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Absorption Refrigeration Techniques with Phase Change Material and Dual Condenser Technology: An Extensive Review

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Abstract: Due to unavailability of source heat at times, temperature fluctuations in the Evaporator chamber occurs which is considered to be one of the drawbacks in this system. To avoid this issue, use of Phase Change Material (PCM) in the Evaporator unit has been suggested. PCM is a latent heat storage device which absorbs the additional heat being generated in the Evaporator chamber. Also during the system OFF condition due to some reason, PCM acts as a backup heat absorber as it absorbs all the heat being generated for some specific time period and prevents the rise in temperature. An approach to use the PCM in the absorption system has been made; advantages and disadvantages of using PCM in this system and exergy analysis of such systems have been discussed in this paper. Different approaches made to improve the thermal efficiency of an absorption system by integrating PCM in it have been presented. Combination of absorption system with compression system (hybrid cycles) to increase the overall efficiency of the system is also analysed. It has been observed that the cooling time of the system increases from 50 minutes to 115 minutes in case of pure ethylene glycol as compared with conventional absorption system without any PCM material under switched off condition. Furthermore, refrigerating effect is also improved by installing the mixture of water and ethylene glycol PCM material that results in the rise of cooling time parameter from 50 minutes to 110 minutes during system in switched off condition
Keywords: Absorption refrigeration, PCM, COP, thermal energy

I. INTRODUCTION

Vapour Absorption system is an attractive method for using the low grade energy directly for cooling. This is an important advantage as compared to the conventional vapour compression system which operates on high grade energy. Another important feature of these systems is that they do not use any moving component except for a very small liquid pump. Vapour absorption system consists of four basic components viz. an evaporator, an absorber (located on low pressure side), a generator and a compressor (located on high pressure side). Refrigerant flows from the condenser to the evaporator, then through absorber to the generator and back to condenser, while the absorbent passes from absorber to the generator and back to absorber. For maximum efficiency, the pressure difference between the low pressure side and high pressure side is maintained as small as possible.

In some places there is a fluctuation in the amount of heat availability which generates cyclic temperature changes in the cooling volume. This change alters the quality of the stored materials like fruits, meat, bakery products etc. So maintaining this temperature is an issue faced by absorption system.

A. Lithium Bromide-Water Absorption System

A simple vapour absorption system consists of an absorber, a pump, a generator and a pressure reducing valve to replace the compressor of vapour compression system. The other components of the system are condenser, receiver, expansion valve and evaporator as in the vapour compression system. In Lithium bromide absorption system, a solution of lithium bromide and water is used. Water is being used as the refrigerant and Lithium bromide acts as an absorbent. Lithium bromide is a hydroscopic salt with high affinity for water vapour due to its very low vapour pressure. This system is generally used in air conditioning systems due to not very low temperature (above 0˚C) requirements.

Figure 1 shows a lithium bromide vapour absorption system. Practically, the absorber and the evaporator are placed in one compartment which operates at the same low pressure of the system. The generator and condenser are placed together in another chamber that operates at the same high pressure of the system. In the absorber, the lithium bromide solution absorbs the water refrigerant, which creates a weak solution of water and lithium bromide. This weak solution is pumped by the pump to the

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Generator where the solution is heated by the available waste heat. The water refrigerant gets vapourized and flows to the Condenser where it is cooled while the strong solution of lithium bromide flows back to the absorber where it further absorbs water coming from the Evaporator. In condenser, water refrigerant loses heat and changes its phase into liquid. Then it passes to the Evaporator through an expansion valve where pressure is reduced drastically. In Evaporator water is sprayed at low pressure which absorbs the heat from the area to be cooled and gets converted into vapour state.

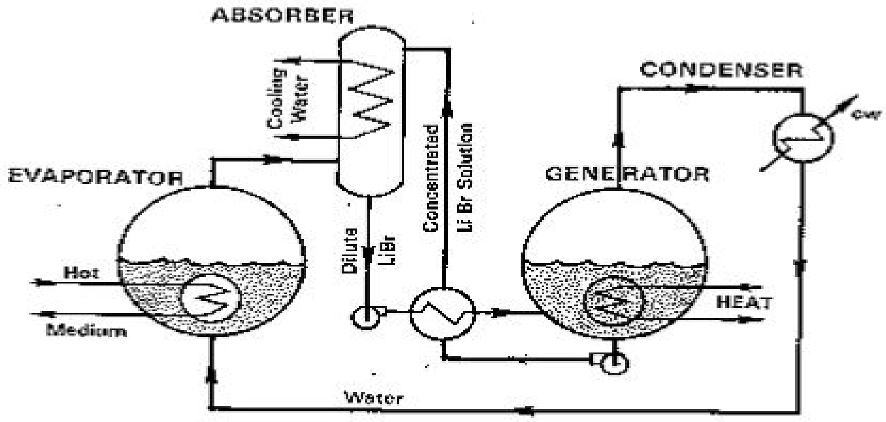

Figure 1 - A Lithium Bromide absorption system

To eliminate the energy losses in the vapour pressure lines, the whole system is combined in two operating vessels as shown in figure 2.

B. Phase Change Materials

A phase-change material (PCM) is a substance with a high heat of fusion which, melting and solidifying at a certain temperature, is able to store and release large amounts of energy. Heat is absorbed or released when the material changes from solid to liquid and vice versa; therefore, PCMs are classified as latent heat storage units.PCM can be used in Evaporator to store energy and can provide additional cooling in the refrigerator. It can absorb heat from the evaporator when the system is not working. Types of Phase change materials are shown in figure 2. Potential for explosion when held in containers, and liability, it may be wise not to use flammable PCMs within residential or other regularly occupied buildings. Phase change materials are also being used in thermal regulation of electronics.

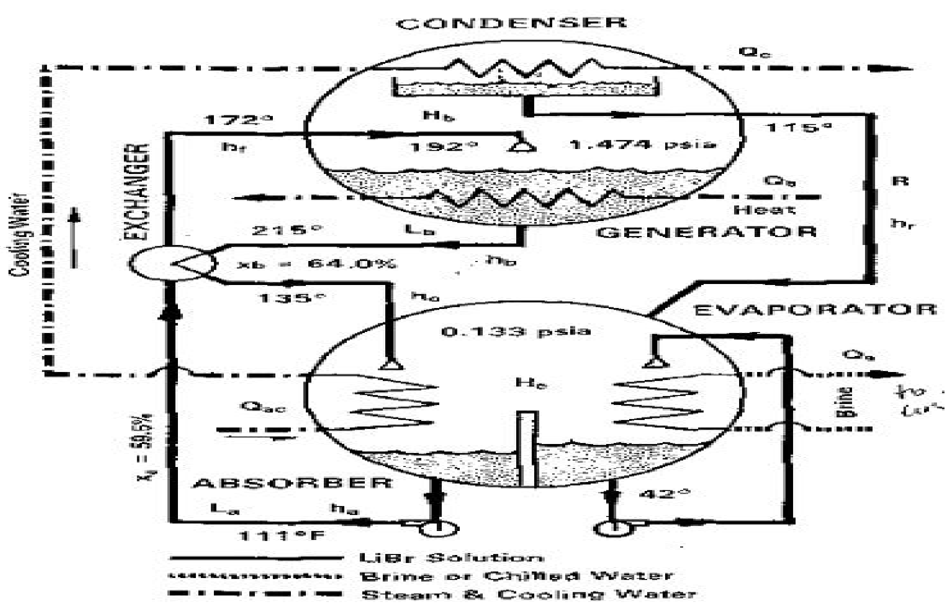

Figure 2 – Practical Lithium Bromide absorption system

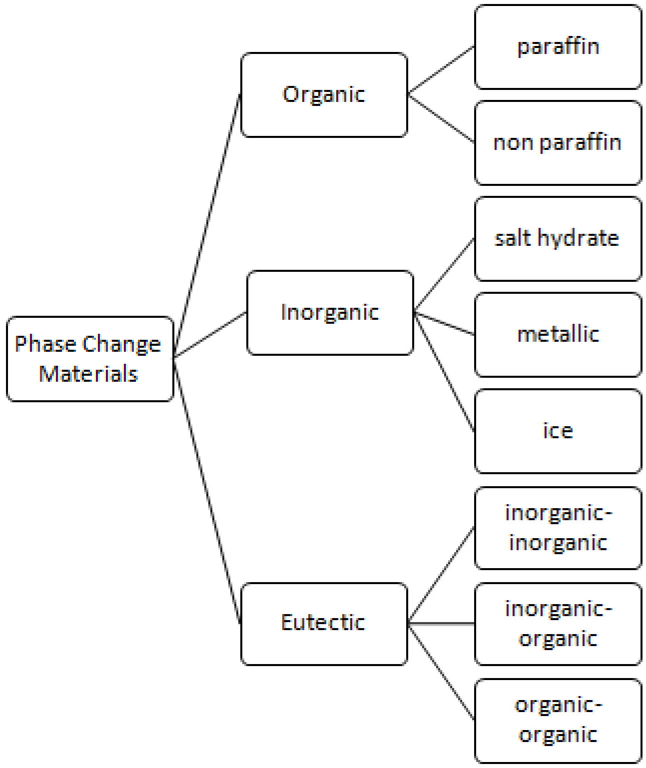

Figure 3- Types of PCM materials

TABLE I
PROPERTIES OF SOME PCM MATERIALS

Material	Type	Composition (wt. %)	Melting point (°C)	Latent heat (kJ/kg)
n-$C_{14}H_{30}$	Organic	-	5.5	226
$Na_2SO4/NaCl/KCl/H2O$	Eutectic	31/13/16/40	4.0	234
H_2O	Water	-	0.0	333
$CuSO_4/H_2O$	Eutectic	11.9	-1.6	291
$FeSO_4/H_2O$	Eutectic	13	-1.8	287
Na_2CO_3/H_2O	Eutectic	5.9	-2.1	310
Na_2SO_4/H_2O	Eutectic	12.7	-3.6	285
$NaCl/H_2O$	Eutectic	90	-5.0	289
$C_{12}H_{26}/C_{13}H_{28}$	Organic	20/80	-5.4	126

C. Using Phase Change Material at Evaporator

Phase change material can be incorporated into either of the two heat exchangers i.e. Condenser and the Evaporator. On investigating the use of PCM in both the heat exchangers it was found that, the COP of the system increases more significantly by using the PCM in the Evaporator rather than using it in the Condenser (Joybari et al.). So in this experiment, Phase change material is used in the Evaporator to reduce the work input given to the system.

In the Evaporator, water as a refrigerant is sprayed at very low pressure so that the heat is absorbed by the refrigerant easily. If the Phase change material is incorporated in the Evaporator, it can take away the heat generated inside the Evaporator when the system is not working. This can reduce the amount of heat required at the generator for a long period of time. Therefore this system can work in the areas where only low grade heat energy is available. This system can also be in Cold storage plants to reduce the overall

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work input to the system for a considerable amount of time.

II. LITERATURE REVIEW

Joybari et al. [1] have analysed different ways of reducing the exergy destruction in a domestic refrigerator. Their main focus was on using the Phase Change Material (PCM) in the evaporator. Comparisons PCM types, thickness and their locations in the system have been done. Previous studies have been referred to in this manuscript for these comparisons. It was found that using the PCM at the evaporator side was much better than applying it on the on the condenser side. But still, some modifications were needed to select the most appropriate PCM type to be used in the evaporator side due to some undesirable results.

In an experiment investigated by Ahmed et al. [2], PCM was used in the evaporator. Ethylene glycol was mixed with water in the ratio 1:4 as the Thermal Energy Storage material. The Evaporator was designed such that the evaporator coils are dipped in the PCM material and the whole arrangement covered with Poly Urethane Foam (PUF) insulation material. It was proved that during compressor OFF time, the temperature rise inside the evaporator increased very slowly as compared to without PCM installation. The modelling of the PCM panels can be worked upon to investigate the future effects.

Rehman et al. [3] investigated the performance improvement of a simple Vapour Compression Refrigeration system by using a Phase Change Material at the Evaporator. A PCM box is built in which the liquid PCM will flow and circulate. The evaporator is kept within the PCM box so that a conductive heat transfer between the refrigerant and the PCM can take place. Due to this enhanced heat transfer, the COP of the system has increased. Use of water as the PCM has been suggested, but there could be an improvement in the selection of the PCM material.

Loaiza et al. [4] worked on the use of Nano fluids as the secondary coolants in the in the Vapour Compression refrigeration system. The heat exchangers (Condenser and Evaporator) were multi-zoned in order to flow both refrigerant and the Nano-fluid. In condenser, Nano fluid flew through the outer circular section and it flew in the inside circular section at the Evaporator. Results in the simulation showed that with increase in volume fraction of nanoparticles and decrease in diameter of nanoparticles, the evaporator area and refrigerant pressure drop is reduced.

Sharma et al. [5] have analysed the changes in COP and exergetic efficiency of the $LiBr/H_2O$ absorption refrigeration system. The varying parameters in this analysis were the temperatures of the cooling water in condenser and absorber, and the Generator. The results obtained showed that with decrease in the cooling water temperature, COP increases along with exergetic efficiency. Also by increasing the heat source temperature, the COP increases upto a certain value of temperature, after that it stabilize and starts decreasing further ahead. This is due to the loss of exergy in further increasing the heat input to the generator.

Rejikumar et al. [6] has showed the comparisons between (1) pure POE oil (2) mineral oil and (3) mineral oil+alumina nanoparticles as lubricants in the vapour compression refrigeration system. It has been found that when the nanoparticles Al_2O_3 were used, the freezing efficiency of the system increased significantly. This was due to the enhancement of the thermal properties of the refrigerant.

Yu et al. [7] worked on increasing the COP of a conventional Ejector Refrigeration system (ERS) and called it the New ejector Refrigeration system (NERS). Same operating conditions were kept for both the systems. Results suggested that COP of NERS can be improved more effectively at the cost of more pump work. Higher exergetic was also obtained in the new system.

Fernadez-Seara et al. [8] have used the flooded evaporator in a conventional Ammonia-water absorption system. The motive was to remove the trapped liquid from inside of the evaporator coils. A blow down system was used to remove the liquid content and also liquid entrainment occurs naturally due to the pressure difference in the system. COP was increased by incorporating the blow down system.

Hyundae Kim et al. [9] performed various experiments to visualize the dispersion of SiO_2 nano particles in binary nano fluids. Distribution stability test, Falling film absorption experiments and Data reduction were done to analyse the improvements of heat transfer rate and mass transfer rate, which was calculated to be 46.8% and 18% respectively, keeping the SiO_2 nanoparticle concentration 0.005 vol%.

Arun et al. [10] found an optimum value of the low pressure generator temperature at which all the vapour generated at the high pressure generator is completely condensed. R32-DMAC was found to be the best refrigerant at high evaporator temperature among all the environment friendly refrigerants.

Reddy et al. [11] did an experimental analysis on Phase Change Maerial as the latent heat storage device. Sodium thiosulphate penta-hydrate was used as the phase change material in this experiment. The PCM was filled in stainless steel capsules of different shapes in order to analyse the best possible shape for better heat transfer. A heat transfer fluid (water in this case) was used to transfer heat energy into the PCM capsules. Higher temperature and mass flow rate, combination of Latent heat and sensible heat and cylindrical capsule shape were the recommendations made for better heat transfer according to the experiment results.

Lee et al. [12] simulated a lithium bromide/water absorption system to analyse the coefficient of performance (COP) of the system. First and second laws of thermodynamics and the mass conservation law were applied to each component Generator, absorber, condenser, Evaporator and Expansion valve mathematically. Effect of rise in heat source temperature on COP and exergetic efficiency was studied. Second law analysis was also performed.

Hosoz et al. [13] compared three types of condensers air-cooled, the water-cooled and the evaporative condensers. Vapour-compression refrigeration system was used to analyse the three types of condensers. It was concluded that the water cooled condenser showed a higher performance significantly over the other two. However evaporative cooled condenser also showed some comparable results. Evaporative cooling was a better to handle process compared to the water cooled condenser, as it requires less maintenance.

Wang and Shen [14] performed an analysis of a novel solar bi-ejector refrigeration system. A new component called injector was added to the system and the pump was removed. Energy and exergy balance was performed on this system using R-123 refrigerant. Exergy losses were calculated for each component and comparisons were made.

A simulation was performed by Kabul et al. [15] using isobutene (R600a) as a refrigerant in the vapour compression refrigeration system. An internal heat exchanger was used in the conventional system and first and second laws of thermodynamics were applied on each component of the system. Results showed that with increase in condenser temperature, coefficient of performance, efficiency ratio and exergy of the system decreased. But, with increase in evaporator temperature, all these parameters increased and the irreversibility rate decreased.

Simulation for an air cooled Lithium bromide/Water absorption refrigeration system was carried out by Oh et al. [16]. Parallel flow heat exchanger of compact size was used for simulation. Energy and Mass balance equations were analysed for each component of the absorption system. Effects of various parameters like solution concentration, air inlet temperature etc., on the system performance were observed and analysed.

Sayyaadi et al. [17] presented different optimization schemes for a cooling tower assisted conventional vapour compression refrigeration system. One of them was thermodynamic single objective optimization in which energy and exergy analysis was done. Nother was economic optimization where cost analysis was done on each component and the whole system using Total Revenue Requirement (TRR) method. Third optimization scenario was the multi-objective optimization which is the combination of both thermodynamic and economic optimization.

Qureshi et al. [18] used different refrigerants in a conventional vapour compression refrigeration system and their results were compared. A dedicated mechanical subcooling instrument was used for two kinds of systems viz. scratch and retrofit. R134a and R717 were used as the main cycle refrigerant one by one and results were analysed. Effects of compressor sizing and fouling were also observed in the respective refrigeration system.

First and second law thermodynamic analyses were simulated by Kilic et al. [19]. Water/lithium bromide absorption refrigeration system was analysed in this experiment. Contribution of exergy losses of each component on the whole system were calculated by simulation. Coefficient of performance, efficiency ratio and Carnot coefficient of performance were calculated by changing the operating parameters of the system. They inferred that a very small exergy loss occurs in the pump, heat exchanger and expansion valve and highest exergy loss takes place in the Generator. Gomri and Hakimi [20] made a thermodynamic analysis of a double-effect vapour absorption refrigeration system. This system consisted of two heat exchangers and two Generators viz. high pressure Generator and low pressure Generator. Second law analysis was performed on it and energy/exergy balance equations were derived for the system. Analysis of each component of the system was done and it was observed that absorber and the high pressure Generator contributed to the highest exergy loss in the system, therefore optimization of these two components should be done.

III. CONCLUSION

A review of vapour absorption refrigeration system integrated with Phase Change Material (PCM) in the evaporator chamber has been presented. Physical and chemical properties of different types of PCM are studied and their applications in the system are also analysed. Some major conclusions drawn from this study are listed below:

A. Absorption refrigeration system has significantly less harmful effect on the environment as compared to the compression refrigeration system.

B. Phase Change material can be used to minimize or even nullify the temperature fluctuations in the evaporator chamber.

C. Ethylene Glycol is one of the most effective Phase change materials that can be used for this purpose.

D. Absorption refrigeration system requires less power input to work and it even works on waste heat rather than using electric current for a compressor.

E. The Ozone Depletion Potential (ODP) and the Global Warming Potential (GWP) of HFC-161 is found to be lower than the R502, R507 and R404a.

F. During switched off system condition, the Phase Change Material provides cooling inside the evaporator chamber for a long period of time.

G. The sequence having de-super heater leads to the 40-50% higher coefficient of performance than the cycle with rectifier.

Exergy analysis can be done on the PCM integrated system to find the contribution of each component in exergy destruction of the system

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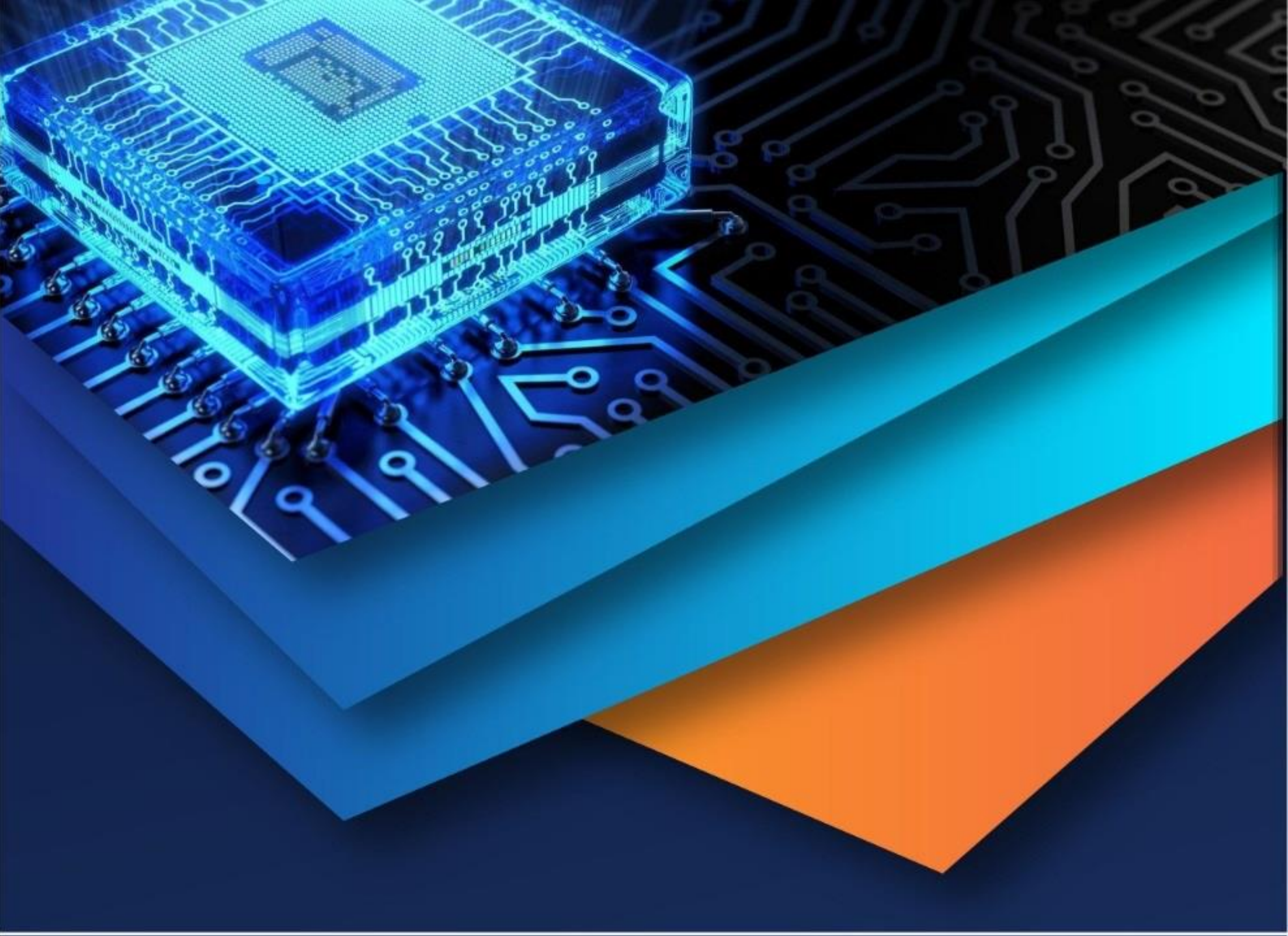

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