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A Numerical Study of the Effect of Rectangular Shaped Ribs Organized in Different Patterns on the Thermal Performance of a Solar Air Heater

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Abstracts: A solar air heater is a useful device that can be used to raise the temperature of a roomby capturing heat from solar energy This paper is about a two-dimensional numerical study that was done to predict the influence of transverse rectangular cross-sectioned ribs on the convective heat transfer properties of a solar air heater. It is a rectangular duct with an absorber plate on top, and heat only falls on the top of the absorber plate. The thermal performance of air flowing through the rectangular duct is significantly altered when different shapes and orientations of ribs/baffles are introduced just beneath the absorber plate.

A comparison was made between the results of thin (high aspect ratio) and square ribs arranged in three patterns, namely, single wall arrangement ,staggered arrangement and in-line arrangement on two opposite walls. The Nusselt number variation with Reynolds number range 4000-25000 was checked at a fixed rib pitch (p) and height (e) values. Computational fluid dynamics (CFD) simulations were performed using commercially available software ANSYS FLUENT v15.0..The results revealed that the thin ribs yielded better performance than the squared ones. Out of the three arrangements, the best thermal performance was given by thin inline ribs whose convective heat transfer coefficient was 1.93 times smooth duct's convective heat transfer coefficient.

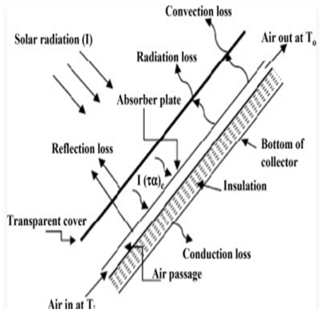
Keyword: Solar, Energy, CFD, Convective, Heater, Reynolds, Nusselt Number

I. INTRODUCTION

Energy and water are the keys to modern life and provide the basis necessary for sustained economic development. Industrialized societies have become increasingly dependent on fossil fuels for myriad uses. Modern conveniences, mechanized agriculture, and global population growth have only been made possible through the exploitation of inexpensive fossil fuels. Securing sustainable and future energy supplies will be the greatest challenge faced by all societies in this century. Due to a growing world population and increasing modernization, global energy demand is projected to more than double during the first half of the twenty-first century and to more than triple by the end of the century. Presently, the world's population is nearly 7 billion, and projections are for a global population approaching 10 billion by midcentury. Future energy demands can only be met by introducing an increasing percentage of alternative fuels. Incremental improvements in existing energy networks will be inadequate to meet this growing energy demand. Due to dwindling reserves and ever-growing concerns over the impact of burning carbon fuels on global climate change, fossil fuel sources cannot be exploited as in the past. Finding sufficient supplies of clean and sustainable energy for the future is the global society's most daunting challenge for the twenty-first century. The future will be a mix of energy technologies with renewable sources such as solar, wind, and biomass playing an increasingly important role in the new global energy economy. The key question is: how long it will take for this sustainable energy changeover to occur? And how much environmental, political, and economic damage is acceptable in the meantime? Solar energy is unique in that it can easily provide electricity and purified water for these people today with minimal infrastructure requirements by using local energy resources that promote local economic development.

Solar air heater is one of the basic equipment through which solar energy is converted into thermal energy. Solar air heaters, because of their simple designing, are cheap and most widely used as a collection devices of solar energy. The main applications of solar air heater are space heating, seasoning of timber, curing of industrial products and these can also be effectively used for curing/drying of concrete/clay building components. A conventional solar air heater generally consists of an absorber plate, a rear plate, insulation below the rear plate, transparent cover on the exposed side, and the air flows between the absorbing plate and rear plate.

A solar air heater is simple in design and requires little maintenance. However, the value of the heat transfer coefficient between the absorber plate and air is low and this result in lower efficiency. For this reason, the surfaces are sometime roughened in the air flow passage.



II. NUMERICAL SETUP

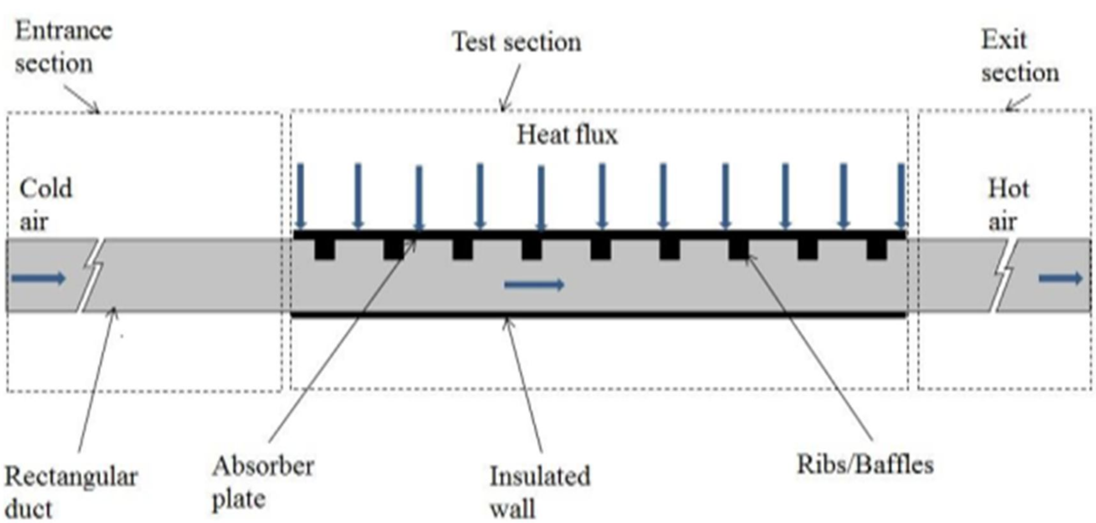
The present work is concerned with carrying out two-dimensional simulations on an artificially roughened solar air heater, through which air of air flows. The air heater internal surface was roughened with the help of transverse-square and thin (high aspect ratio) ribs. The ribs were arranged in different patterns namely one wall only, staggered and in-line on both lower and upper faces.

Computational fluid dynamics (CFD) provide a path of real predicting the behavior of a real fluid without having to perform any experiment and change in the problem setup are easily made. CFD simulation is created in some step such as

1) Geometry modeling
2) Meshing consideration
3) Boundary condition
4) Numerical calculation and Governing equation
5) Result and discussion

A. Geometry Modeling

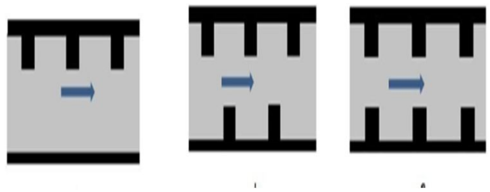
A rectangular section was considered. It consisted of three sections, test section of length L2, entrance section of length L1 and exit length of length L3. The domain on which numerical simulations were performed was two-dimensional. Their rectangular duct was of length 2000 mm, width 300 mm and 30 mm with a test section length of 440 mm. Hence our domain test section length was 440 mm and its entrance and exit length dimensions were selected on the basis of ASHRAE recommendations, according to which an exit length more than 2.5√WH and entrance length more that5√WH.



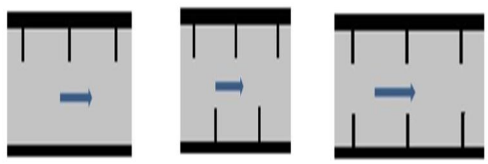
ANSYS Geometry of test section

B. Shows the Geometry of the Computational Domain

The different rib arrangements employed for simulation are indicated



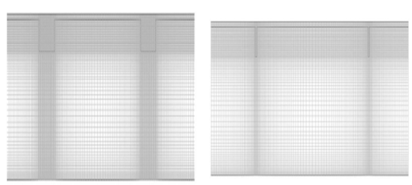
(A) Single square ribs (B) Staggered square ribs (C)In-line square ribs



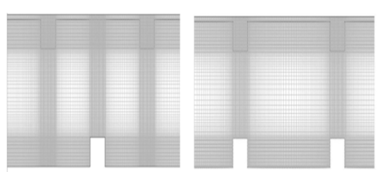
(D) Single thin ribs (E) Staggered thin rib (F)In line thin ribs

C. Meshing Consideration

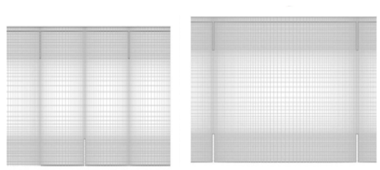
The result of numerical analyses depend upon the meshing of the model that is used. A too coarse mesh will give a higher error in the result and finer mesh size give low error in the final result. A fine mesh is require where the flow is changing rapidly, while a coarser mesh can be used where flow is uniform and less accuracy is needed . If size of mesh element is small enough so that numerical result is nearest to the experimental result



(A) Single square ribs (B) Single thin ribs



(C) Staggered square ribs (D) In-line square ribs



(E) Staggered thin ribs(F) In-line thin ribs

Details of two-dimensional meshing of (A) single square ribs, (B) single thin ribs,
(C) staggered square ribs, (D) in-line square ribs, (E) staggered thin ribs and (F) in-line thin ribs

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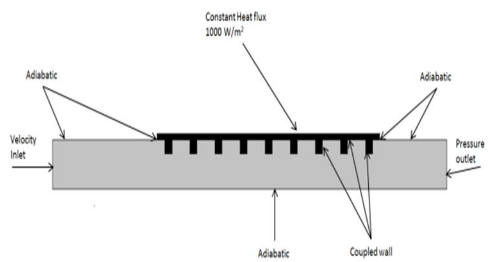
D. Boundary Condition

Operating and Geometrical parameters used for CFD analysis

Test length of duct,	L2 440 mm
Entrance length of duct	L1 500 mm
Exit length of duct	L3 240 mm
Duct height, H	30 mm
Duct width, W	300 mm
Duct hydraulic diameter, Dh	54.54 mm
Aspect ratio of duct,W/H	10
Constant heat flux	, q" 1000 W/m2
Range of Reynolds number	5000-23000



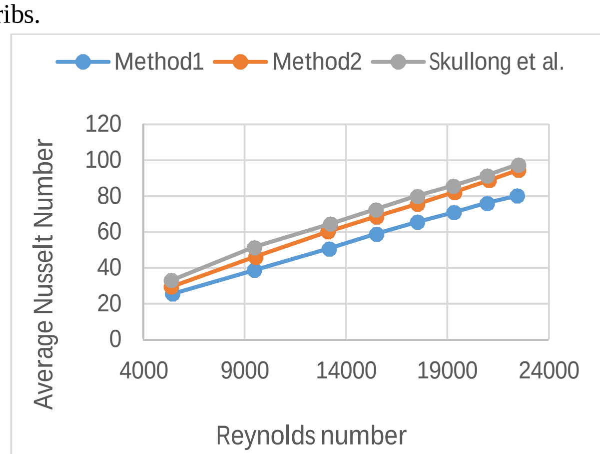
Different boundary conditions assigned to edges of computational domain

III. RESULTS AND DISCUSSIONS

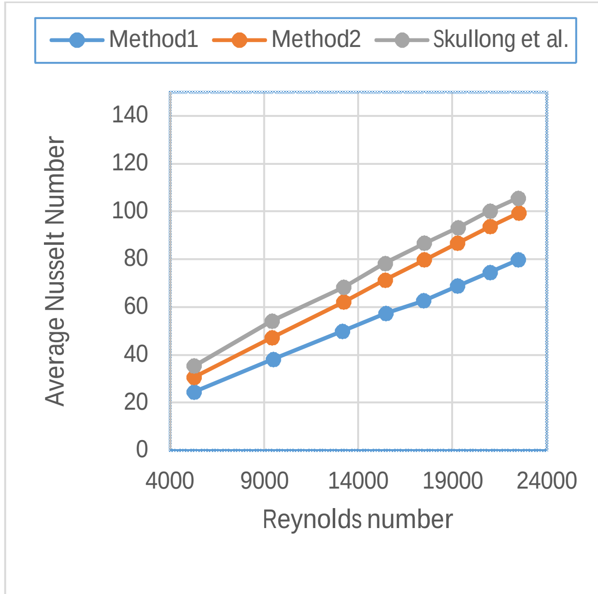
In this project, a computational model was constructed to measure a solar air heater's thermal performance. It consisted of baffles/ribs just below its absorber plate.

A. Simulation For Different Roughened Ducts At Different Reynolds Number

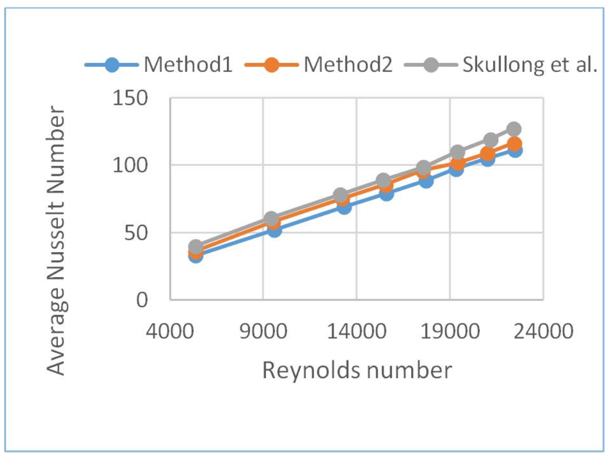
The average convective Nusselt number was measured using two methods. The first method (method-1) is given by equation 3.7 and takes the average of all 32 the local Nusselt numbers along the test section length. The second method (method-2) used Eq. 3.8 and it is the most widely employed method of calculating Nusselt number in experimental works. The second method was used by Skullonget . Fig. clearly depicts the outcome of average Nusselt number alteration with Re for the geometries separately. As Re was raised, the average Nusselt number increased for all cases. The reason why this trend was observed was that as the Re was raised, the flow became more turbulent (more dominance of inertial effects over viscous effects) and hence the heat transfer rate increased. There was a decent agreement when numerical outputs were compared with the experimental ones existing in the literature. Excellent matching between Nusselt numbers calculated using method 2 and the existing ones was observed for square ribs but good agreement was found in case of thin ribs.



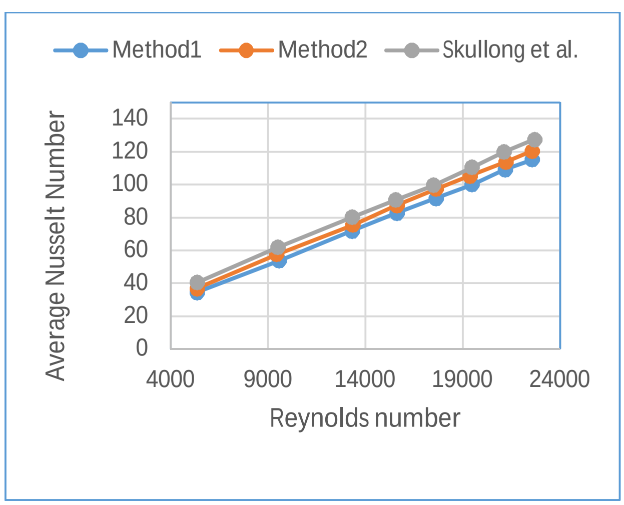
Results of numerical analysis at different Reynolds number for single square ribs



Results of numerical analysis at different Reynolds number for single thin ribs



Results of numerical analysis at different Reynolds number for staggered square ribs



Results of numerical analysis at different Reynolds number for In-line square ribs

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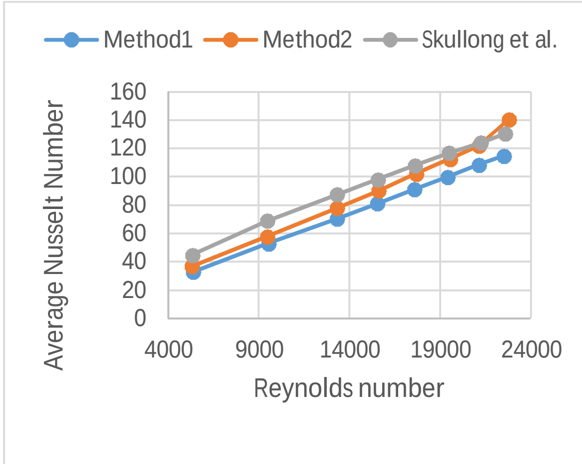
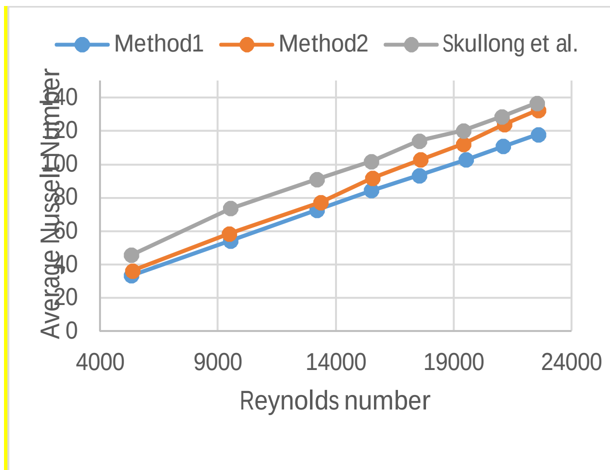


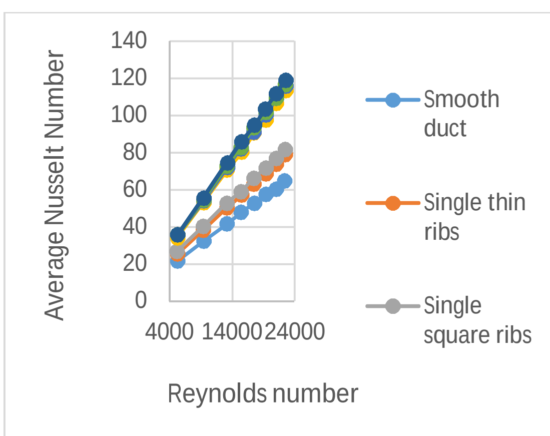
Results of numerical analysis at different Reynolds number for staggered thin ribs



Results of numerical analysis at different Reynolds number for Inline thin ribs

B. *Comparison of Nusselt number variation with Reynolds number for all the Geometries*

Gaphically outlines a comparison between Nusselt number and Reynolds number for all the geometries. It can be inferred from the graph that there was a considerable augmentation in Nusselt number for both thin as well as square ribs. Interestingly, thin ribs gave much better thermal performance than their square counterparts. In-line gave the highest Nusselt number for the complete Reynolds number range used in this simulation.



Variation of Nu with Re for all the cases

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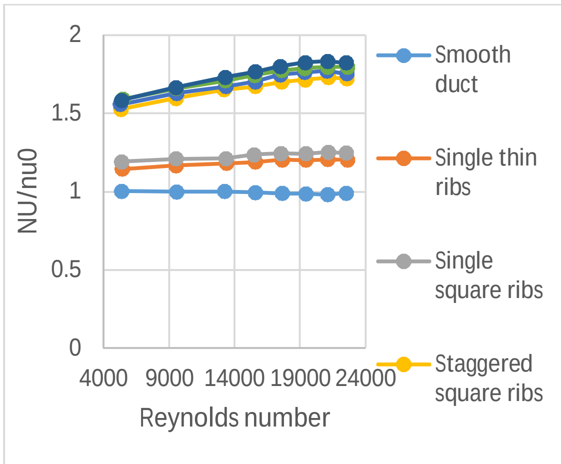
The ribbed configurations in the increasing order of Nusselt number are single thin ribs, single square ribs, staggered square ribs, in-line square ribs, thin staggered ribs and thin inline ribs. The same pattern was observed in the experimental results of except that single thinribs in the present work gave the lowest Nusselt numbers.

C. Nusselt Number Enhancement (Nu/Nu0) versus Reynolds number for Separate Geometries

Nusselt number enhancement ratio gives information about the increment in Nusselt number of a solar air heater with ribs from that of a smooth one. Figure gives a comparison Nusselt number enhancement alteration with Re for all the arrangements. In-line thin ribs yielded the best Nusselt number enhancement ratio. The maximum Nu/Nu0 values with square ribs were 1.27, 1.73, 1.78 for single, staggered and in-line patterns respectively and those with thin ribs were 1.23, 1.79 and 1.85 respectively thereby clearly indicating that thin ribs have advantage over the square ones. The highest value of Nu/Nu0 was observed for thin-in line ribs at Re = 21040. In the experimental work of Skullong et al. , the maximum Nu/Nu0 values with square ribs were 1.52, 1.82 and 1.87 1.74 for single, staggered and in-line patterns respectively and those with thin ribs were 1.65, 2.06 and 2.15 respectively.



Variation of Nu/Nu0 with Re for all the cases

IV. CONCLUSION

A rectangular ductwas constructed and numerical analysis was carried out on square and thin (high aspect ratio) ribshapes arranged in different fashion, namely single wall, staggered and in-line ribs arranged ontwo opposite walls including the absorber plate. Air was the working fluid and constant heat fluxwas applied only on the absorber plate's top surface. The output of numerical simulations drewthe following conclusions

1) On comparing simulation results, pertaining to smooth duct's average Nusselt number, for different turbulent models, it was found that SST-k-omega can best predict the thermal performance of the solar air heater.
2) For all the cases considered in this study, increase in Reynolds number leads to augmentation in Nusselt number.
3) When ribs/baffles are introduced just beneath the collector plate, there was a considerable alteration in the heat transfer coefficient of air.
4) The results revealed that the thin ribs yielded better performance than the squared ones. Similar results were also observed by Skullonget al.in their experimental work. The staggered ribs gave lower Nusselt number than the in-line ones.
5) Out of the three arrangements, the best thermal performance was given by thin inline ribs whose convective heat transfer coefficient was 1.93 times that of smooth duct.

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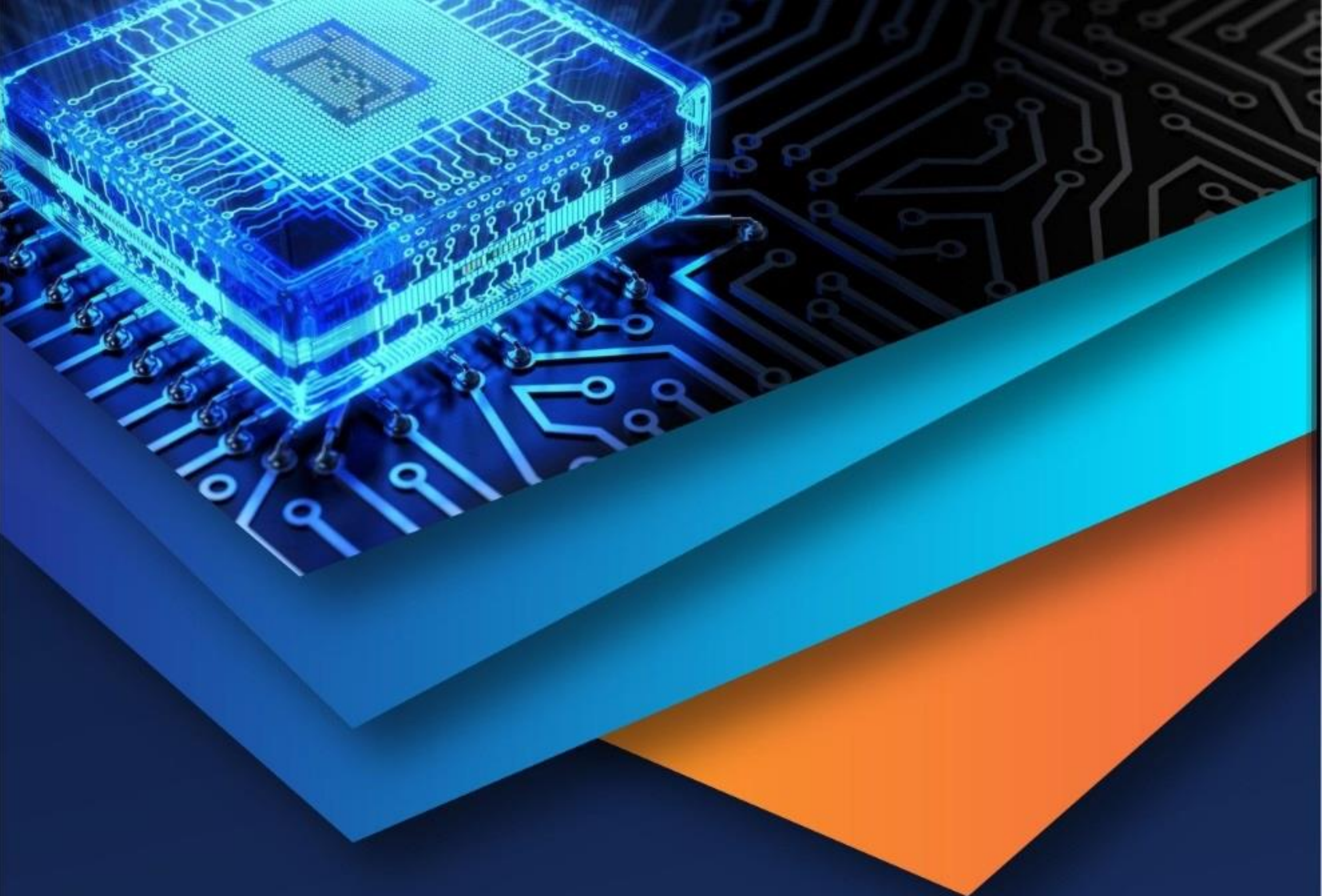

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