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Review on Comparative Study between Straight Tube Heat Exchanger and Helical Coil Heat Exchanger

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Abstract: The main purpose of this study is to determine the relative advantage of using a helically coiled heat exchanger over a straight tube heat exchanger. It is found that the heat transfer in helical circular tubes is higher as compared to Straight tube due to their geometrical shape. Helical coils offer advantages over straight tubes due to their compactness and increased heat transfer coefficient. The increased heat transfer coefficients are a consequence of the curvature of the coil, which induces centrifugal forces to act on the moving fluid, resulting in the development of secondary flow. The curvature of the coil governs the centrifugal force while the pitch (or helix angle) influences the torsion to which the fluid is subjected to. The difference in velocity sets-in secondary flows. The fluid particles flowing at the core of the pipe have higher velocities than those flowing near to the pipe wall. Thus the fluid particles flowing close to the tube wall experience a lower centrifugal force than the fluid particles flowing in the tube core. This causes the fluid from the core region to be pushed towards the outer wall. This additional convective transport increases heat transfer and the pressure drop when compared to that in a straight tube.
Keywords: Helical coil heat exchanger, heat transfer, secondary flow, straight tube heat exchanger,

I. INTRODUCTION

Several techniques are being used to increase the thermal performance of the heat exchanger. Active techniques, passive techniques and compound techniques are used for enhancing the heat transfer. The active techniques require external forces like fluid vibration. The passive techniques require special surface geometries. The compound technique is the combination of any two or more methods of used for improving the performance of heat exchanger. Helical coiled tubes are superior to straight tube due to their compactness and increased heat transfer coefficients. Flow in curved tube is different from the flow in straight tube because of the presence of the centrifugal forces. It induces the secondary flow in liquid. The intensity of secondary flow developed in the tube is the function of tube diameter (d) and coil diameter (D). Due to enhanced heat transfer in helical coiled configuration the study of flow and heat transfer characteristics in the curved tube is of prime importance. The secondary fluid flow of helical tubes was first studied by Dean with toroidal system. Based on the perturbation method, Germano solved the fluid flow equations of a helical duct with elliptical cross section. This secondary flow pattern generally consists of two vortices, which move fluid from the inner wall of the tube across the center of the tube to the outer wall. Upon reaching the outer wall it travels back to the inner wall. The secondary flow increases heat transfer rates as it moves fluid across the temperature gradient. Thus, there is an additional convective heat transfer mechanism, perpendicular to the axial flow, which does not exist in straight tube heat exchangers The amount of heat transferred depends upon various factors like type of fluid flow, area of heat transfer, thermal conductivity of the separating wall etc. There are three primary classifications of heat exchangers according to their flow arrangement. Parallel flow heat exchangers, Counter-flow heat exchangers, Cross-current or cross-flow heat exchangers. Helical coil heat exchangers are of great use in industrial applications such as power generation, nuclear industry, process plants, heat recovery systems, refrigeration, food industry, etc due to its compact structure and high heat transfer coefficient. They are widely used in chemical and petrochemical plants, refineries and sewage treatment.

II. LITERATURE REVIEW

The following research papers are studied in detail and the abstract of the work is presented here:
The intensity of secondary flow developed in the tube is the function of tube diameter (d) and coil diameter (D) as presented by Dravid et al [1]. Due to enhanced heat transfer in helical coiled configuration the study of flow and heat transfer characteristics in the curved tube is of prime importance. Developing fluid-to-fluid helical heat exchangers (fluid is present on both sides of the tube

wall) requires a firm understanding of the heat transfer mechanism on both sides of the tube wall. Though much investigation has been performed on heat transfer coefficients inside coiled tubes, little work has been reported on the outside heat transfer coefficients. The result shows that the increasing of the coiled tube pitch decreases the inside Nusselt Number. He also studied that helical coil have compact size and higher heat transfer coefficient they are widely used in industrial applications such as food preservation, refrigeration, process plant, power generation etc.

Timothy J. Rennie, Vijaya G.S. Raghavan [2]Have done An experimental study of a double-pipe helical heat exchanger. Two heat exchanger sizes and both parallel flow and counter flow configurations were tested. Flow rates in the inner tube and in the annulus were varied and temperature data recorded. An attempt has been made to study the parallel flow and counter flow of inner higher temperature fluid flow and lower temperature fluid flow, which are separated by copper surface in a helical coil heat exchanger. Helical geometry allows the effective handling at higher temperatures and extreme temperature differentials without any highly induced stress or expansion of joints. This type of heat exchanger consists of series of stacked helical coiled tubes and the tube ends are connected by manifolds, which also acts as fluid entry and exit locations. In this paper, we focus on design parameters and heat transfer conditions of a vaporizer or generator of a simple vapor absorption refrigeration system having flow condition of refrigerant taken as laminar flow,

The research was done by Kondhalkar and Kapatkat [3] on performance analysis of spiral tube heat exchanger used in oil extraction system . They discussed about the effective use of spiral tube heat exchanger in oil extraction process. They carried out research on the performance analysis of spiral tube heat exchanger over the shell and tube type heat exchanger. They studied the Performance of spiral tube heat exchanger and shell and tube heat exchanger for sugandhmantri oil emulsion. They found that the relation between mass flow rate and effectiveness and found out that for the same mass flow rate effectiveness increases for the spiral tube heat exchanger. Also it was observed that the heat transfer coefficient increased with increase in Reynolds number. Also they investigated the relation between Reynolds numbers and Nusselt number and concluded that Nusselt number increases with increase in Reynolds number. .

Zhengguo Zhang [4] et al.were made attempts to investigate the heat transfer characteristics of a helically baffled heat exchanger combined with one three-dimensional finned tube. For the counter mode operation, experiments were carried out and overall heat transfer coefficient determined using modified Wilson plot. The agreement with the numerical and experimental predictions of Nusselt number and pressure drop values were well within 6.3% for Nusselt number and 9.8% for pressure drop in the shell side respectively. Shinde D. &Dange M.[5] experimental investigation of heat transfer in cone shaped helical coil heat exchanger is reported for various Reynolds number. The purpose of this article is to compare the heat transfer in cone shaped helical coil and simple helical coil. The pitch, height and length of both the coils are kept same for comparative analysis. The calculations have been performed for the steady state condition and experiments were conducted for different flow rates in laminar and turbulent flow regime. The coil side flow rate is kept varying while the coil side flow rate is kept constant. It was observed that the effectiveness of the heat exchanger for the cone shaped helical coil is more than that for the simple helical coil. Results show that the heat transfer rates for the cone shaped helical coil are comparatively higher than that of the simple helical coil. It was found that the heat transfer rates are 1.18 to 1.38 times more for the cone shaped helical coil than that of simple helical coil. Bibin Prasad et al. [**6**] helical pipes are universally used for heat transfer enhancement in heat exchangers. In the present work, CFD simulations are carried out for a counter flow double pipe helical heat exchanger byvarying the flow rates of a single fluid (water). The heat transfer characteristics of the same are compared withthat of a counter flow double pipe straight tube heat exchanger for the same flow rates. The results were interpreted by developing correlations between Nusselt number and Dean Number for both the inner and outer helical pipes which shows a strong linear relationship.

A. Parameters to be taken into consideration for calculation of performance assessment of heat exchanger:

1) For the turbulent flow region ($Re \geq 10^4$),

$Nu = Re^{0.8} Pr^{1/3} (\mu/\mu_w)^{0.14}$

Where,

Nu = Nusselt Number = hd/k	D_0,Di =Outside and Inside diameter of the pipe
Re = Reynold's Number = DVρ/μ	V = average fluid velocity.
Pr = Prandtl Number = cpμ/k	Cp,μ,ρ,k = Fluid properties at avg. bulk temperature.

It is observed that Nuincreases with increase in Re. This shows that the secondary's developed in the fluid flow goes on increasing, as *Re* increases, which increases the turbulence in the fluid flow. The increase in turbulence allows proper mixing of the fluid, which enhances the *Nu.* And all the remaining parameters indirectly depend on Reynold's number and Nusselt number.

2) Overall heat transfer coefficient: (U)

$U= Q/A_0\Delta T$

$A_0=\pi D_0 L$

3) The fouling factor for the exchanger is given as:

$R_D= R_{Di}(Do/Di)+ R_{Do}$

Fouling could considerably impact on the thermal and mechanical performance of heat exchangers. It also impedes fluid flow, accelerates corrosion and will increase pressure drop across heat exchangers. Helical geometry provides low fouling characteristics which increases the schedule cleaning period of tube bundle.

4) Capacity Ratio

$$C_R = \frac{(\dot{m}c_p)_{min}}{(\dot{m}c_p)_{max}}$$

5) Number Of Transfer Units(NTU):

$$NTU = \frac{UA}{(\dot{m}c_p)_{min}}$$

It is a dimensionless quantity and it is an indicator of size of heat transferring areas of heat exchanger. Large value of NTU means large heat transferring area.

6) LMTD-Log mean temperature difference:

$LMTD= (dT_A – dT_B)/\ln(dT_A/dT_B)$

$dT_A= T_{hot\ in} – T_{cold\ out}$

$dT_B=T_{hot\ out} – T_{cold\ in}$

For constant heat and mass transfer,

$LMTD_{shell\ and\ tube} > LMTD_{counterflow} > LMTD_{cross\ flow} > LMTD_{parallel\ flow}$

7) Friction factor

$f = 64/R_e$ ....(For laminar flow)

$f= 0.4137\ R_e^{-0.2385}$.............(For turbulent flow)

This friction factor, f is a dimensionless factor that depends mainly on velocity v, diameter D, density and viscosity.

8) Effectiveness

€ = Q/Q_{max}

Q = Actual heat transfer rate

Q_{max}=Maximum possible heat transfer rate

B. Straight Tube Heat Exchanger

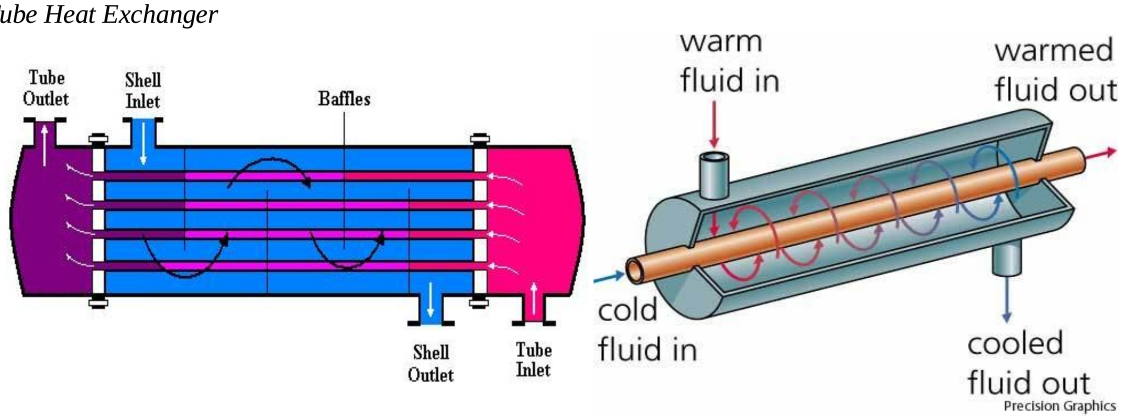

Fig 1.1 Simple shell and straight tube heat exchanger

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Shell-and-tube exchangers are classified and constructed in accordance with the widely used TEMA (Tubular Exchanger Manufacturers Association). When the medium containing heat is a liquid or a vapour which heats another liquid, then the shell and tube heat exchanger must be used since both paths must be sealed to contain the pressures of their respective fluid. The shell contains the tube bundle, and usually internal baffles, to direct the fluid in the shell over the tubes in multiple passes. The shell is inherently weaker than the tubes so that the higher-pressure fluid is circulated in the tubes while the lower pressure fluid flows through the shell. Tube and shell heat exchangers are available in a wide range of standard sizes with many
combinations of materials for the tubes and shells. Heat transfer in straight tubes is governed by Reynolds and Prandtl Numbers, under both laminar and turbulent flow conditions, and is usually presented in a form such as:

$N_{nu} = c\ N\ Re^{a} N_{pr}^{\ b}$ ....(1)

Where, N_{Nu} is the Nusselt number, with the a, b, and c being constants, Re is the Reynolds number, pr is prandtl number. Heat transfer rate of shell and tube heat exchanger depends on some of following parameters such as length of tube, number of baffles, baffle cut. Generally the shell and heat type heat exchanger are widely used for various purposes having limitation to be designed for maximum up to 15000 psi and 1000 ^{0}F.

There are few disadvantages concerned with shell and tube heat exchangers are: 1)Fixed tube sheet type exchanger having cleaning issues as well as can be used for low temperature difference as there is no provision for the thermal expansion of the same. 2)Shell and tube heat exchanger are Subject to flow induced vibration which can lead to equipment failure. Subject to flow mal-distribution especially with two phase inlet streams.

They can be designed for special operating conditions: vibration, heavy fouling, highly viscous fluids, erosion, corrosion.

C. Helical Coil Heat Exchanger

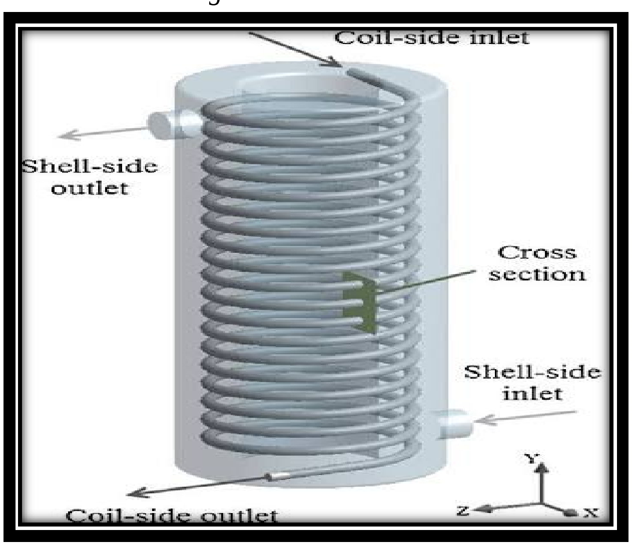

Fig. 2.1 helical coil heat exchanger

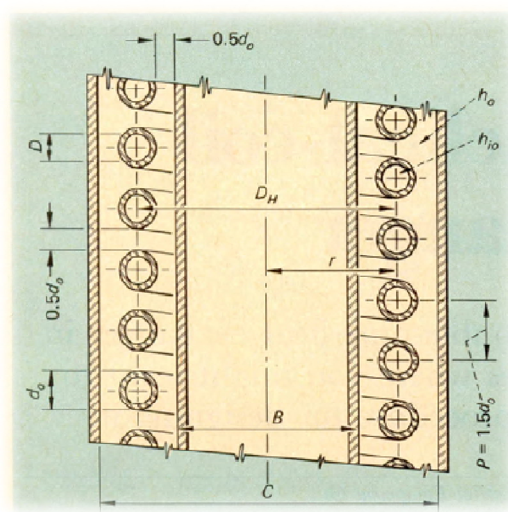

Fig. 2.2 Cut section of helical coil

Helically coiled exchangers have compact size provides a distinct benefit. Helical geometry permits handling of high temperatures and extreme temperature differentials without high induced stresses or costly expansion joints. High-pressure capability and the ability to fully clean the service fluid flow area add to the exchanger's advantages, Although various configurations of coil are available. A typical shell and coiled tube heat exchanger is shown in Fig.2.1. In coiled tubes, the heat transfer coefficients are higher due to the presence of secondary flow, which increases the extent of mixing. The difference between the heat transfer coefficient (h) in coiled tubes and straight tubes is significant.

$$NNuc = NNus\ [1+ 3.5\ (r / R)] \ .... (2)$$

Heat transfer rate of helical coil heat exchanger depends on some of following parameters such as coil pitch, Pitch circle diameter, pipe diameter.

D. Comparison Between Straight Tube Heat Exchanger And Helical Coil Heat Exchanger

Variation of overall heat transfer coefficient for straight tube parallel flow, straight tube counter flow, helical coil parallel flow and helical coil counter flow, when hot water mass flow rate is constant and cold water mass flow rate varied. As the mass flow rate through the shell increases the overall heat transfer coefficient increases, and it is observed that hot mass flow rate inside tube increases the overall heat transfer coefficient also increases. Overall heat transfer coefficient of counter flow heat exchanger is high compared to corresponding exchanger parallel flow. Helical coil counter flow has max. Overall heat transfer coefficient and straight tube parallel flow has lowest overall heat transfer coefficient.

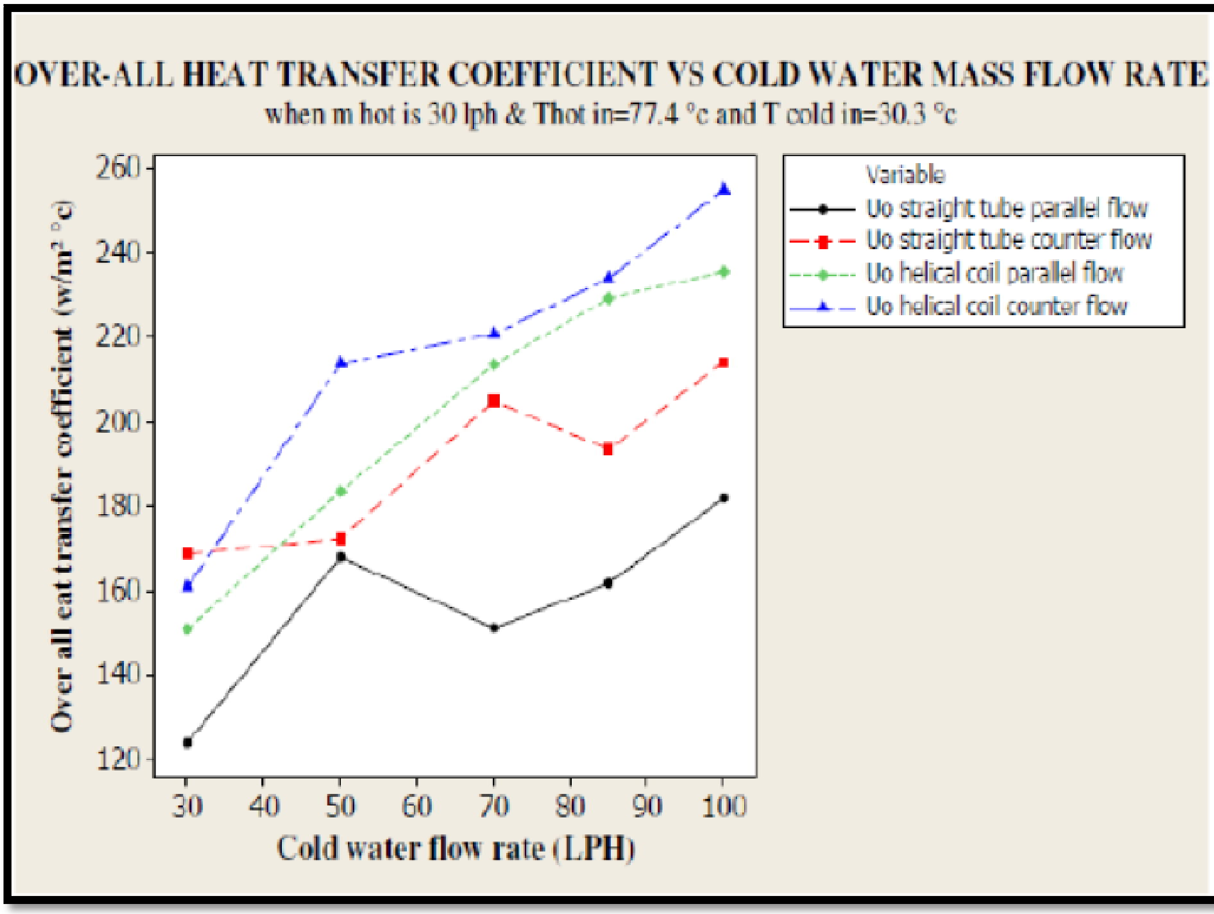

Fig. variation of overall heat transfer coefficient when mass flow rate inside the tube is 30 LPH

Overall heat transfer coefficient (U) in the helical heat exchanger is much higher than that in straight tubular heat exchangers. For all values of Reynolds numbers, the overall heat transfer coefficient in the helical coils was larger than that in the straight tubes. The overall heat transfer coefficient (U) in the helical heat exchanger increased with flow rate and approached a maximum value at higher flow rates.

III. CONCLUSION

From study it is clear that, Helical coil counter flow is most effective in all these conditions and straight tube parallel flow heat exchanger is least effective. There is some gap between results we are getting from current heat exchangers and results we should get. This gap can be bridged by making use of helical coil heat exchangers with some design modifications for betterment of the results. Overall heat transfer coefficient increases with increase in hot water mass flow rate and cold water mass flow rate. The torsional forces induced by the pitch causes oscillations in the Nusselt number. However, the average Nusselt number is not affected by the coil pitch. Unlike the flow through a straight pipe, the centrifugal force caused due to the curvature of the pipe causes heavier fluid (water-phase) to flow along the outer side of the pipe. High velocity and high temperature are also observed along the outer side.As the pitch is increased, higher velocity and higher temperature regions are on the bottom half of the pipe. Increase in pipe diameter, keeping the inlet velocity constant, causes higher heat transfer coefficient and lower pressure drop. This effect is due to the influence of secondary flows. By making use of helical geometry the centrifugal force and shear stress can be increased to reduce the fouling effect. For a particular mass flow rate, helical tube heat exchanger provides an increase in heat transfer coefficient by 10%. Heat exchangers used now a days have certain disadvantages such as less effectiveness, less heat transfer coefficient. These demerits can be over comed by using multi pass helical coil heat exchangers.

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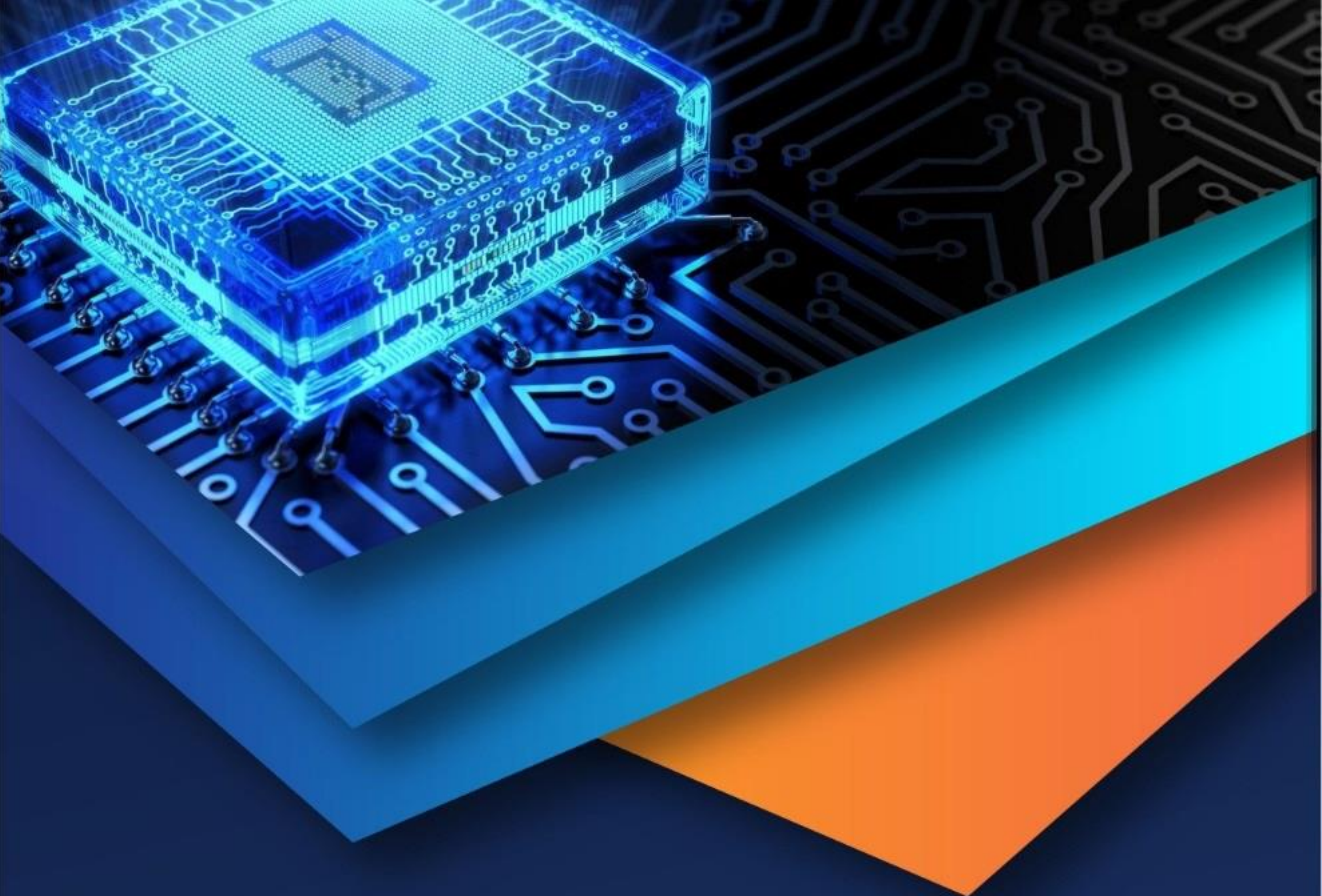

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