to natural drying. The benefit over natural drying of solar and mixed drying is obvious from the graph. It is seen that faster drying rates are observed for mixed drying as compared to solar drying. It should be noted that the effect of changing the air flow rate on the drying time is more noticeable in solar drying than in mixed drying.

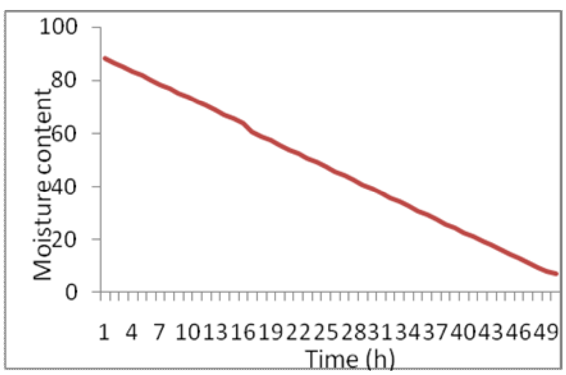

Figure1 (a). Shows the graph between moisture and time (hrs) for natural mode drying.

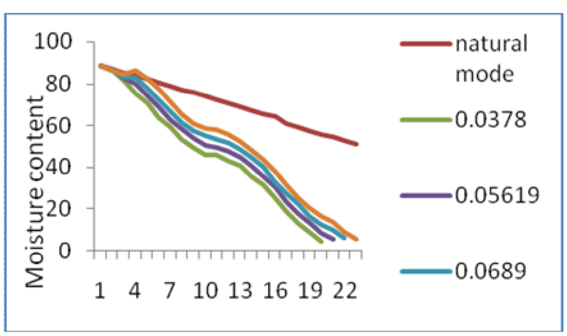

Figure1 (b). The graph between moisture and time (hrs) for natural and forced mode for different flow rates

Volume 3 Issue III, March 2015
ISSN: 2321-9653
International Journal for Research in Applied Science & Engineering Technology (IJRASET)

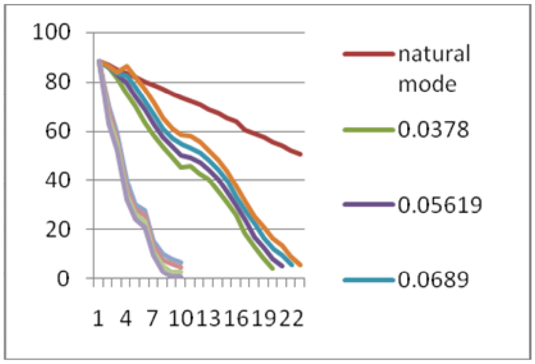

Figure2. The variation of moisture content with different flow rate and is compared with using heater with forced convection mode.

B. Collector efficiency

The collector efficiency is given by the graph; this graph shows the relation between the collector efficiency and drying time. the collector efficiency was seen to be first increasing and then decreasing. as the solar intensity of the radiation first increases and then decreases and this is due to this reason that the collector efficiency was seen to be monotonically increasing and then decreasing.

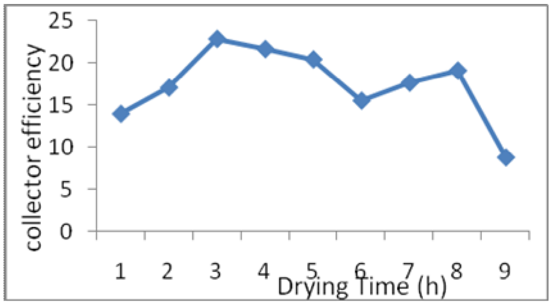

Figure 3. The variation of collector efficiency with time

C. Drying rate

The drying rate was seen to be decreasing with the time and is shown by the given graph in fig4.

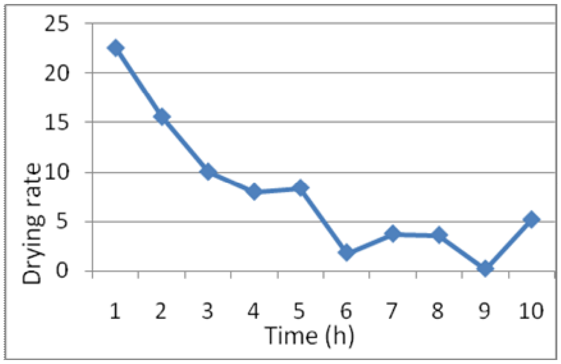

Figure4. The variation of drying rate with time.

D. Drying efficiency

The drying efficiency was seen to be decreasing with time and is shown in the fig5. There are some peaks and falls in the curve and the curve is not monotonically decreasing.

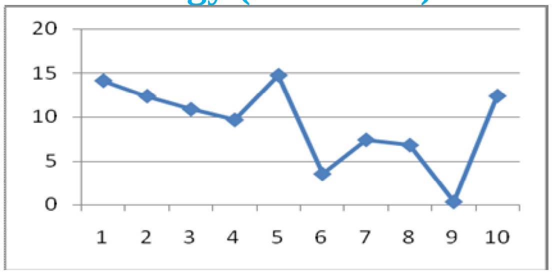

Figure5. The graph between drying efficiency with time.

E. Relative humidity

The relative humidity at the desired points is shown in the fig6, and it was found to be first decreasing and then increasing. The relative humidity inside was found to be higher than relative humidity at outside.

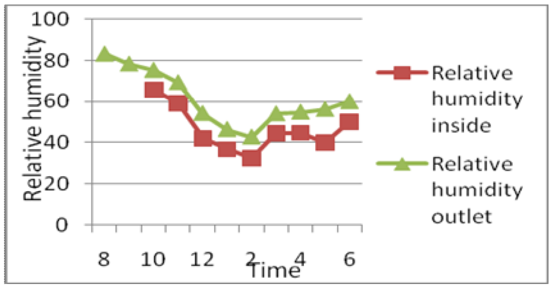

Figure6. The variation of relative humidity with time.

F. Temperature

The temperature variations in the system are shown in the fig7, and it was found to be first increasing and then decreasing. The reason for this monotonically increasing and then decreasing is due to available solar intensity which was seen to be increasing first and then decreasing.

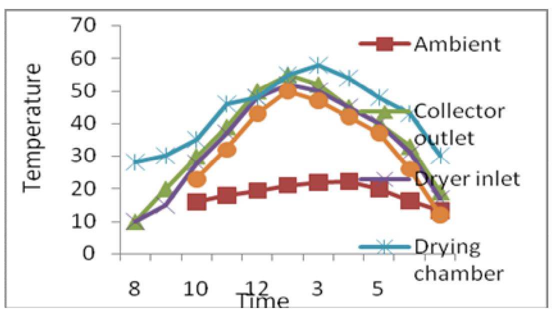

Figure7. Shows the variation of temperature vs. time

G. Solar intensity

The variation of solar intensity with time is shown in the fig8, and it was first seen to be increasing and then decreasing.

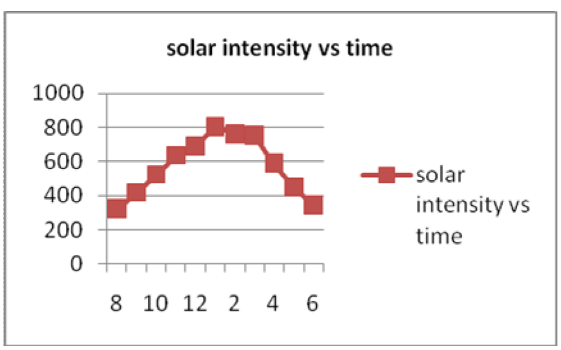

Figure8. Shows the variation of solar intensity vs. time

IV.CONCLUSION

As it was seen that with the increase in flow rate there will be a considerable increase in the drying rate and moisture removal rate would be faster. Also it was seen that when heater was used there were almost negligible effect of flow variation in the moisture removal rate. Thus it was seen that it will be beneficial to use blower with different flow rates instead of using a completely natural solar dryer. It should be noted that using a blower may consume more energy but it adds to less time in drying the product and may lead to more net profit.

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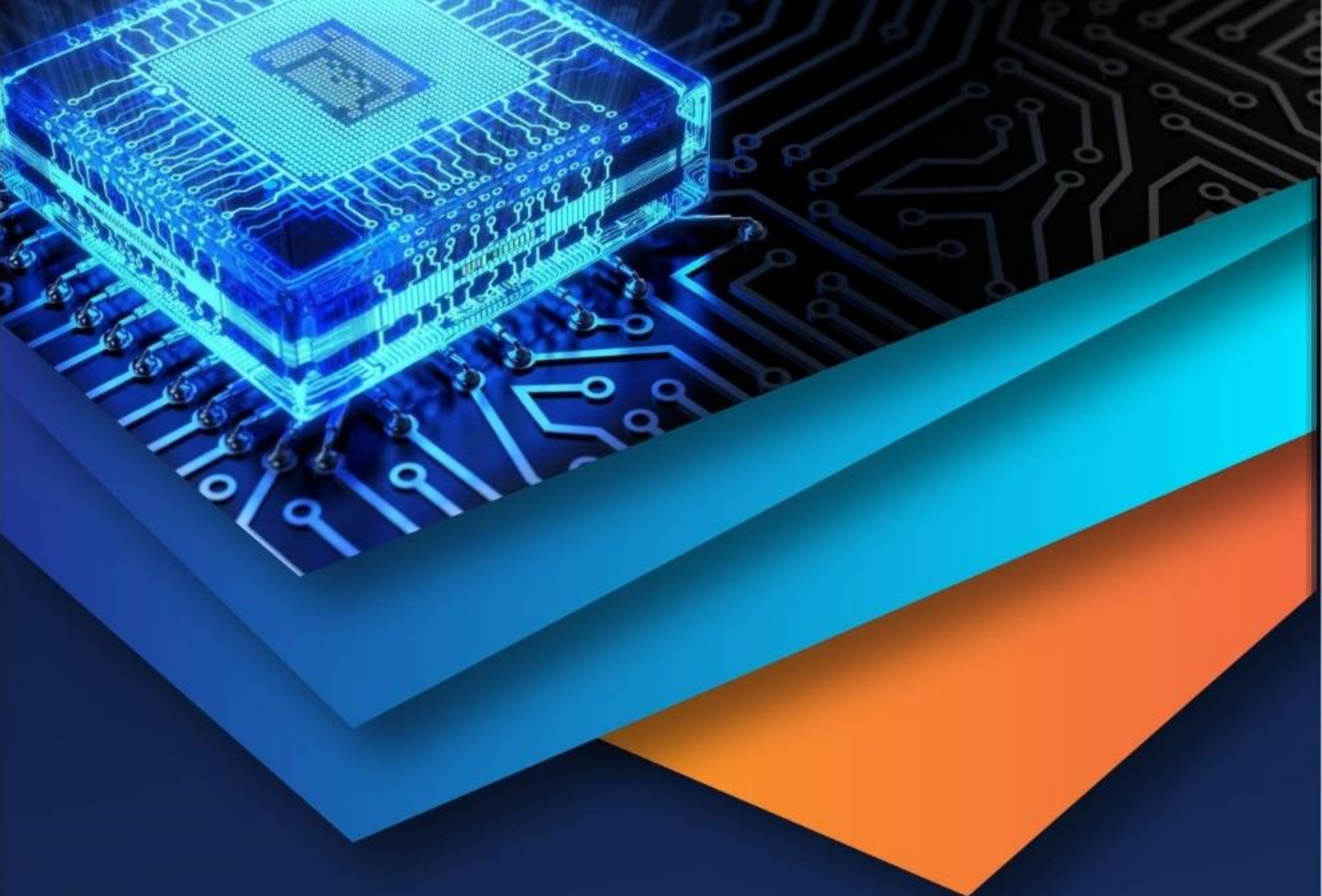

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