iJRASET
International Journal For Research in Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 4 **Issue:** I **Month of publication:** January 2016

DOI:

www.ijraset.com

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Volume 4 Issue I, January 2016
ISSN: 2321-9653
International Journal for Research in Applied Science & Engineering Technology (IJRASET)

Experimental Investigation for Performance Enhancement of Solar Still Using Solar Pond

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Abstract: ***Today fresh water demand is increasing continuously, because of the industrial development, intensified agriculture, improvement of standard of life and increase of the world population. Lack of fresh water is a prime factor in inhibiting regional economic development. Seawater and sometimes brackish water distillation constitute an important option for satisfying current and future demands for fresh water in arid regions. Distillation can be achieved by using a number of techniques. It is said that presently more than 2000 million people do not get potable water. Looking at the scarcity and large demand of fresh water, needs the water distillation system which is operated on renewable energy sources. Solar still is the best option for the domestic purpose to get the distilled water. The productivity can be enhanced by applying methods like black balls of spherical shape, by keeping optimum depth of basin water, by integrating solar still with evaporative tube collector or by incorporating the still with two glass cover.***

I. INTRODUCTION

Access to Water has emerged a major challenge to many people in the country. Today fresh water demand is increasing continuously, because of the industrial development, intensified agriculture, improvement of standard of life and increase of the world population. Only about 3 % of the world water is potable and this amount is not evenly distributed on the earth large quantities of fresh water are required in many parts of the world for agricultural, industrial and domestic uses. Lack of fresh water is a prime factor in inhibiting regional economic development. Seawater and sometimes brackish water distillation constitute an important option for satisfying current and future demands for fresh water in arid regions. Distillation can be achieved by using a number of techniques. The conventional distillation process namely reverse osmosis, electro dialysis, multi-effect evaporation etc are not only energy intensive but also uneconomical when the demand for the fresh water is small.

The Supreme Court of India passed an order in March 2009 that the water problem in the country must be solved using best of recourses to technology. The Secretary Science and Technology has been assigned the task of addressing water challenges using the best of technologies in the world. Technology Mission Winning, Augmentation and Renovation (WAR) for Water have been launched with a budget of Rs 145 cores. So the goal should be to employs water efficient technologies, potable water is available to all & natural water resources are enriched employing innovative mechanisms.

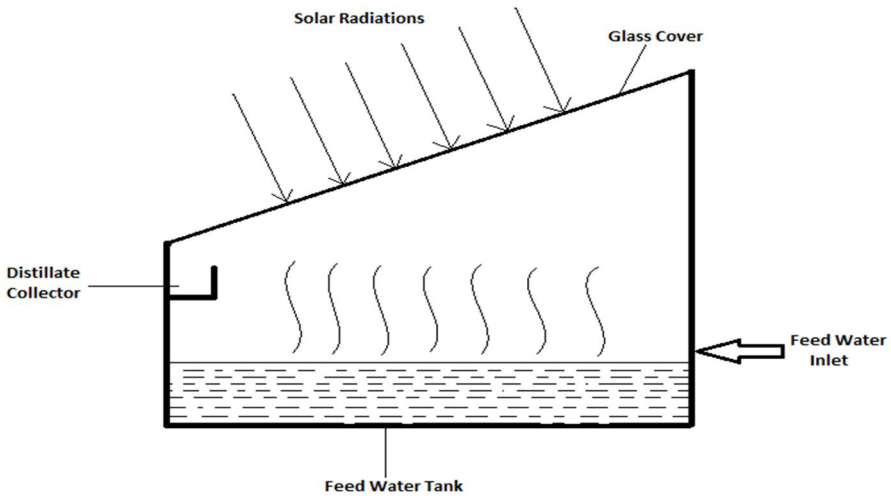

Fig. 1 Schematic diagram of Solar Still

Figure 1 shows a single-basin still. The incident solar radiation is transmitted through the glass cover and is absorbed as heat by a black surface in contact with the water to be distilled. The water is thus heated and gives off water vapour. The vapour condenses on the glass cover, which is at a lower temperature because it is in contact with the ambient air, and runs down into a gutter from where it is fed to a storage tank.

Elkader et al. (2000) experimentally evaluated some of the published mathematical models for water desalination by solar still was presented in this work. The validity and the applicability of these models under the Egyptian weather conditions were examined. Using a computer program, the considered models were evaluated at the same operating conditions. The computer results showed a wide range of discrepancy between the evaluated models. Experimental single sloped solar still was constructed for the outdoor work within the city of Suez. The obtained results are in a good agreement with some of the considered models. The daily productivity of a single-sloped, solar still was determined experimentally as 5.5 (litre/m^2.day) under the Egyptian climatic of August 1998. Also, the average thermal efficiency of the unit was estimated as 42 %. Under the same operating conditions of 15° glass angle and 2 cm water depth, the basin temperature ranges from 30°C to 76°C. The computer results showed a wide range of discrepancy between the considered models for the estimation of the daily productivity and thermal efficiency of the solar still. Also, this deviation was appeared in the brine temperature variation along the daytime. Both solar still productivity, which were computed by the models of Malik et al. (1982) and Clark (1990), were similar and in a good agreement with the obtained experimental results, under the Egyptian weather conditions. The computer results showed a wide range of discrepancy between the considered models for the estimation of the daily productivity and thermal efficiency of the solar still. Also, this deviation was appeared in the brine temperature variation along the daytime.

Hassan et al. (2004) A numerical study had been carried out to investigate the transient thermal performance of a naturally circulated humidifying or dehumidifying solar still. The results show still productivity and efficiency of about 5.1 kg/m^2.d, similar to that of a forced circulation model. In addition to its simplicity, natural circulation is more economical and technically less complex than a forced circulation still. The influence of different environmental, design, and operational parameters shows that increasing solar intensity (high input energy) and ambient temperature (less energy loss) improved the still's productivity. This was an advantage of solar desalination as water production increases under summer conditions, which were consistent with the water demand during this season. Different attempts to partially store basin energy and/or recover condensation energy were also studied. These attempts cover (1) only partial storage of basin energy for overnight reuse, (2) only partial recovery of condensation energy at the condenser, and (3) a combination of energy storage and partial recovery. The results showed an insignificant improvement in the still's productivity. It was more economical, therefore, to store water rather than store energy. An economical assessment of water production costs shows that 1.0 m3 of product water costs 45 EP ($9). However, if the still cost was reduced to 100 EP, then 1.0 m^3 will cost only 25 EP ($5). In general, solar stills cannot challenge the lower cost of large units (MSF, RO, etc.). However, for special applications of (1) very small communities demands, (2) unavailability of fresh drinking water in remote areas, (3) unavailability of energy (fuel or electricity) and (4) unavailability of technical support within the communities, solar stills seem to be the only (technically and economically) competing alternative.

Muafag Suleiman et al. (2007) studied the Effect of Water Depth on the Performance Evaluation of Solar Still. The accepted thermal performance of the constructed solar still with an increased evaporation rate and the faster condensation was achieved due to the appreciated contribution of the improved design parameters and the operational. The merit contribution of using the plastic jackets had a significant role for minimizing the effort of cleaning the deposited scale (by using a new jacket when needed) and maintaining efficient capturing of solar irradiation. The deciding role of cooling the glass cover was strongly observed on the increased temperature difference (Tw-Tg) as well as on the increased water productivity. Higher attention must be spent to the times of applying the cooling method. The concept of using the greenhouse solar stills was found to be very attractive method for obtaining the fresh water even for a small-scale demands, because of several economic and technical advantages such as, the inexpensive technology including the material prices and manufacturing. The efficient utilization of the solar energy with a percentage of 70% was reached and demonstrated by the good agreement between the obtained productivity of 6.7 Lit/day and the theoretical productivity of 9.5 Lit/day that could be obtained under the available climatic conditions. The possibility of increasing the water productivity could be reached by lowering the water depths on the basin- absorbing plate. It was found that the geographical location may having a significant positive effect on the increased water productivity, especially for those locations with an abundant solar

irradiation and situated at higher elevations above the sea level, where the reduced boiling point of water and the corresponded saturation pressure were below the standard atmosphere.

Ragh et al. (2011) did a comparative energy and exergy analysis of various conventional solar distillation systems. This study included passive solar distillation systems such as single and double slope solar stills. In a single slope solar still category, three solar stills with inclination angles 15º, 30º and 45º and a 15º inclined single slope multi wick solar still had been considered. Whereas one double slope solar stills and one double slope multi wick solar still, both inclined at 15º with east-west orientation, had been considered in double slope solar still category. The embodied energy was an important factor which depends on locally available materials and their manufacturing technologies. Materials like concrete, wood, steel etc were considered to calculate the embodied energy for the solar still equivalent to the fibre reinforced plastic after deriving the formulae. On the basis of above analysis and literature survey, the energy, exergy and embodied energy of single slope solar still were found higher than that of double slope solar still. Those materials which had lower thermal conductivity and low embodied energy than that of FRP such as concrete, PVC, wood can replace the FRP to save the embodied energy for similar performance. The metals had high embodied energy hence these cannot be considered in terms of embodied energy despite the use of insulation. PVC material had been found to be better in terms of embodied energy in comparison to other materials.

Amimul Ahsan et al. (2011) studied the Evaporation Phenomenon Inside a Solar Still:- From Water Surface to Humid Air. The cover material of the first model of the Tubular Solar Still (TSS), a transparent vinyl chloride sheet was changed to a polythene film for the second model. Thus, the second model was simpler, lighter, cheaper and more durable than the first one. These improvements make the assembly and maintenance of the new TSS easier. A special experimental technique was developed to observe the evaporation, condensation and production performance independently and simultaneously. As a result, the evaporation was detected first and then the condensation and the production followed it in turn. As for second model, the hourly evaporation and production fluxes were slightly lower than the first one under the same experimental conditions. It was revealed that the relative humidity of the humid air was definitely not saturated and the hourly evaporation, condensation and production fluxes were proportional to the humid air temperature and relative humidity fraction. The hourly evaporation was linearly proportional to the trough width, B, regardless of the trough length, L, for $0.49 \leq L \leq 1.5$m (Ahsan & Fukuhara, 2008). The movement of the humid air in the TSS belongs to turbulent natural convection state. The evaporation coefficient was proportional to the temperature difference between the water in a trough and the tubular still cover. The present model was able to reproduce the hourly evaporation mass flux obtained from the previous field-TSS experiment. It was concluded that once the four parameters (Ahsan & Fukuhara, 2008); that was, the water temperature, humid air temperature, tubular cover temperature and the relative humidity of humid air were measured, the present model was capable of evaluating the diurnal variation of evaporation mass flux from the water surface in a trough with an arbitrary size.

Shobha et al.(2012) studied passive solar still which was used for solar distillation plants due to its simplicity in construction and operation, low cost and however the yield was low. Various active methods had been developed to overcome this issue. These developments creates additional cost for the system. The main objective of this project was to effective utilization of the solar water heater for solar still productivity enhancement, which works as a hybrid system. The evacuated tube collector model solar water heater was coupled to a solar still, and the performance study was conducted at various timings with different operating conditions like Solar still operated alone and Hybrid Still operated during daytime with various water depths and various water samples. Both Theoretical and Experimental analysis were conducted and the results were compared. The water quality results for different water samples for both untreated and treated water were tabulated. An experimental investigation was done for comparing a passive solar still and an ETC solar water heater coupled with a solar still. Productivity of Solar Still increases from 39 to 59% with hybrid unit. i.e. when a Solar Still was coupled to an ETC type of solar water heater and operated from 8AM to 5PM. The efficiency for 1cm water depth ranges from 43 to 52%, for 1.5cm it ranged from 39 to 48% and for 2cm it ranged from 32 to 41% for a Hybrid Solar Still operated during day time. Hence it can be concluded that the efficiency of the still decreases with the increase in water depth. The active solar still gives the higher thermal efficiency than the passive solar still. It ranged from 32% to 48% for hybrid unit operated during the day. Adding the dissolved salt like KMnO4 to river water increased the efficiency from 46.91% to 48.83% for a water depth of 1cm. The theoretical analysis was in good agreement with the experimental results.

Ehssan et al. (2013) experimentally investigated a simple still for solar distillation that has no moving parts and does not use any other source of energy. Experiments were carried out during the months from May to August. The experiments investigated the effect of changing initial water volume, water to ball volumetric ratio and black solid material diameters on the productivity and the efficiency of the still. The highest volume of distillate water was obtained with 4mm diameter black plastic balls, and water to ball ratio 1.8, this rate was 4 m^3/m^2 day with an average efficiency of 49%. It was also found that solids with high heat capacity gives better rates of distillation and higher efficiency in the afternoon hours. The still was used for desalination of sea water and gave almost the same rate of production at the best conditions. From the results of the preliminary experiments, it was evident that both the amount of solids and the initial volume of water have an effect on the productivity of the still as indicated by the amount of water produced hourly. A series of experiments were carried out in which the volumetric ratio of the water to balls was varied to check this combined effect. This in turn will depend on the size of the spheres used. The experiments were carried in consecutive days during the month of June. These were for noon 1 p.m.4 p.m. and 5 p.m. presenting the peak hours and afternoon hours of the day. The obtained results show that the hourly productivity and hourly efficiency increase with increasing water to ball ratio and then decrease again. The range of ratios investigated was from 1 to 2.5 approximately. Increasing the surface area increases the quantity of solar radiation absorbed by the solid material surface; this effect has a positive effect on the solar distillation process.

Asaad et al.(2013) developed basin solar still by adding a magnetic treatment unit, its energy 0.12 Tesla and two layer of glass provided with water between them. The study was conducted by testing the device by using magnetic water plus double glass provided with water, non magnetic water plus double glass cover, magnetic water plus single glass cover, non magnetic water plus single glass cover and control treatment (without additions). Intensity of incidence solar radiation in Basrah province during the month of April, temperature in the basin solar still, glass cover surface, ambient, pH, water electric conductivity, productivity, density, physical and chemical properties were measured. Theoretical productivity and efficiency were calculated. The results showed that the average of solar radiation intensity was 889.55 W/m^2. Temperature of basin solar still, glass cover surface and ambient was increased with increasing solar radiation intensity. The maximum of temperature in the basin water of solar still was 56.61°C at using magnetic water plus single glass cover which has best performance compare with other treatments and having pH 7.03, minimum electric conductivity was 0.000672 S/m and density reached to 1000 kg/m^3 and its productivity improved by 50% compared with conventional. A basin solar still was fabricated and tested. The optimized modified desalination system was magnetic water plus single glass cover. The efficiency was calculated as 32.55% which was comparable with stills being worldwide. Also it was found that quality of distilled water using magnetic water plus single glass cover was better than other treatments.

Huda et al. (2013) studied pyramidal solar still (PSS) and a single basin solar still (SBSS) built of transparent glass with a thickness (4 mm) and had the same dimensions of absorber plate which contains the Saline water, and constructed under different atmospheric circumstances of Basra city (Iraq). An experimental investigation was carried out on two solar stills under the same conditions. He found in this experimental study that the efficiency of the single basin solar still (SBSS) was (55%) and increases to (66.5 %) of the pyramidal solar still (PSS). The largest part of distillate production was seen to take place between noon and sunset, where the productivity was increased with the increase of solar radiation. The high distillate production of the pyramidal solar stills occurred in June, which was related to the high incident radiation. The thermal efficiency arrived to 66.5 % for the pyramidal solar still (PSS) while 55 % for the single basin solar still (SBSS). The pyramidal solar still (PSS) was the best design appropriately in Basra region in this work. The hourly variation behaviour of yield was similar to that of solar intensity. The daily production of the maximum value arrived to (7368 ml/m^2) at (20 June 2013) for the PSS and (5570 ml/m^2) at (20 June 2013) for the SBSS, where the sky was clear, where the production of the solar still had been depending on the intensity of solar radiation, while the less value of production to (1640 ml/m^2) on the day of (20 December 2013) where the sky was not clear but partly cloudy. The hourly production of the two stills had the same behavior, and there was a significant increase in the productivity of (PSS) due to the effect of the pyramidal solar still .

Arunkumar et al. (2013) designed a compound parabolic concentrator-concentric tubular solar still (CPC-CTSS) and experimental analysis was done. A idea was proposed to study the characteristic features of CPC for desalination to produce a large quantity of distillate. The water level in the basin decreased due to fast evaporation from the basin during operation, so a dry spot appeared in the basin. This may be avoided in successive trials by flowing the water continuously in the still with the help of a graduated tube. This continuous supply of water was maintained by a water storage tank which was kept near to the CPC still. The outlet from the

storage tank was connected to the inlet of the CPC still. After saline water was poured inside the basin, the entire arrangement was sealed properly with a rubber cork to ensure that there is no air leakage. The cooling air was flowing at a constant flow rate of 4.5 m/s. This research article invented a new compound parabolic concentric-tubular solar still (CPC-CTSS), which had been designed for and tested under the various climatic conditions of Coimbatore, India. The effect of cooling air flowing over the glass surface was studied. The daily distillate output of CPC-CTSS was found 1445 ml/day and 16.2% efficiency with natural air flow and 2020 ml/day and 18.9% efficiency with air flow at a constant flow rate of 4.5 m/s. To bound in a nutshell, this innovative approach of concentrator assisted tubular solar still with air flow augments the performance with enhanced rate of evaporation and condensation with safer operation procedures.

M. Koilraj et al.(2013) did a Comparative study of Performance Analysis between Single Basin Solar Still made up of Copper and GI. Two solar stills made up of galvanized iron sheet and copper sheet of the same size were fabricated and tested experimentally. The production rate varies as time passes from the early morning until late afternoon. If the atm. temperature increases or the wind velocity decreases, the heat loss from solar still decreases resulting in higher distillation rate. In this innovative copper still the productivity was increased significantly because Copper has higher thermal conductivity and it conducts more heat to the water in the basin. The solar radiation was also absorbed by black coated inside bottom of the basin and thus increases the temperature of the water. The amount of distillate collected in this still was higher (2490 ml/day) and hence the increase in efficiency by 80 % when compared to the still made up of Galvanized Iron sheet for the same basin area. The efficiency increases as the insulation thickness increases because of decrease in the heat loss from the still to the surroundings. The water temperature has a direct effect on the productivity. But if the depth of water increases, the daily still output decreases i.e. inversely proportional. There was an increase in the productivity for the minimum depths of water level because of lower thermal capacity and thus increase in water temperature. If the level of salt concentration was much higher, then a portion of incident solar radiation was utilized for heating the water rather to heat the salt inside the still. So that temperature of water inside the basin was decreased and in turn the amount of water evaporated was lowered. Therefore higher the salt concentrations lower the distillate collected. Hence, there was a decrease in efficiency of the still for the incident solar radiation. Thus the efficiency was higher for a solar still made up of copper sheet and it can be used at each house for producing the distillate.

K. Shanmugasundaram et al. (2013) investigate the performance of the single basin double slope solar still by integrating with shallow solar pond to enhance the productivity. The performance of the solar still integrated with the shallow solar pond provides better performance compared with the still without integration. The total distillate yield of the still with pond was found to be 6.340 liters/day. The efficiency of the double slope single basin solar still was increased when coupled with shallow solar pond. It had shown great potential in terms of higher distillate yield per unit area and its operation process was very steady. The maximum instantaneous efficiency of the solar still coupled with and without shallow solar pond was found to be 48% and 65%. The solar still can be used as a water purifier for domestic purposes by using solar energy in winter and summer seasons. Though the still has been analyzed during the months January to March, it was possible to find the performance of the still can be found by using the proposed thermal model.

Rahul Dev et al.(2014) developed Double slop Solar still. Experimental and theoretical results had been compared for the composite climate of New Delhi, India. On the basis of above analysis, the new thermal model of DSSS had been found in fair agreement with experimental observations. Further, the characteristic equations based on the thermal model and experimental data had been obtained. Non-linear characteristic curves had been found more accurate for DSSS in comparison to its linear characteristic curves. A fair agreement in temperature of water with root mean percentage square (RMS) error 6.8% (coefficient of correlation r=0.9671) had been found. RMS error for total amount of yield obtained experimentally and theoretically from both east and west sides of DSSS had been found 34.7% with r=0.9753.

Ibrahim et al.(2014) designed and fabricated three identical stills labeled as still A, still B and still C, were filled with water at depth of 5mm, 10mm and 20mm above the basin respectively. The basin of the stills measured 260cm^2 and 12cm deep were made of steel plates. The total heat loss from Still A was higher as compared to still B and C. This shows that the heat loss in a solar still is a measure of the basin water depth which can be contributed to the relatively higher basin water temperature for the lower water depths. The daily productivity of the stills A, B and C were 43.76, 29.09 and 11.69 kg/m^2 respectively. Efficiencies of the stills A,B and C were 35%, 23.30% and 9.4% respectively. The daily condensate collected in collector of the stills varies linearly with the basin water depths. Lower the basin water depths, the higher will be the evaporation rate.

Kalidasa et al.(2014) studied performance of a single basin double slope solar still theoretically and experimentally. Four thermocouples were placed in the basin at different locations. Two thermocouples are placed in the each side of the drain to measure the condensate temperature. The hole was closed with insulating material to avoid the heat and vapor loss. Another hole was provided for water inlet. Through this hole, water tube from piezometer is inserted to supply raw water continuously to the basin from storage tank through control valves which regulates the flow, to keep the mass of water in the basin always constant. Theoretical and thermal models were used to predict the year round performance for the year 2008. Radiation model and meteorological data for the local place were used to estimate the irradiances received at the covers in different months. The production rate variations for different months had been studied as a function of local time. In November and March the variations were steeper. Similarly the time for maximum production rate was also different for different months. This was due to variations in irradiance incidence on the covers, atmospheric temperatureand wind velocity. The overall production was higher in March, April, August, November and December and it was around 4 L/day. The average production of the still was 2.1 L/day/m^2.

Ali et al. (2014) did an experimental investigation on a passive solar still with myristic acid as phase change material was carried out to examine the effect of both the mass of phase change material and basin water on the daily distillate output and efficiency of the system under indoor simulated condition. The experiments were started at 7:00 a.m. under simulated conditions with an aim to record the temperatures of ambience, outer and inner surfaces of glass cover, basin liner, stored water and PCM at every one hour interval till 7:00 p. m. The values of operating voltage, current, and distillate output were also recorded. It was clear from the figures that the increase in temperature was directly proportional to the input energy which was similar to the trends of solar radiation till 6:00 p. m. The heaters were switched off at 6: 00 p. m. to simulate the post sunset condition. The latent energy stored in the myristic acid kept the system operational during the night to deliver distillate output. However, the decreasing trend of all above temperatures show that the quantity of distillate output is reduced and due to little difference in the temperature of glass cover and ambience that continues until next day morning.

II. CONCLUSION

Fresh water, which was available from rivers, lakes and ponds in plenty, is becoming scarce because of industrialization and population explosion. Moreover, these potable water sources are being polluted constantly by industrial wastes and sewage. It is said that presently more than 2000 million people do not get potable water. Looking at the scarcity and large demand of fresh water, needs the water distillation system which is operated on renewable energy sources. Solar still is the best option for the domestic purpose to get the distilled water. The following design parameters were reported as follows:-

A. Glass angle 15^0.

B. Still facing to east-west direction.

C. Depth of water 5mm

The productivity can be enhanced by applying methods like black balls of spherical shape, by keeping optimum depth of basin water, by integrating solar still with evaporative tube collector or by incorporating the still with two glass cover.

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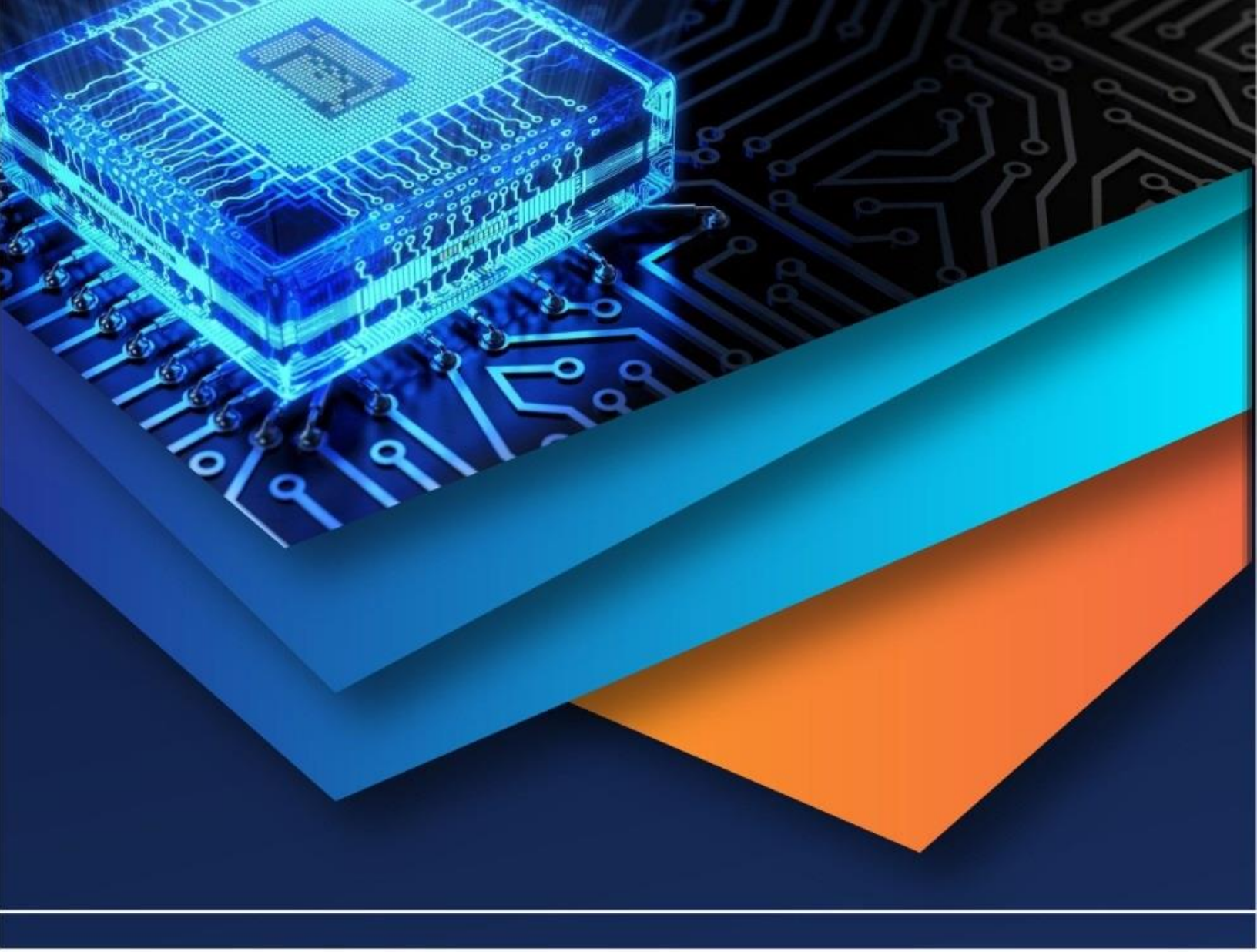

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