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Study of Efficacy of Riser and Downcomer Plates as Light Receivers: For microalgae Culture in a Vertical Flat Plate Airlift Photobioreactor

Nirpesh Dhakal[#1], Tika Bahadur Karki[#2], Sanjaya Lama[#3], Angela Shrestha[#4] and Parash Mani Timilsina[#5]

[#]*Department of Biotechnology, Kathmandu University, P.O. Box- 6250, Dhulikhel, Nepal*

Abstract— Photobioreactor are considered to have high productivity in a controlled condition for microalgae cultivation. Among different types of photobioreactor, tubular and vertical airlift systems were evaluated to be effective for scale up cultures. Further, limitation arose in scale up of tubular systems are thought to be overcome by using flat plate reactors. Vertical plate system has advantage over tubular system as they could be tilted towards light source or sun, absorbing maximum incident energy. In case of vertical flat plate airlift photobioreactor, as both of its plates (i.e. downcomer and riser plate) could be used as light receiver, it is important to identify effectiveness of these plates for outdoor culture. In our study downcomer plate was found to be better light receiver compared to riser plate as specific growth rate was increased from 0.332 ± .01 day^{-1} to 0.514 ± 0.06 day^{-1}.

Keywords— Photobioreactor, flat plate, airlift, downcomer, riser, light, microalgae.

I. INTRODUCTION

Microalgae are photosynthetic microorganism which utilizes CO_2 to produce valuable products like food, feed, biofuel, and bioactive secondary metabolites [1]. Ongoing issue of climate change and environmental degradation has also explored it's high potentiality in CO_2 sequestration and waste water treatment [2], [3]. These are considered as one of the world's fastest growing photosynthetic microorganisms, thus much focus is given towards its commercial cultivation [4].

Commercial cultivation of microalgae could be either done in an open system, such as raceway ponds, or in a closed photobioreactor. Although, open system of cultivation is considered as much simple and cost effective for commercial purpose, it has lower productivity, small surface area to volume ratio, high risk of contamination and lacks controlled environment. On other hand photobioreactor has high productivity in a controlled condition. With its large surface area to volume ratio it allows effective distribution of light and enhances the mixing of the culture. Either natural or artificial lights could be used for photosynthesis. Since, it could be operated with controlled parameters such as light, pH, temperature, dissolved oxygen, aeration, mixing, etc., it could be considered as best means for the study of culture and its productivity with respects to these variables. Fully closed and aseptic system allows more efficient mono-culture with less chance of contamination of other fast growing phytoplankton or predator organisms [5], [6].

There are several types of photobioreactor which includes stirred tank, plastic bags, tubular, column and flat plate photobioreactors. First generation photobioreactors, such as tanks and plastic bags had limitation over scalability with sharp decrease in its surface area to volume ratio [5]. Although, this ratio was maintained high in horizontal tubular types, they were reported less feasible for commercial large scale culture as they had low productivity. Further, they seem more susceptible to culture heating and photo inhibition during high light intensity period (summer). Vertical systems, such as bubble column and airlift (tubular or flat plate), were evaluated to overcome these limitations and were more scalable for large scale production [7]. With better flow pattern in airlift system, it has advantages over bubble column for effective mixing and systematic light/dark cycle. Chiu et. al. (2009) reported that specific growth rate and overall cell

concentration was higher in tubular airlift system as compared to bubble column [8]. Limitations arise during scale up of tubular airlift system and these are proportional with the increased tube height. Limitation includes long oxygen path, decreased efficiency to create turbulence, and increased mixing period, thus affecting overall control of the system. Issarapayup et. al. (2009) reported that, scaling up of cylindrical airlift photobioreactor from 3 litres to 17 litres sharply decreased growth rate for the culture of *H. pluvialis* [9]. He further compared growth rates and cell densities of 17 litres cylindrical airlift system with 17 litres and 90 litres vertical flat plate airlift system and found that cultures in 17 litres and 90 litres flat plate reactors had both higher cell densities and growth rates compared to cylindrical system. Although growth rate in 90 litres reactor was lesser than 17 litres system, it had comparative cell densities. Increased height of 17 litres cylindrical system was considered to be the reason for its lower productivity.

Vertical flat plate air lift reactors are generally designed with long breadth and short height that effectively reduces oxygen path. Aeration is maintained throughout its length through perforated sparger, thus turbulent is readily streamed throughout the reactor. Further, its height is significantly low as compared to vertical system with similar volume and surface area. Moreover, vertical plate system has advantage over tubular system as they could be tilted towards light source or sun, absorbing maximum incident energy [10].

Microalgae culture in the airlift system circulates through riser towards downcomer. In contrast to the tubular system, in vertical plate system we could consider both riser and downcomer as two different plates for light receiver. During the outdoor culture either of these plates could be faced towards the light but it is important indentify which of these plates provides higher photosynthetic efficiency. Compared to riser, downcomer has short light path, larger surface area to volume ratio and short culture retention time. Although riser has a long light path, remarkable amount of volume is occupied by the air bubble and has longer retention [9], [11]. During the study on the effect of gas holdup in irradiance, it has been reported that in a bubbled reactor irradiance is enhanced when light source is aligned normal to the vertical axis of the column [7]. Issarapayup et. al. (2009) and Mansa et. al. (2012) conducted their work using white florescence light to irradiate the culture in vertical flat plate airlift reactor but description about position of light was missing [9], [11]. Thus, this study was conducted to evaluate better plate face as light receiver. Paper discusses on the comparative culture growth and productivity due to irradiance received by the culture, upon the position of riser and downcomer plates towards the light source.

II. Materials and Methods

A. Microbial Strain and Culture Condition

Chlorella vulgaris (GOSCV) isolated from Gosainkunda lake at Rasuwa district of Nepal was used as microbial strain for our studies. Isolation was done in 2% bacteriological agar in Bold Basal Medium at Department of Biotechnology, Kathmandu University [12].

Starter cultures of *C. vulgaris* were prepared in Bold Basal Medium (BBM), as it was reported as suitable medium for most of the fresh water microalgae [13]. Scaled up cultures in a 5 litres stirred tank photobioreactor, during its log phase, was use as starter culture for 115 litres vertical flat plate airlift photobioreactor (VFLPAPBR). Culture in VFLPAPBR was studied using tap water. Reported quantities of media components were directly dissolved in the tap water, except for H_3BO_3, EDTA. Na_2-KOH, $FeSO_4.7H_20$-conc. HCL and trace metal solutions, which were dissolved in distilled H_20 using autoclave. Cultures were carried out at 25 ± 2^0C, which was the average room temperature of the laboratory.

To evaluate better plate face for light receiver *C. vulgaris* culture in VFLPAPR was studied by positioning light source was aligned normal to the vertical axis of downcomer and riser plates alternatively.

B. Photobioreactor design

A vertical flat plate airlift photobioreactor (VFLPAPR) of working volume 115 litres was designed with reference from Issarapayup et. al. (2009) and Mansa et. al. (2012) [9], [11]. Detail dimension of the reactor is given in Table I. Slight modification was made in the design to minimize associated cost. Fabrication was done by using 8 mm and 5 mm soda-lime glass for outer body and inner plate respectively. Bottom of the reactor was kept flat instead of semi-cylindrical to simplify. To minimize expansion, three glass clamps of 6.5 cm width was attached to reactor as shown in Fig. 1.Vertical plate of 50 cm height was placed along the length of the reactor with 10 cm bottom clearance. Plate was positioned to maintain area of the downcomer (A_d) to area of the riser (A_r) ratio approximately 0.4 as reported earlier [9].

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TABLE I
DETAILS OF VFPALPBR BASED UPON ITS INTERNAL DIMENSIONS

Details	Unit	Internal Dimension
Width (W)	cm	18.4
Length (L)	cm	98.4
Height (H)	cm	70
Glass thickness (T)	mm	8
Plate height (H_p)	cm	50
Plate width (W_p)	Cm	18.4
Plate thickness ($T_{p)}$	Mm	5
Working height (H_w)	Cm	65
Bottom clearance (C_b)	Cm	10
Total volume (V_t)	l	125
Working Volume (V_w)	l	115

VFPALPBR was aerated using a compressor (Rocker 420, Tarson®) with 26 l/min of volumetric flow rate. Tygothane tubing with internal diameter 0.64 cm was place at the centre of the riser, along the length of the reactor. Approximately about 0.1 mm of pores was perforated along the length of the tube with the distance between each pore of 3 cm. A thermostat and temperature controller was installed to maintain the temperature during the winter. Six 6500^0K cool day florescence light from Bajaj Electrical Limited used to irradiate the culture. A stainless stand with slot for light panel was designed to support the reactor.

C. Analytical methods

Circulation time and mixing time of VLFPAPR were measured by using 1M NaOH solution as tracer as reported by

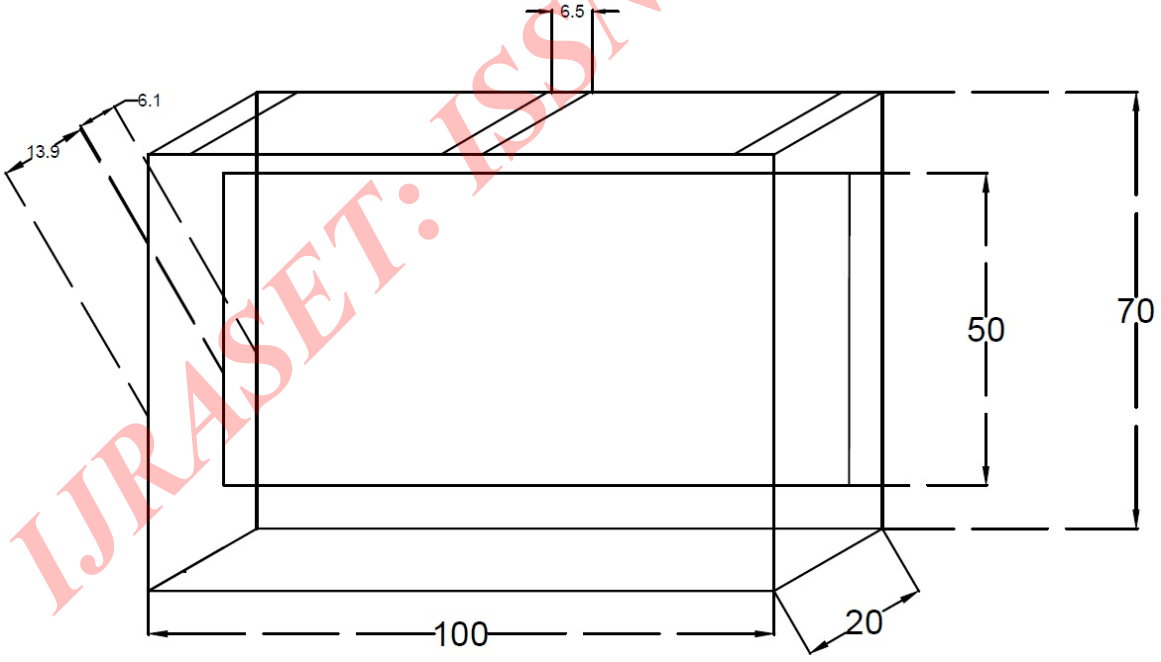

FIG. 1 SCHEMATIC DIAGRAM VFPALPBR WITH ITS DIMENSIONS IN CM.

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Chisti (1989) [14]. Tracer was added at the centre (along its length), in the downcomer side of the reactor. Time for the pH peaks were noted for the circulation time. Whereas, mixing time was determined after constant indication of pH through pH probe (AZ8601, AZ instruments) with 10% deviation from the initial and final concentration.

Illumination intensity was measured by placing the Lux meter (TES 1330A) at different position inside the empty reactor and average values were reported. Total light intensity was converted to irradiance by converting 1 Lux= 0.0141 µmols m^{-2} s^{-1} (for cool day light fluorescent tube).

Optical densities of the culture were measured on daily basis by using CT-1500 spectrophotometer (Chromtech, Taiwan) at 540 nm. Neburar heamocytometer was used to count cell density and reported as cells ml^{-1}. Standard calibration curves for cells ml^{-1} with respect to the optical density were plotted using regression method. Specific growth rate (µ) was calculated as day^{-1}, using semi-logarithmic plot, following Equation 1[15].

$$\mu = \frac{\ln(C_2) - \ln(C_1)}{t_2 - t_1} \quad \text{..... (1)}$$

Were, C_1 and C_2 are the cell concentration, cells ml^{-1}, at time t_1 & t_2. Volumetric productivity, P_v, (cells ml^{-1} day^{-1}) and areal productivity, P_a, (cells cm^{-2} day^{-1}) were calculated from Equation 2 and 3 [16]:

$$P_v = \frac{W_2 - W_1}{t_2 - t_1} \quad \text{..... (2)}$$

$$P_a = V\frac{W_2 - W_1}{t_2 - t_1} \quad \text{..... (3)}$$

Were, V is the total volume of the culture per m^2 illuminated surface area of the culture.

All the experiments were carried out in triplicate and average of all three results were reported. Standard error of mean for all culture experiments were calculated and shown in the figures.

III. RESULT AND DISCUSSION

At its working volume of 115 litres VFPALPR had a total mixing time of 56 sec with circulation of 14 sec. Average light intensity at downcomer and riser portion of the reactor was 95 µmol m^{-2} s^{-1} and 121 µmol m^{-2} s^{-1} respectively.

During the culture of *C. vulgaris* light incidence towards downcomer face was found to be more appropriate as compared to the riser plate considering their maximum cell concentration, specific growth rate and productivity. Maximum cell density of 8.13 ± 0.96 × 10^7 cells ml^{-1} were achieved on 17 days of culture on average basis, with culture time of 5-6 days on logarithmic phase. Whereas this was of only 4.4 ± 0.49 × 10^7 cells ml^{-1} on 19 days time for riser plate, with culture time of 7-8 days on logarithmic phase (Fig. 2). Culture specific growth rate was of 0.514 ± 0.06 day^{-1}, volumetric and areal productivities were of 7.2 ± 0.38 × 10^6 cells ml^{-1} day^{-1} and 1.3 ± 0.68 × 10^3 cells cm^{-2} day^{-1} respectively. Light incidence upon riser face sharply declined specific growth rate to 0.332 ± .01 day^{-1} and volumetric and areal productivities were also decreased to 2.8 ± 0.13 × 10^6 cells ml^{-1} day^{-1} and 0.5 ± 0.23 × 10^3 cells cm^{-2} day^{-1} respectively as seen in Fig. 3.

This decrease in the overall productivity of riser portion may raise the issues of light intensity, light path, bubbling in riser column and light/dark cycle. Although average light intensity at downcomer portion was higher compared to that of riser, both of these intensities of 121 µmol m^{-2} s^{-1} and 95 µmol m^{-2} s^{-1} could be considered to be above saturation level.

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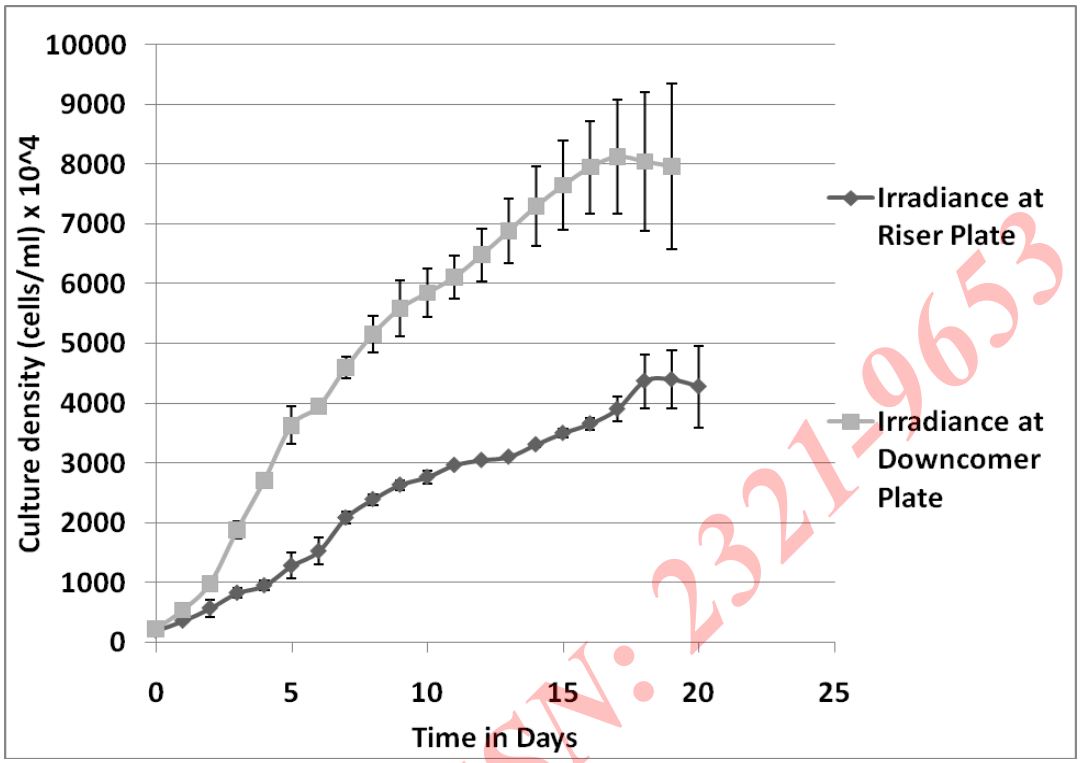

FIG. 2 GROWTH CURVE OF C. VULGARIS IN VFPALPBR DURING IRRADIANCE AT DOWNCOMER AND RISER PLATE. CULTURE CONDITION AT 25±2^{O}C TEMPERATURE AND 26 L MIN^{-1} OF VOLUMETRIC AIR FLOW RATE. AVERAGE IRRADIANCE OF 121 µMOL M^{-2} S^{-1} AND 95 µMOL M^{-2} S^{-1}AT DOWNCOMER AND RISER RESPECTIVELY.

Sorokin and Krauss (1958) reported that culture of *C. vulgaris* shown no increase in its growth over the light intensity of 300 to 350 ft-c [17]. Considering this report there could only be minimal effect on the culture output due to variation of these light intensities.

During circulation in airlift system, cell retention time varies with downcomer and riser. Due to this there arise variations in light/dark cycle depending upon the irradiated plates. As downcomer area is smaller as compared to riser, it has higher liquid velocity [18], [19]. This states that riser has comparatively longer culture retention time. During irradiance at its plate culture this is reported good as culture is exposed to light for longer period. During the culture of *Chlamydomonas reinharditi* and *Dunaliella tertiolecta* specific growth rate was decreased from 0.085 to 0.033 h^{-1} and 0.0356 to 0.154 h^{-1} respectively when the L/D cycle was changed from 10/5 sec to 5/10 sec [20]. Obtained result from our work on *C. vulgaris* contradicts with above results as µ decreased from 0.514 day^{-1} to 0.332 day^{-1} by changing irradiance from downcomer to riser.

When irradiance is considered as constant, photosynthetic efficiency (PE) is directly proportional to the productivity [21]. In VFPALPBR overall PE was higher at downcomer portion as compared to riser. Riser and downcomer portion of the reactor varies according to their dimensions of light path from outer to inner plates. Riser has long light path as compared to down comer. Richmond and Wu, (2001) and Qiang et. al. (2014) during their study on the *Nanochloropsis* sp. and *Spirullina* sp. cultures respectively, reported that increasing light path has adverse effect on overall culture productivity. Internal irradiance of the culture decreases as length increases due to mutual shading among the cells, which

also effects the light/dark cycle [10], [16]. From both of these reports, analysis could be made that decreasing trend in productivity decreases from light path approximately above 5 cm. Whereas, light path was greater than 6 cm for both the portion of VFPALPBR, thus effect due to light path could be comparatively less for above result. Moreover, it would be more appropriate to consider light path as 20 cm which includes total width of the reactor. Almost all of the fabricated materials which come in contact with light are made up of transparent glass with negligible shading from inner plate.

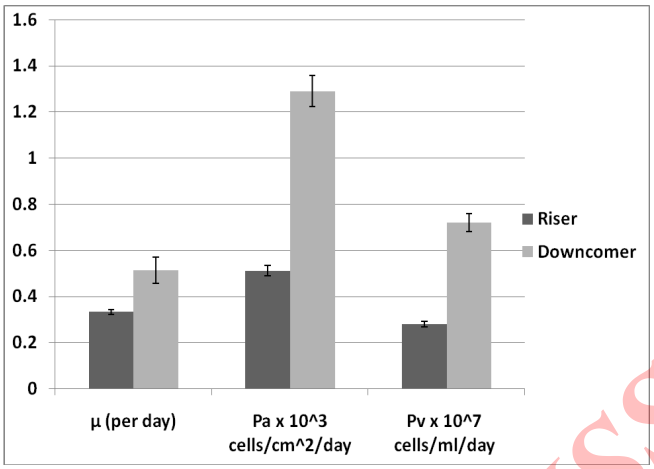

FIG. 3 SPECIFIC GROWTH RATE (μ DAY^{-1}), AREAL PRODUCTIVITY (P_A × 103 CELLS CM^{-2} DAY^{-1}) AND VOLUMETRIC PRODUCTIVITY (P_V × 107 CELLS ML^{-1} DAY^{-1}) OF C. VULGARIS DURING IRRADIANCE AT RISER AND DOWNCOMER PLATES RESPECTIVELY. (DERIVED FROM FIG. 2)

At riser aeration takes place with considerable amount of liquid volume occupied by air bubble. It was reported by Mirón et. al. (1999) that air bubble plays vital role in reflection of light [7]. When the source is normal to vertical axis of the plates, presence of air bubbles increases internal irradiance of the culture. According to this report, at superficial air velocity and gas hold up (ε) of 0.051 m s^{-1} and 0.10 respectively, difference of internal irradiance varies between aerated and non-aerated reactor by about 30-35%. Along with reflection there is also shading effect as these ellipsoidal bubble shades the area behind it. Since perforated tube runs from the centre of the riser with distance of riser and downcomer plates from the bubble source was around 7.35 and 12.65 cm. Further, it was seen our work that bubble convexes towards the riser plate to the top of the reactor due to high velocity movement of liquid from the downcomer. Thus there occurs very less available volume, within the distance from the bubble path to the riser plate. Considering riser as light receiver, very large volume of culture behind the bubble path to the downcomer (more than 65% of total volume) is thought to be shaded as described by later work. There may also occurs a high intensity of irradiance loss as light being reflected either back towards the plate or, above or below the vertical axis of the bubble [7]. On other hand, due to the internal reflection, irradiance at the downcomer plate could be provided with large surface area for illumination with minimal loss of the incident light. Thus, possible reason for our result could be the decrease or loss of total irradiance at the riser plate, thus providing the less output as compared to downcomer as light receiver.

IV. Conclusion

From above result and discussion we could derive a conclusion that downcomer plate could be more suitable as light receiver as compared to riser. Along with shading through the bubble as major factor, light path and average light intensity could also provide some impact for decrease in PE at riser plate. Further study is recommended in VFPALPBR to analyse the effect of light and its direction in the algal culture in presence and absence air bubbles.

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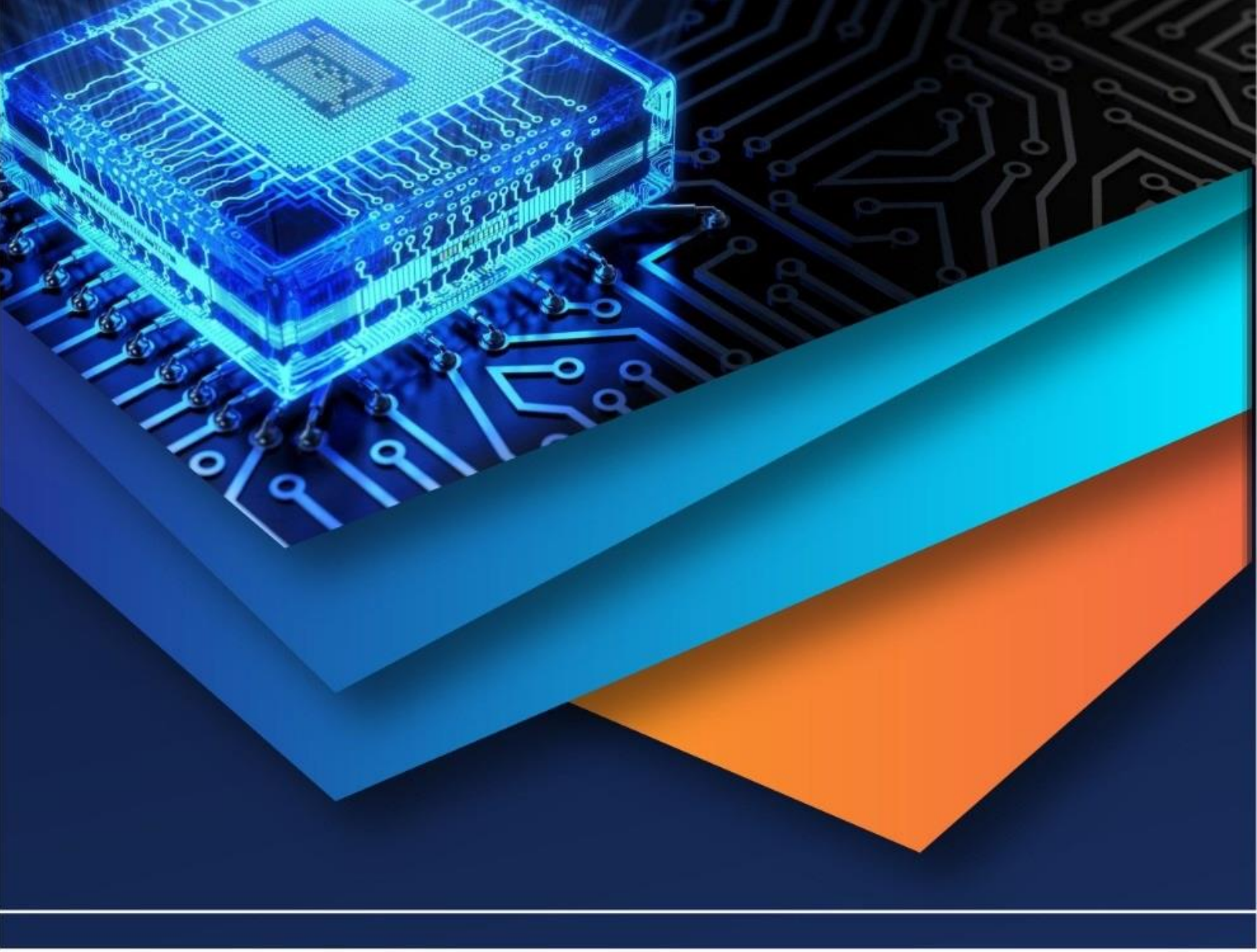

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