International Journal For Research in Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 5 Issue: X Month of publication: October 2017

DOI: http://doi.org/10.22214/ijraset.2017.10310

Recent Advancements In Stepped Solar Still & Its Performance Parameters

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Abstract: Solar distillation is a simple technique to get fresh and pure water. Different designs of solar distillation has been studied in different regions of the world. Stepped basin type solar still is an efficient design in which flat basin of conventional solar still is replaced with stepped tray basin. Different types of design, operational and climatic parameters of stepped solar still has been studied in this review paper. Stepped solar still with 5mm water depth and 120mm tray width resulted optimum design parameter. Stepped basin solar still with the combination of solar collector, hot water tank, internal and external reflector and condenser resulted higher yield which is sufficient to fullfill the small family need. The performance of stepped solar still can be highly improvedwith the use of energy storage material, additives, sponges etc. Climatic parameter like solar radiation, wind speed and ambient temperature also effect the productivity of stepped solar still. Higher wind speed decreases the temperature difference between the glass cover and basin water temperature and thus increases the productivity.
Keywords: solar still, stepped solar still, performance parameters, weir design

I. INTRODUCTION

Water is the basic necessity of every human being that lives on earth. Fresh water is available in rivers, lakes and underground water reservoirs. About 71% of the earth surface is covered with water, of which 96.5% is found in ocean, 1.7% in groundwater, 1.7% in glaciers and ice caps and 0.01% in the air as vapors and clouds. Only 2.5% of the earth water is drinkable water. Human that living on earth requires nearly 30-50 L/day of potable water for drinking and cooking purpose. But the availability of fresh water from the natural water resources is shrinking day by day due to rapid growth of population, water pollution and poor water management. Contaminated water always contains some harmful bacteria, viruses, dissolved and undisclosed materials, chemical and physical contaminants which causes serious damage to health on consumption [1-3]. There are different kind of purification methods suchas sedimentation, filtration, and distillation etc. which are used to get pure water from the contaminated water. There are also some biological(slow sand filters or biologically activecarbon), chemical (flocculation and chlorination) and electromagnetic processes (ultraviolet light) that are used for extraction of fresh water. The industrial desalination methods which involve either phase change phenomenon or semi-permeable membranes for extraction of pure water are namely, multiple effect desalination, multi stage flash desalination, thermal vapour compression, mechanical vapour compression etc. These conventional methods of producing fresh water are highly energy consuming and required heat in the form of mechanical or electrical work. Solar desalination seems to be the economical and viable techniques of purifying the saline water [4].

A. Solar still background

The first use of solar distillation comes to know by Arab alchemists in year 1551.The first solar distillation plant was set up in 1872 by Swedish Charles Wilson to supply fresh water to mining community. In this plant, wooden bays were used for basins which had bottoms blackened by logwood dye and alum. This plant produced fresh water of neraly 4.9 kg/m^2 and 23000 litres in a day and was being operated for around 40 years. After that, many solar distillation plants were developed in upcoming centuries at many places in the world [5].

B. Solar still and its types

The solar still structure consists of an absorber plate, glass cover, insulation and distillate collection trough. Glass cover is attached at top of still through which solar radiations are transmitted on absorber surface. Absorber surface is generally made of concrete/cement, steel etc. and water is placed on it at certain depth. Insulation is provided at bottom and sides of the distillation unit to prevent heat losses. A distillate trough is provided at lower side of glass cover to collect distilled water [6].The schematic view of the solar still is shown in Fig.1.

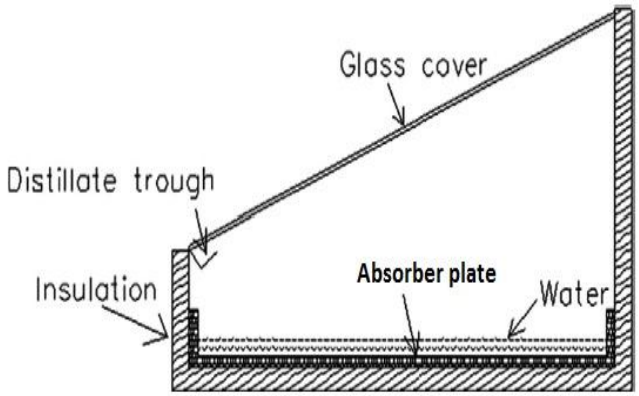

Fig.1. schematic view of Single slope solar still [6].

1) *Basin type:* The impure water is filled in an air tight basin where this water evaporates by absorbing solar radiations and condenses on glass cover as a distillate.
2) *Wick type*In this type, water is passed through a porous absorbing pad (wick) provided in the basin. This wick forms a small water depth which further improves productivity.
3) *Stepped solar still*In this type, flat basin of conventional solar still is replaced with step tray basin. These steps increase surface area of water in small space to cause more evaporation and thus increase the production rate of distilled water.Schematic view of Steeped solar still as shown in Fig 2.

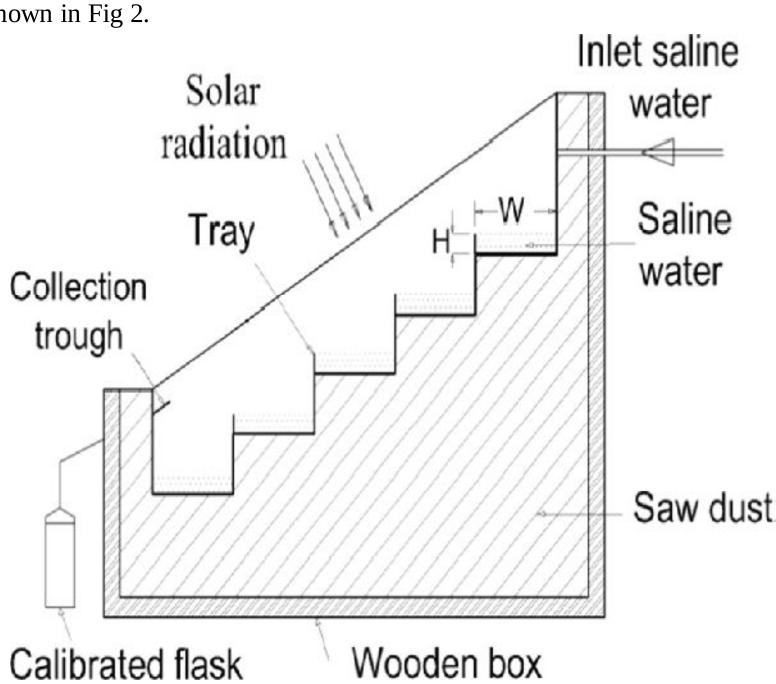

Fig.2.Schematic view of Stepped Solar Still

4) *Weir type solar still*:In this type, the barriers are provided across steps so as to distribute the water uniformly over each step ina stepped solar still.
5) *Spherical solar still:*In this type, a spherical glass cover is used as a transparent cover and a metallic absorber plate is placed at the centre. The evapoarated water condenses on glass cover and can be collected as distillate.
6) *Parameters affecting performance of stepped solar still :*The various parameters that can affect the performance of stepped solar still are shown in Fig.3.

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor:6.887
Volume 5 Issue X, October 2017- Available at www.ijraset.com

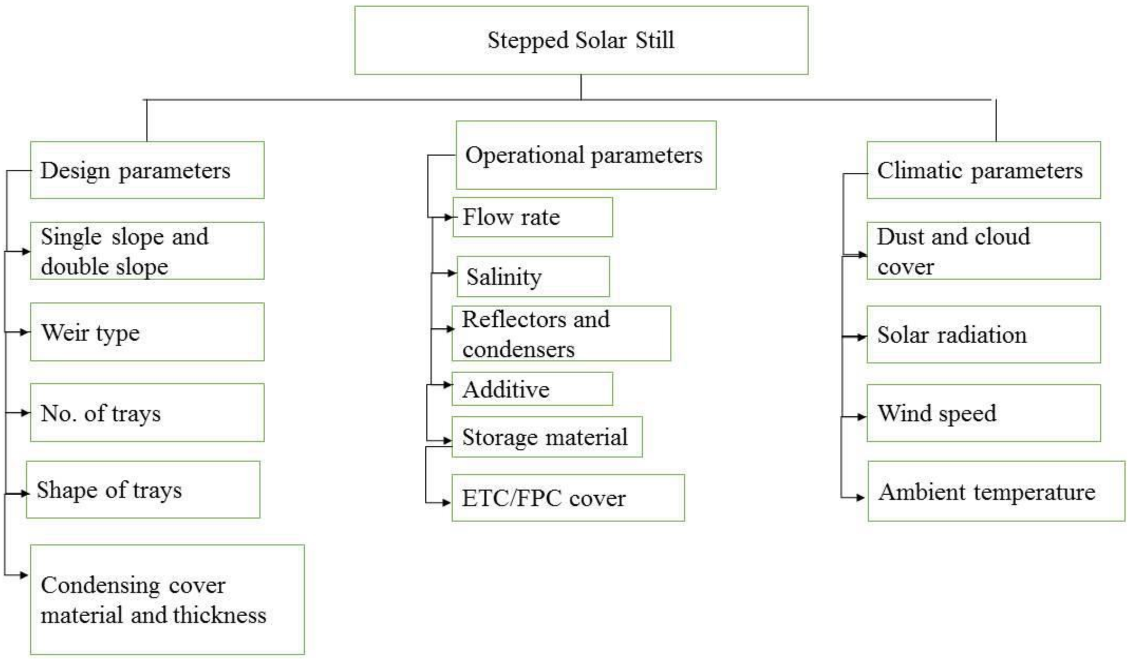

Fig.3.Parameters affecting stepped still performance

II. LITERATURE REVIEW

In this review paper different type of design, operational, and climatic parameter which affect the performance of stepped solar still are studied. In this section some important researches carried out on stepped solar still in different regions by considering various design, operational, and climatic parameters have been discussed. Stepped type solar still is studied by various researcher due to its advantage over simple solar still.

A. *Design Parameters*

1) *Studies on simple stepped solar still :*Velmurugan et al. (2009) fabricated and tested a stepped solar still for effluent desalination. Maximum increase of 98% in productivity was obtained from stepped solar still with use of fins, sponges and pebbles in basin [8]. Kabeel et al. (2012) experimentally investigatedthe effect of depth and width of stepped solar still on its performance. Maximum productivity of stepped solarstill was obtained at 5mm tray depth and width 120mm [9]. Ziabari et al. (2013) experimentally investigateddifferent odified design to improve solar still performance. During their experiment they found that the average fresh water production for the modified cascade solar still was around 6.7 litre/day/m^2, which was 26% more in comparison to the initial site's units [10]. Pillai et al. (2013) studied the effect of sealed an unsealed parameter on stepped solar still. They used a special design in which basin surface is close to the condensation surface due to this internal volume decrease and productivity increased [11]. Asadi et al. (2013)tested a pilot scale odel of stepped solar still for the treatment of domestic and industrial wastewater. The stepped solar still was concluded as an effective design for removal of organic, inorganic contaminants and harmful bacteria from waste water [12]. Kumar and Manchanda (2016) made a comparative study on stepped and weir type solar stills. The distillate output and efficiency of the weir type solar still was observed 20% and 22% higher than simple stepped solar still [13].
2) *Effect of basin shape:* and Lalit (2013) investigated the effect of shape of the absorber surface of the stepped solar still on its yield. The shapes of the absorber surfaces used in the basins ofstepped solar stills were flat, convex and concave, respectively.When the convex and concave type stepped solar stills were used, the average daily water distillate had been found to be 56.60% and 29.24% higher than that of flat type stepped solar still, respetively [14].

Alaudeen et al. (2014) studied the stepped solar still along with inclined flat plate collector as shown in Fig.4. Maximum productivity of 1468 kg/cm^2 was observed from developed still at 2 cm water depth and lowest productivity of 1150 kg/m^2 for 4 cm water depth was recorded for the modified stepped solar still [15].

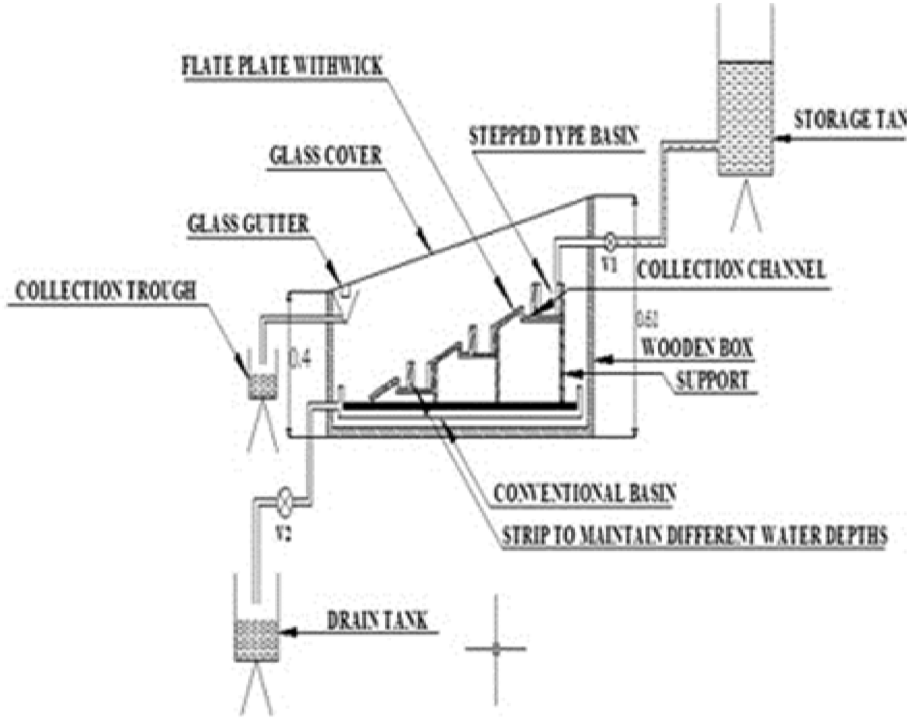

Fig.4. Sectional view of the stepped type solar still [15]

Sudhakar et al. (2015) studied single slope basin, double slope basin, hemispherical basin, and pyramidal basin with internal and external reflector. They also worked on solar water heater combine with basin and increased the efficiency of still from 17.4-45% [16].

B. Effect of different type of Operational Parameter in Stepped Solar Still

1) *Effect of external heat sources and insulation thickness:*Abdullah et al. (2013) designed a new stepped solar still coupled with a solar air heater, storage material, and glass cover cooling for improving the performance of still. The hot air through the solar heater was passed beneath the base of stepped solar still to increase its temperature. Aluminium filling was used thermal storage material under the absorber plate for keeping the temperature of water high enough to produce distilled water in absence of sun shine. The performance of the still increased by 112% as compared to conventional solar still, when still is coupled with the glass cover cooling, solar air heater and storage material performance was increased by 53% compared with conventional still [17].Chow etal.(2013) studied single phase-solar water heater and double phase solar water heater tubes. In Single phase solar water heater there are two tubes which were connected parallel to each other and inner part of these tube was coated with absorbing material. Double phase solar water heater contain condensation and evaporation both type of zones. Double phase provided more productivity than the single phase solar water heater [18].Garg and Mann (1976) investigated the effect of insulation thickness on solar still. Low cost saw dust was used as an insulation (25mm) to protect heat loss form the basin and observed an productivity improvement of nearly 7% [19]. Ghoneyem and Ileri (1997) studied effect of glass thickness on productivity of solar still and found that productivity was increased by 16.5 % when 3 mm thick glass cover was used in place of 6 mm glass cover [20].
2) *Effect of sun tracking system and wick material:* Abdallah and Badran (2008)experimental found that sun tracking system increases the overall efficiency of solar still up to 2% and productivity up to 22% [21]. Kavitiet al.(2016) modified the design of basin by using wick type of basin. The evaporation rate was faster than the simple type of solar still because wick causes increase in surface area and thus increases the productivity. The efficiency was increased up to 78% in wick basin [22].
3) *Effect of condenser, salinityand water mass flow rate*Omara et al. (2014) experimentally showed the effect of condenser and reflector on stepped solar still. Internal and external reflector was used for increasing the energy input. The stepped still showed 75% higher output than the ordinary still. The efficiency of stepped solar still with internal reflector was nearly 56% [23].El-Samadony et al. (2015) used internal and external mirror with exterior condenser on stepped solar still. Width of step still was

taken equal to step width. A suction fan fixed on top side of basin so as to collect water vapour to the condenser. Experiments showed that with the use of both mirror and condenser the glass temperature increased about 10 ^{0}C. Use of exterior condenser with mirror improved water output of stepped still by about 165% over ordinary still [24]. Tabrizi et al. (2010) studied the effect of water flow rate on daily productivity of a weir type solar still. The daily productivity was found to be 7.4 and 4.3 kg/m^2 day, for minimum and maximum flow rates respectively [25]. EL-Zahaby et al. (2011)experimentally studied the effect of stepped solar still with reciprocating spray feeding system which increases the efficiency about 77.35% [26]. El-Agouz (2014) investigated the effect of continuous water circulation using storage tank and black cotton absorber for stepped solar still. Maximum efficiency of stepped solar still was observed with black cotton absorber and at salt water circulation of 3L/min and at sea water circulation 1L/min [27].Kumar et al. (2008) studied the effect of salinity on the productivity of solar still and concluded that distillate yield will decrease with increase in salinity because evaporation rate will be less for saline water [28].

4) *Effect of phase change material and glass cover cooling:* Sakthivel et al. (2010) studied the effect of vertical jute cloth inside the basin of stepped solar still. These vertical jute cloths also act as a storage medium of energy. When the jute cloth was put at the middle of solar still it properly utilizes its latent heat of condensation.Use of vertical jute cloth increase the productivity about 20% and efficiency by 8% [29].Sivakumaret al.(2013) reviewed the various improvement techniques of solar still efficiency [30].Singh et al. (2013) proposed a model of passive solar still integrated with the evacuated tube collector in natural circulation mode and compared its results with experimental results and found good agreement [31]. Abad et al. (2013) carried out several experiments with pulsating heat pipe integrated with a solar still. Distillate output of the present still was increased by 40% by use of pulsating heat pipe compared with conventional solar still [32].Sathyamurthy et al. (2014) studied the effect of water mass and phase change material on the performance of triangular pyramid solar still. Higher productivity was obtained at lower water mass in the still. With the use of phase change material in the pyramid solar still the productivity was observed nearly 35% higher than the solar still without phase change material [33].El-Samadonyand Kabeel (2014) showed the effect of water film cooling thickness, flow rate, inlet temperature, and air wind speed on the stepped solar still to improve the output performance. The presence of the glass cover water film cooling rise the difference between the temperature of glass surface and plate surface and thus improve its output upto 8.2% [34].

C. *Effect of Climatic Parameter of Stepped Solar Still*

1) *Effect of dust, cloud cover, wind speed and solar radiation:*Velmurugan et al. (2009) tested a stepped solar still with an effluent settling tank. The effluent is purified in an effluent settling tank. In this tank, large and fine solid particles were settled and clarified. The settled effluents are used as raw water in the stepped solar still. For better performance, fin, sponge, pebble and combination of the above are used for enhancing the productivity of the stepped solar still. When fin, sponge and pebbles were used in stepped solar still its maximum productivity was increased in upto 98%[35].Muftah et al. (2014) showed that climatic parameters such as wind speed, solar radiation, and ambient temperature affect the productivity of stepped solar still. If wind speed and solar radiation were increased then productivity of solar still increased [36].Some more researches carried out on stepped solar still considering different process parameters are tabulated in table 1.

Table 1.Researches carried out on stepped solar still considering different process parameters.

S. N.	Researchers	Type of still with modification	Result/Conclusion
1.	Tabrizi et al. (2010) [37]	Weir type cascade solar still with latent heat thermal storage system (LHTSS).	Weir solar still with LHTSS gives productivity about 3.4 kg/m^2 and without LHTSS gives 2.1 kg/m^2.
2.	Mohammad and Tabrizi (2011) [38]	Weir type cascade solar still with PCM	PCM material increased the productivity in weir still about 31%.
3.	Omara et al. (2012) [39]	Modified stepped solar still with preheating the water	At 5mm water depth, 120mm width of stepped solar still gave 57.3% more productivity than conventional solar still.
4.	Awad and El- Agouz (2013) [40]	Stepped solar still with	The humidification-

		humidification and dehumidifiction	dehumidification process with the conventional solar still increases hourly productivity by about 57% and the hourly efficiency by about 47%.
5.	Zoori et al. (2013) [41]	Energy and exergy in weir type cascade solar still	In weir solar still efficiency of energy and exergy increases 83.3% and 10.5% respectively.
6.	Yadav et al.(2016) [42]	Stepped and weir type solar still	Stepped and weir type solar still increases the distillate output around 60-80%.

III. SUMMARY

Some of the important findings on stepped solar still with their performance parameter are summarized below:

A. Step-wise basin can improve the performance upto nearly 180% as compared to the conventional solar still.
B. With the use of fins, sponge and pebbles the productivity of stepped solar still can be increased upto98% than simple solar still.
C. The average daily water distillate ofconvex and concave type stepped solar stills were found to be 56.60% and 29.24% greater than that of flat type stepped solar still respectively.
D. The efficiency of stepped solar still with internal mirror was found to be nearly 56% higher than ordinary solar still.
E. Use of external condenser and mirrors improved the water output of stepped still by 165% over conventional solar still.
F. The performance of the stepped solar still was increased by 112% as compared to conventional solar still, with the glass cover cooling and solar air heater. With the use of black gravel and PCM material in double basin solar still theproductivitycan be increased by 66% in comparison to simple solar still.

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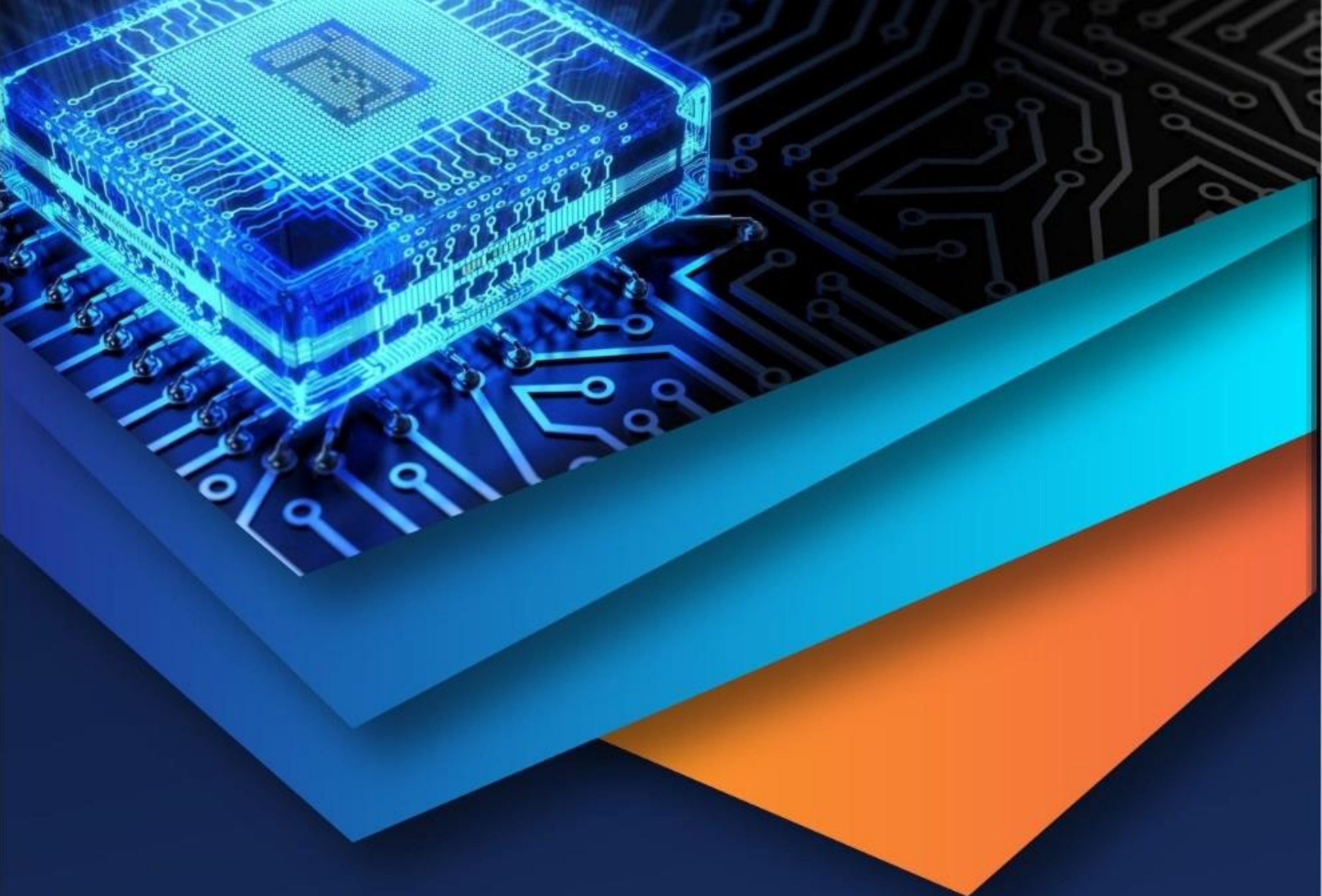

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