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Performance Enhancement Analysis of Double Effect Vapor Absorption System Using Loop Heat Pipes

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Abstract: A high temperature heat source cannot be used efficiently for a single effect vapor absorption refrigeration system (VARS). For the utilization of such high temperature source a double effect system can be brought into action. The COP I and COP II of a double effect VARS are generally higher than that of the single effect system. This research work implements some major modifications with the use of a Loop Heat Pipe (LHP) in the design of the double effect VARS to attain an enhanced performance. The simulations have found that the improved COP I and COP II are 2.09 and 0.4571 respectively. Also the percentage increase on the modified system has been recorded as 75.82% and 28.2 % respectively. Simulations also found that the average T_C can be maintained at 104.2ºC. The increase in the performance characteristics shows a positive gradient with the increase in the temperature of operation of LHP.

I. INTRODUCTION

The fundamental of loop heat pipes(LHP) (Fig 1) is evaporation and condensation. On the heated side '1', the working liquid evaporates and on the cool side'3, 4, 5' it condenses. As every material has different properties (section A-A), it is required to choose the set of material properly. At the source the cool fluid is evaporated, the hot vapor stream is later moved to the sink through the vapor line'2', where the vapor condenses again and is transported back to the source through liquid line '5'. Highly efficient heat exchange is a direct result of the low heat resistance of vapors. This low heat resistance is because of little effective length of heat exchange through strong porous wick walls.

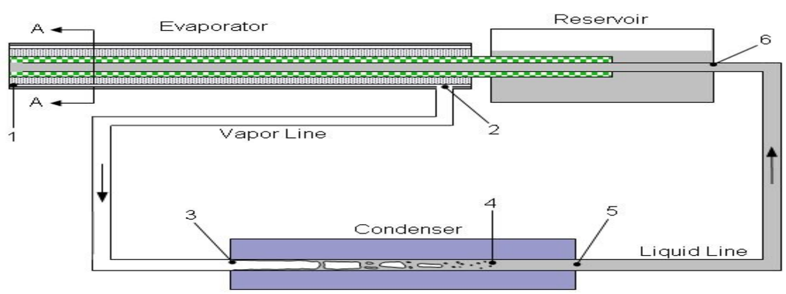

Fig 1: Cyclic process of a Loop Heat Pipe [35]

The LHPs have an inverted wick (Fig 2), and the vapors are located adjacent to the heated surface. These wicks are prepared by power metallurgy. The outer surface of the wick is in contact with the heated surface. Circumferential and axial grooves are required to generate flow channels for the vapors flow which can be machined in the wick, or to the evaporator body.

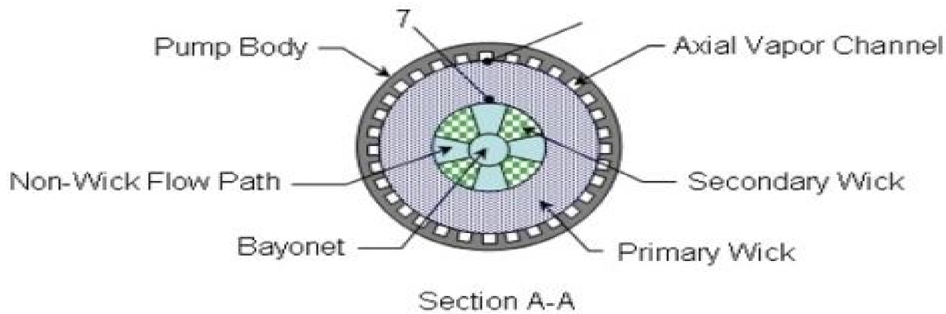

Fig 2: Porous Wick in the LHP[35].

The single effect VARS is not well suited for the utilization of heat from a source with temperature higher than a certain temperature (The COP decreases with increase in temperature beyond a certain point). Hence the requirement of Double Effect VARS(Fig.3) is realised.

II. LITERATURE REVIEW

Fabian Korn et al. [2012]performed several vital experiments on heat pipes to establish it to be one of the most effective procedures to transport thermal energy from one point to another, mostly used for cooling[6].Sameer Khandekaret al.[2010]performed experiments on the global thermal performance modeling of Pulsating Heat Pipes (PHPs) requires local, spati-o-temporally coupled, flow and heat transfer information during the characteristic, self-sustained thermally driven oscillating Taylor bubble flow, under different operating conditions[7].JozefHužvár, Patrik Nemecet al. [2007]used heat pipe, observed its basic principles and operating limits. High temperature heat pipes were evaluated for use in energy conversion applications such as fuel cells, gas turbine re-combustors, and Stirling cycle heat sources, with the resurgence of space nuclear power, additional applications include reactor heat removal elements and radiator elements[8].R.Z. Wanget al.[2008]added heat pipes in adsorption water chiller or ice maker initials. His work showed that the adsorption refrigerators are very efficient [10].Pracha Yeunyongkul et al.[2009]aimedat experimentally investigating the application of a closed loop oscillating heat pipe (CLOHP) as the condenser for a vapor compression refrigeration system[14].R. Rajashree et al.[1990]went through a numerical analysis of an unsteady, viscous, laminar, incompressible, two dimensional heat and mass transfer, in the vapor gas region of gas loaded circular heat pipe [20]. Da-Wen Sun (1996) performed a detailed thermodynamic analysis of the properties of these binary fluids and expressed in polynomial equations. The performances of three cycles were compared. M.M. Talbi et al. (2000) carried out an exergy analysis on a single-effect absorption refrigeration cycle with lithium-bromide±water as the working Fuid pair. E. Kurem et al.(2001) analyzed the Absorption Heat Pump (AHP) and Absorption Heat Transformers (AHT) using ammonia-water and water-lithium bromide solutions. A fundamental AHP and AHT systems was described and explained the operating sequence. R.D. Misra et al. (2002) applied the therm-o-economic theory is to the economic optimization of a single effect water/LiBrvapor absorption refrigeration system for air-conditioning application. S.A. Adewusi et al (2004). studied the performance of single-stage and two-stage ammonia–water absorption refrigeration systems (ARSs).They calculated entropy generation of each component and the total entropy generation of all the system components as well as COP of the ARSs . S. Arivazhagan et al. (2006) investigated experimentally on the performance of a two-stage half effect vapor absorption cooling system .The prototype is designed for 1 kW cooling capacity using HFC based working fluids (R134a as refrigerant and DMAC as absorbent). Rabah Gomri et al. (2008) performed exergy analysis of double effect lithium bromide/water absorption refrigeration system. The system consisted of a second effect generator between the generator and condenser of the single effect absorption refrigeration system, including two solution heat exchangers between the absorber and the two generators. S.C. Kaushik et al. (2009) presented the energy and exergy analysis of single effect and series flow double effect water–lithium bromide absorption systems. They developed a computational model for the parametric investigation of the systems. Berhane H. Gebreslassie et al. (2010) performed an exergy analysis, which only considered the unavoidable exergy destruction, conducted for single, double, triple and half effect Water–Lithium bromide absorption cycles. Gulshan Sachdeva et al.(2014) performed anexergy analysis of VAR system using LiBr-H2O as working fluid with the modified Gouy-Stodola approach. Karl Ochsner (2008)et al. (2008) developed a new CO2-heat pipe with high-grade steel corrugated pipe system, which – contrary to other pipe systems permits raw length up to 100 m. They also described the establishment of the heat pump system in general. Research works have thoroughly studied thermodynamic and thermo-economic problems of the various VARS, namely half; single, double, triple effects etc. Some works have already done the exergetic analysis of the VAR systems. They work on the heat input, so these systems can be interconnected with other power generating systems, using the waste heat of the power development cycles. Also the heat is rejected from the condenser of VARS while the rich refrigerant is condensed. This heat can also be used to reduce the actual heat input in the generator. In the research work LHP can be used as the new component to be used for intra-cycle heat exchange and reduce the requirement of heat input for the cycle to operate. The LHP acts as a super conductor owing to its high heat transfer coefficients associated with the boiling and condensation. Also replacements of other bulky components by the LHP can be done, which would reduce the cost and size of the system.

III. SYSTEMS DESCRIPTION

Fig 3 shows a series flow double effect VARS working on Ammonia-Water (NH_3-H_2O) operating between 130ºC and 4ºC. It consists of 2 generators, a condenser, an evaporator, an absorber, a pump, 2 solution heat exchangers two solution reducing valves and a refrigerant expansion valves. This system has five temperature levels (temperature in LPG, temperature in HPG, evaporator temperature, condenser temperature, and absorber temperature) and three pressure levels (low pressure in the evaporator and absorber, medium pressure in the condenser and the low pressure generator, the high pressure in the high pressure generator). The strong solution is pumped to the HPG where it is heated to boil out the refrigerant vapor from the solution. The primary vapor, from the HPG moves to the LPG heating the medium concentration solution and then it's condensed. The heat of condensation of the primary vapor from the HPG is used in the LPG to get the secondary vapor. Thus, the total amount of liquid refrigerant leaving condenser is the sum of refrigerant originating from HPG and LPG. The refrigerant from the condenser expands into the evaporator where it extracts the heat of vaporization and cools the ambient. [7]

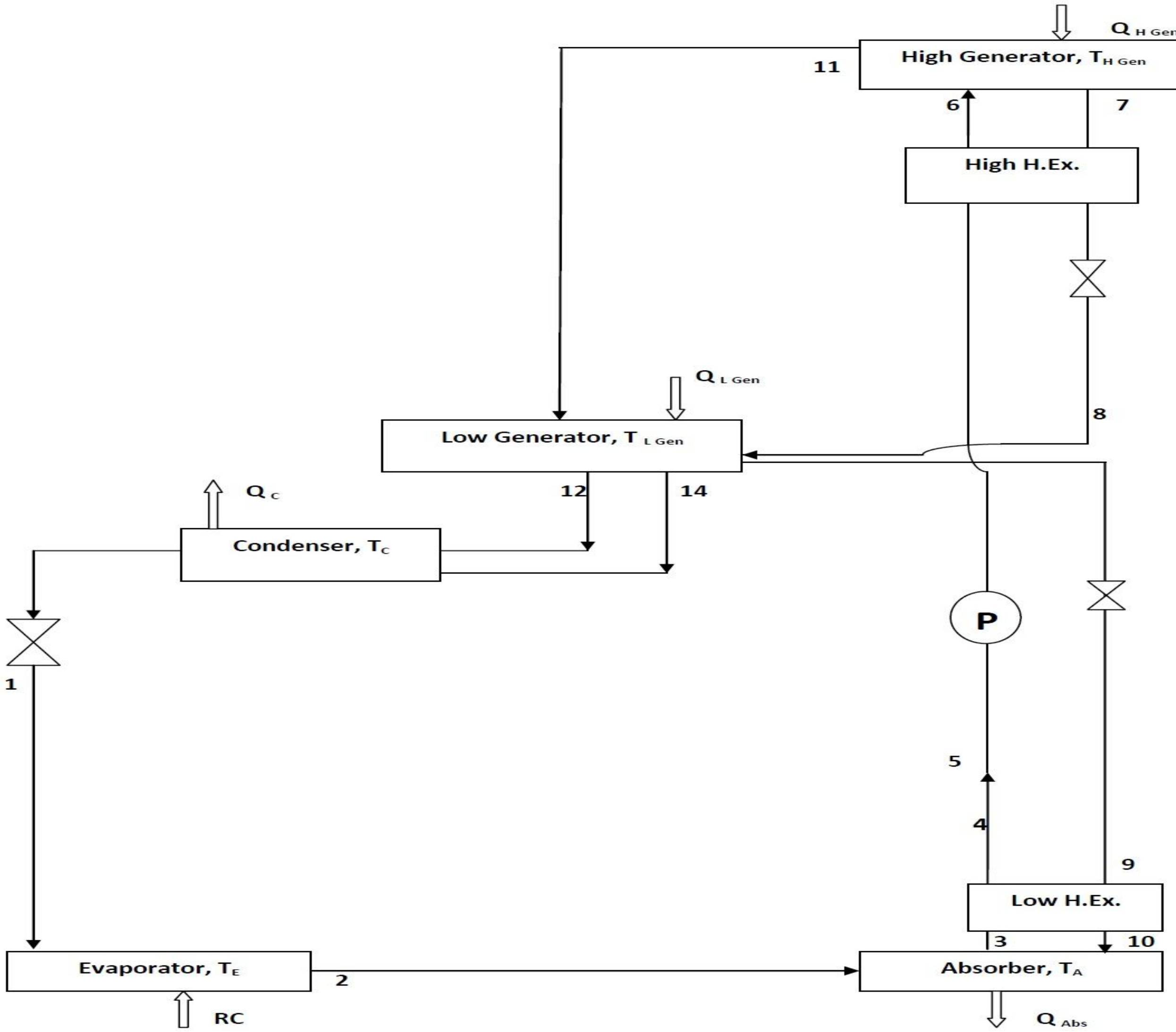

Fig 3: A Double Effect (Series)Vapor Absorption System

The proposed modifications in the double effect system have been showed in the fig 4. The main focus is on the reduction in the heat input in the HPG to improve the COP $_I$. Also the condenser is being replaced with the LHP which would be heating the mixture from the absorber using the heat which was going to be exhausted in the condenser. There are different materials that can be used to enhance the heat transferred to the working fluid of the LHP in the evaporator part. Effective wick area, pore radius, figure of merit etc affect the heat transfer factor of the heat pipe. [33] A better utilization of the waste heat will help in reducing the loss of exergy and in a way increasing the COP $_{II}$. Replacement of the condenser will also result in the total cost of the system, also it reduces the size.The LHP makes a cycle of heat exchange occur without any energy input.The table 1 consists of the terminology used in the analysis.

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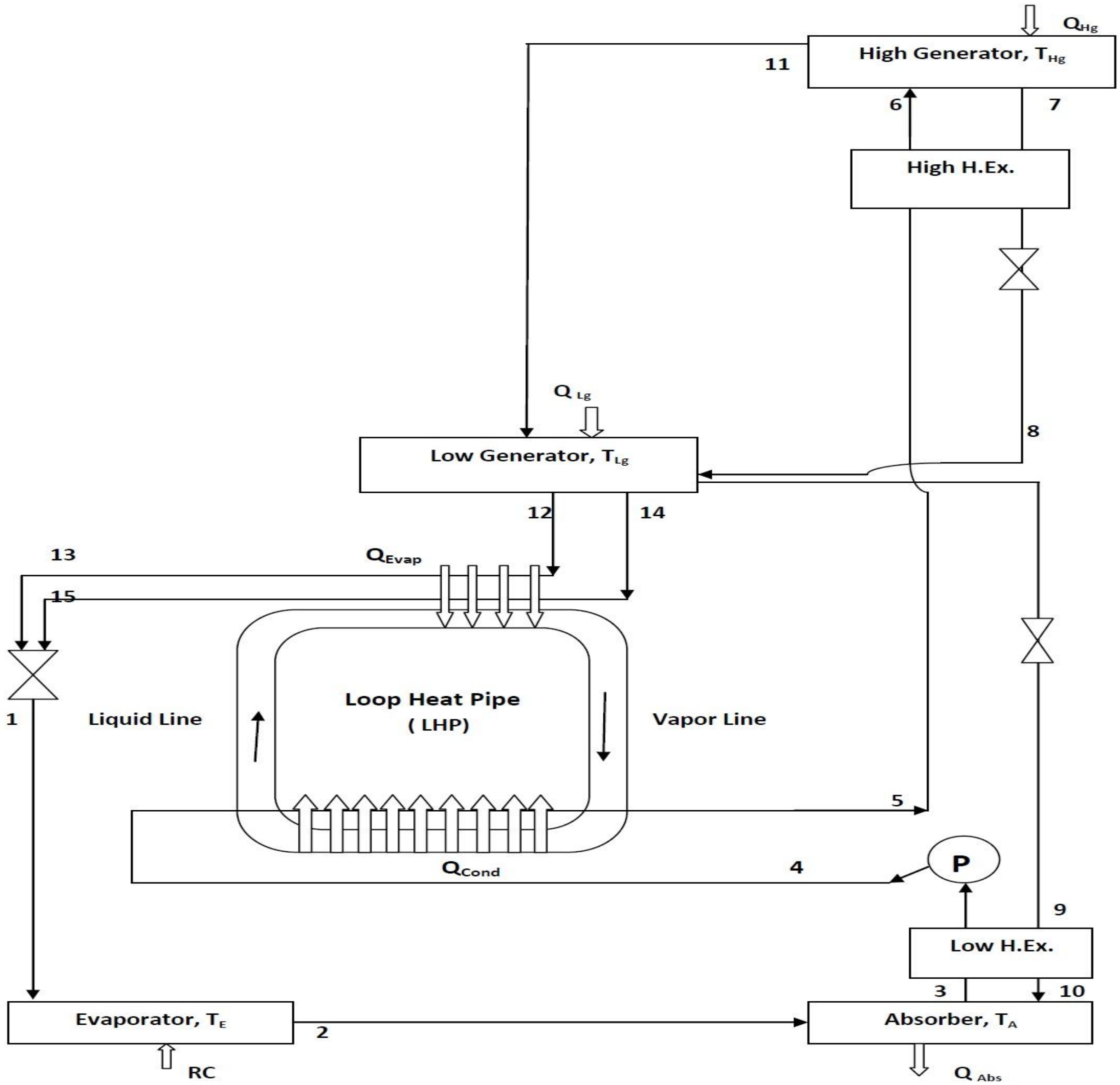

Fig.4: Modified Double Effect Vapor Absorption System

Table 1: Terms Used in Simulation

Terms	Abbreviations
Refrigeration Effect in kW	RE (kW)
Heat rejected in absorber in kW	Q_a(kW)
Heat supplied in generator in kW	Q_g (kW)
Heat rejected in condenser of LHP in kW	Q_{cond}(kW)
Heat absorbed in evaporator of LHP in kW	Q_{eva}(kW)
Absorber Temperature in°C	T_{La},T_{Ha}(°C)
Generator Temperature in °C	T_{Hg}, T_{LG} (°C)
LHP Condenser Temperature in °C	T_c (°C)
Evaporator Temperature in °C	T_E,T_e(°C)
Heat Rejected in Condenser in kW	Q_C (kW)

First Law Coefficient of Performance	COP_{I}
Second Law Coefficient of Performance	COP_{II}
Heat Leaked from the LHP in kW	Q_{Leak} (kW)
Percentage Improvement in First Law Coefficient of Performance	$\%COP_{I\ imp}$
Percentage Improvement in Second Law Coefficient of Performance	$\%COP_{II\ imp}$
Improvement in First Law Coefficient of Performance	$COP_{I\ imp}$
Improvement in Second Law Coefficient of Performance	$COP_{II\ imp}$
Low Pressure Generator	LPG
High Pressure Generator	HPG

IV. RESULTS AND DICSUSSIONS

The Fig 5,6 and 7 show the variation of COP_{I}& COP_{II} with the heat being utilized in the LHP Q_{Cond}. Fig 5 shows the comparison COP_{I} of the modified system with the basic system.

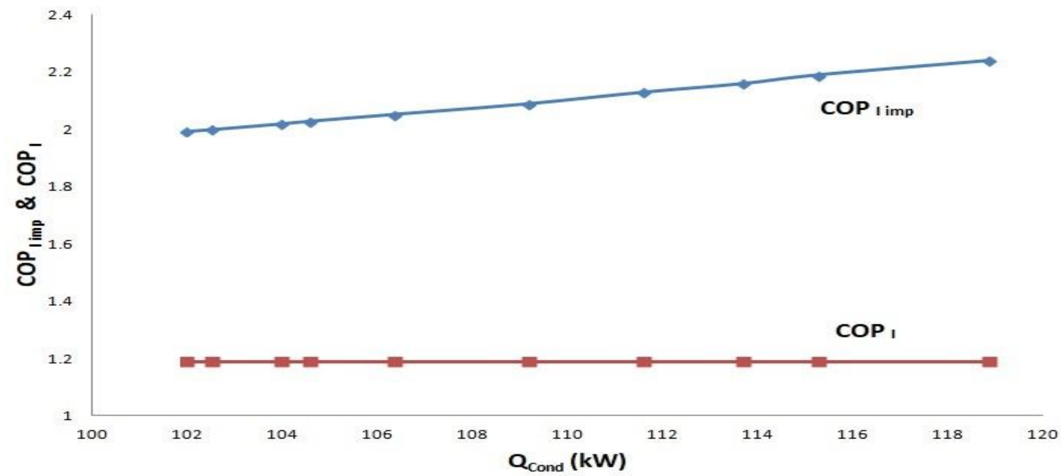

Fig 5: Comparison between COP_{I} and $COP_{I\ imp}$ plotted with Q_{Cond}

The average enhanced COP_{I} for the modified system is 2.09 where as the COP_{I} of the basic system is 1.189.

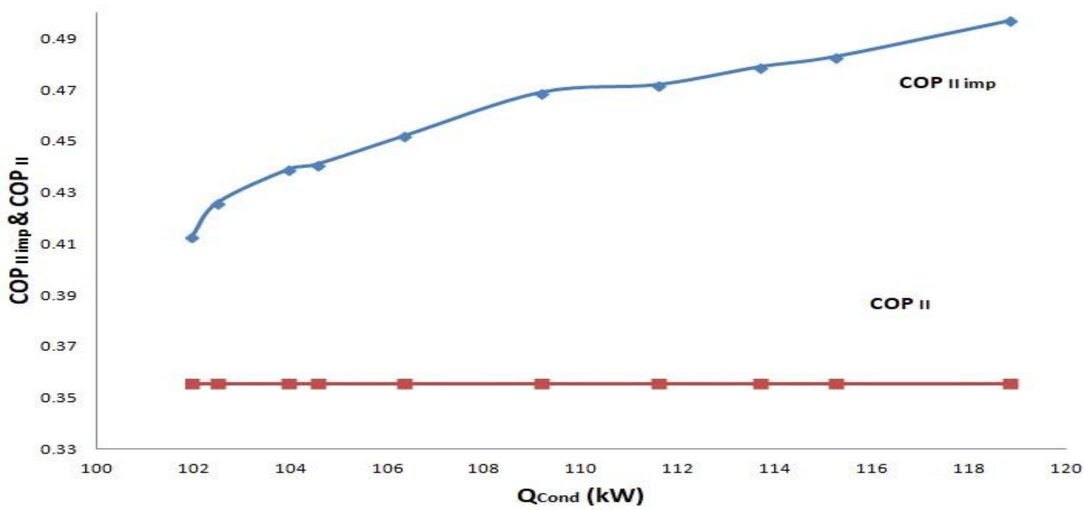

Fig 6: Comparison between COP_{II} and $COP_{II\ imp}$ plotted with Q_{Cond}

The fig 6 describes the variation of COP $_{II}$ of the modified system with the basic system. The average COP $_{II}$ upon this modification is 0.4571, where the original COP $_{II}$is 0.3557.

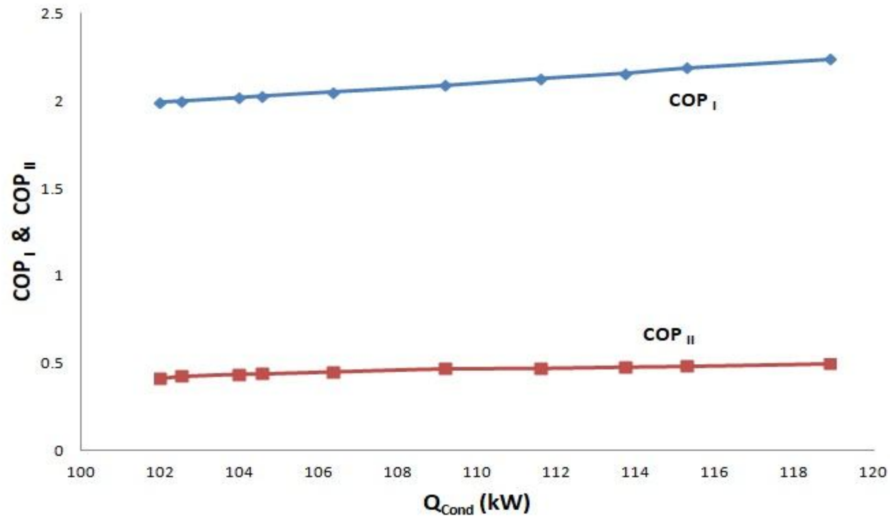

Fig 7: COP $_{I}$ and COP $_{II}$plotted with Q_{Cond}

The fig 7 compares the COP $_{I}$ and the COP $_{II}$ of the modified system with a variable Q_{Cond}. It can be seen that the increase in the performance parameters is gradual and consistent. More the heat utilized with the help of LHP, higher are the performances based on First law and Second law. It can be said that a modification inside the LHP will help in enhancing the performance. Fig 8, 9 and 10 help in analysing the %age improvement happening due to the modification of the system. Fig 8 shows the variation with the Q_{Cond}. The COP $_{II}$ has a sharper rise over the range when compared to the COP $_{I}$.

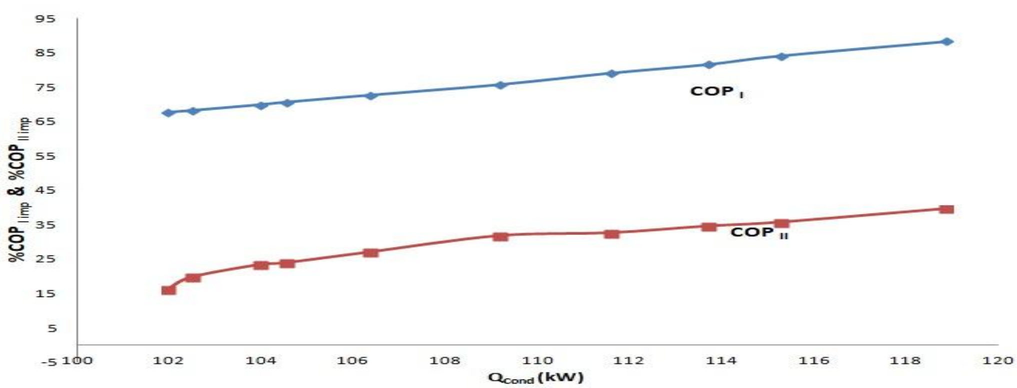

Fig8: Variation of %COP $_{I\ imp}$ and % COP $_{II\ imp}$ plotted with Q_{Cond}

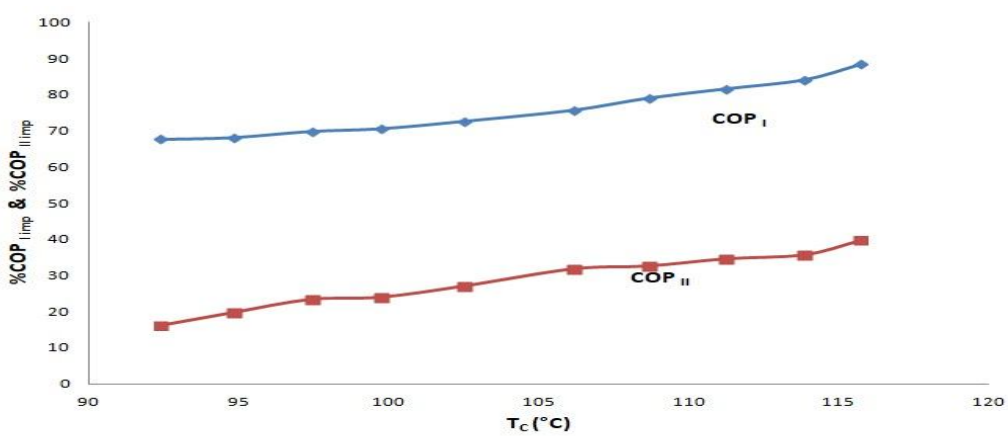

Fig9: Comparison of %age improvements in COP $_{I}$& COP $_{II}$ varying the T_C

The fig 9 shows the %age rise in COP $_{I}$ and COP $_{II}$ with varying T_C. The COP I shows a increasing slope for the entire range while the COP II shows a decreasing slope. Further increase in the T_C may not result in the in the enhancement in the COP $_{II}$, as the COP $_{I}$ will show improvement for further increase in T_C. The average %age increase in COP I is 75.82.

Here fig 10 shows the variation of the above with a range of T_G. The trending is similar to that of fig 9. With the increase in the T_G the COP $_{I}$ is expected to increase (Fig 12). But with the rise in T_G also there will be a rise in Evaporator temperature of LHP along with the rise in T_C and decrease in the Q_{Leak}, hence the utilization of heat will increase. Along with this increases the COP $_{II}$ (Fig 11). The %age increase in COP $_{II}$ is 28.5.

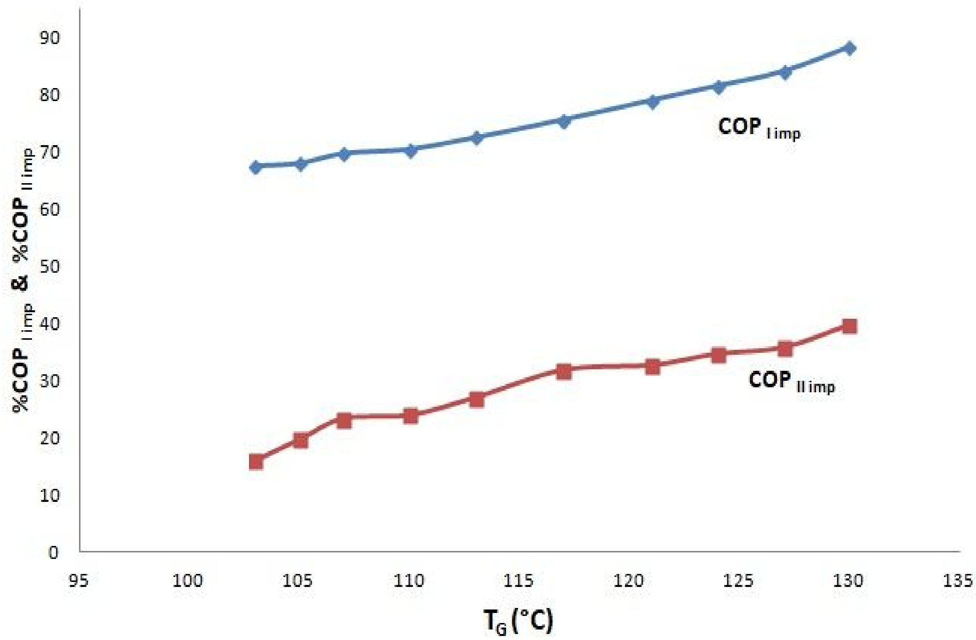

Fig 10: Comparison of %age improvements in COP $_{I}$& COP $_{II}$ varying the T_G

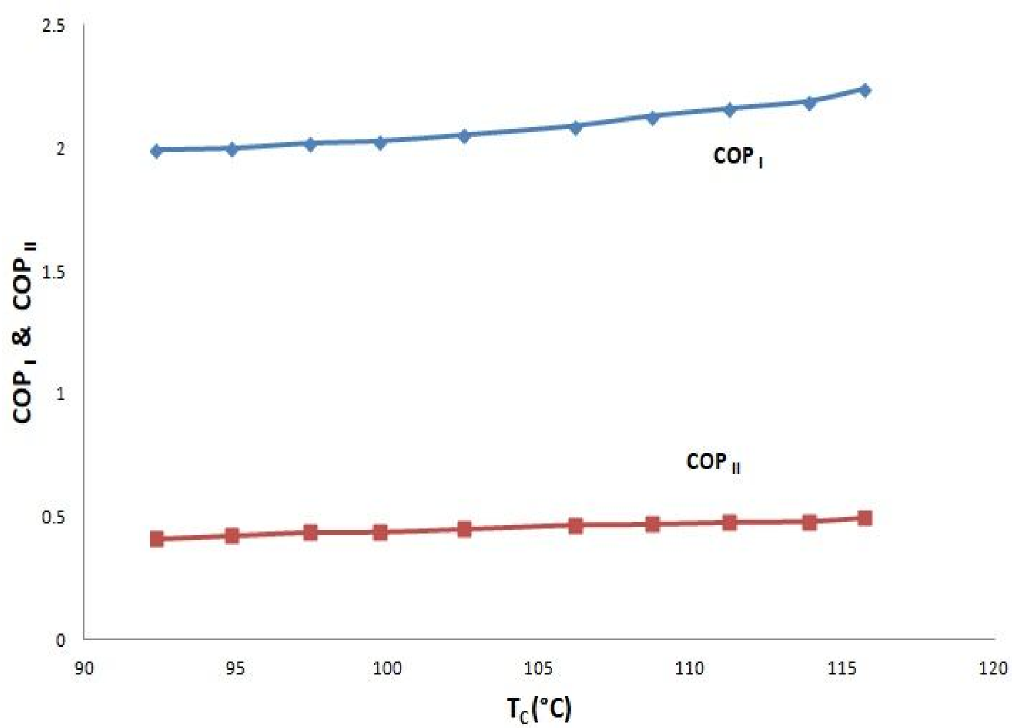

Fig 11: Comparison of COP $_{I}$& COP $_{II}$ varying the T_C

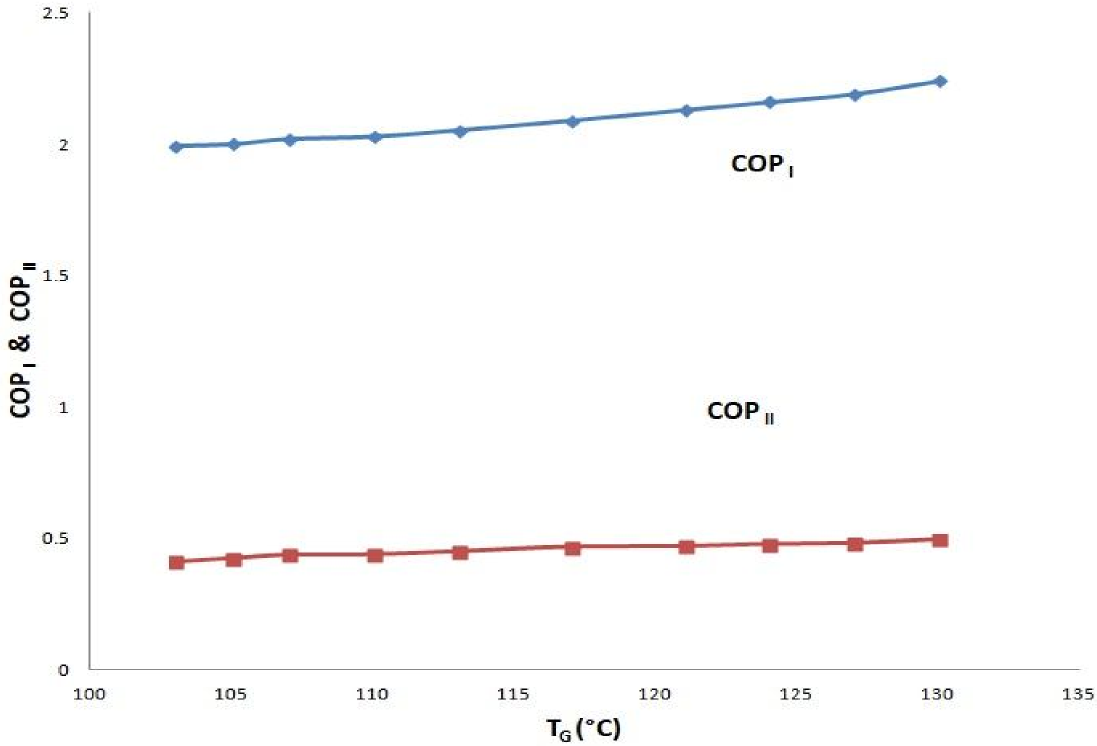

Fig 12: Comparison of COP $_I$& COP $_{II}$ varying the T_G

It has been observed that with increase in the T_G, COP $_I$, COP $_{II}$ and T_C all increase. Fig 13 and fig 14 show the variation of Q_{Cond} and Q_{Leak} with T_C and T_G respectively. In both the figures it can be easily noticed that the increase in the temperature provides desirable results such as reduction in the Q_{Leak} and increase in Q_{Cond}.

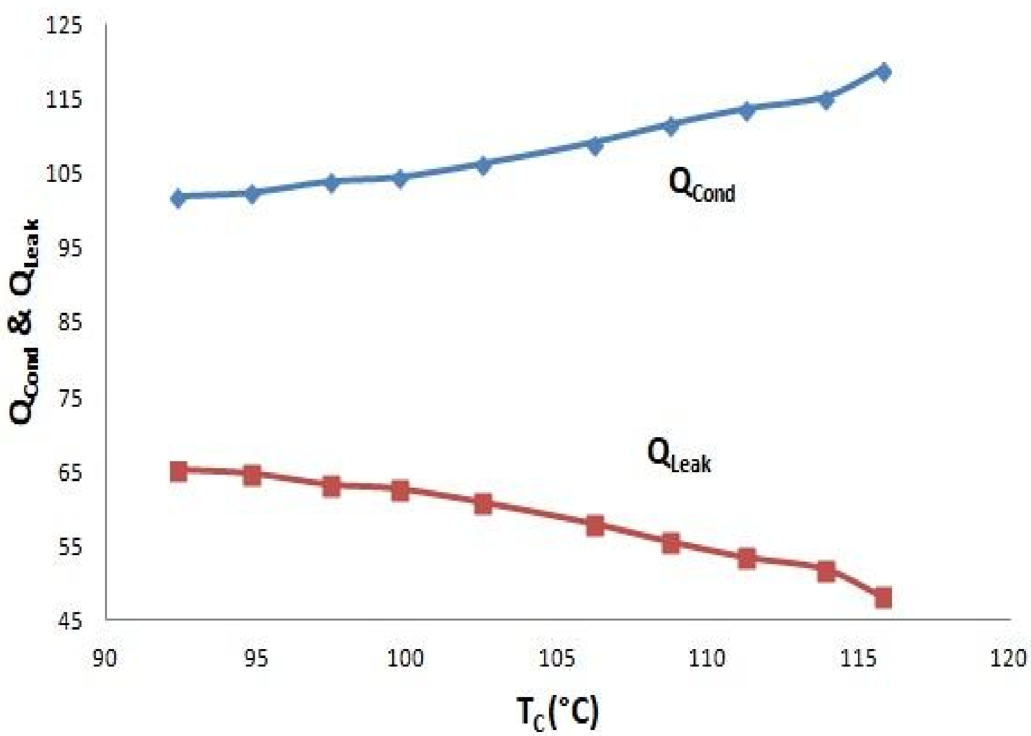

Fig 13: Comparison of Q_{Leak}&Q_{Cond}varying the T_C

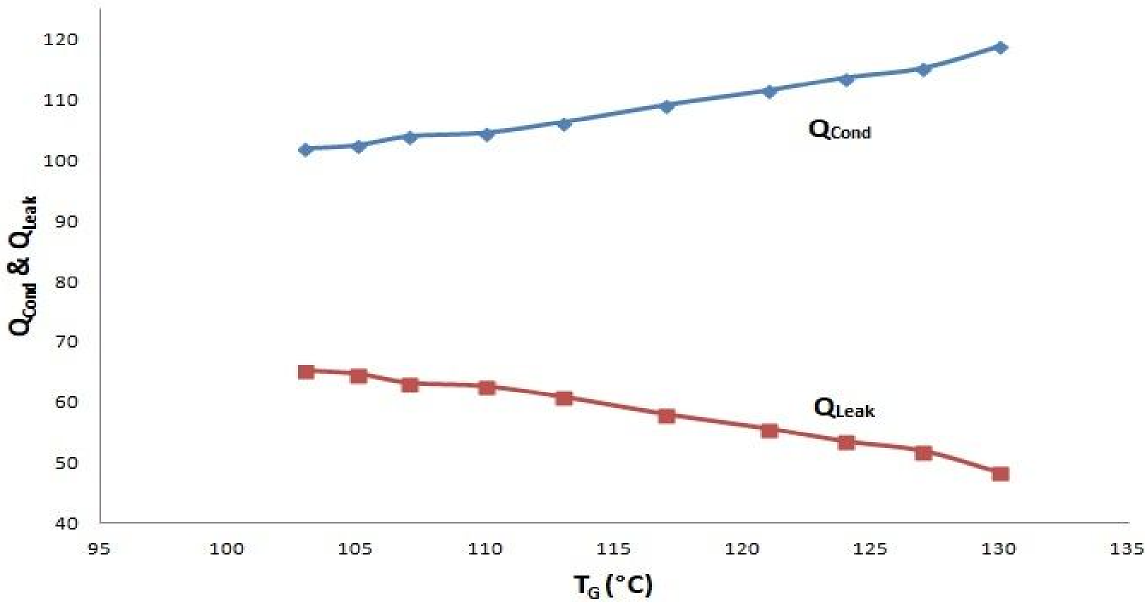

Fig 14: Comparison of Q_{Leak}&Q_{Cond} varying the T_G

The Q_{Cond} has a positive gradient in both the figures. Further increase in the temperature will increase the Q_{Cond} and hence the leakage of heat will decrease. The limit of the temperature is 130ºC; other methods have to be sorted out to increase the Q_{Cond}, such as changing the material and changing the arrangements of heat transfer surface of the LHP.

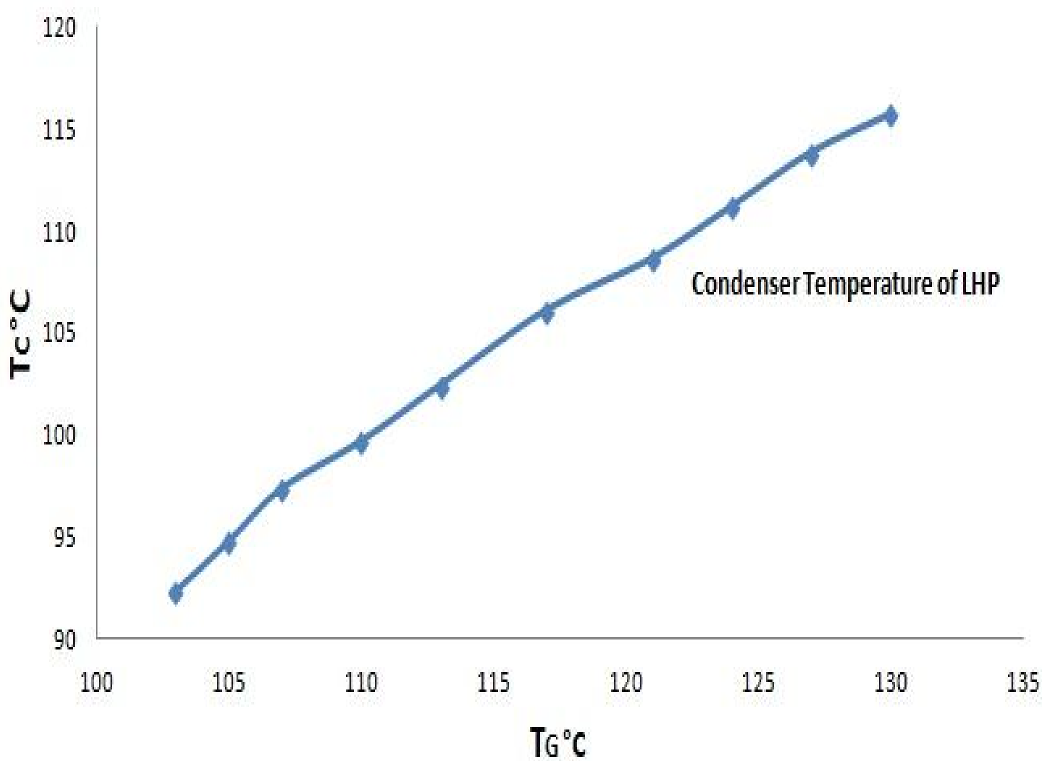

Fig 15: Variation of T_C with the T_G

Figure15 shows the increase in Condenser temperature of LHP. It helps in the availability of the heat to be utilized and the extent of heat transfer that can take place to the mixture. At the limit of the T_G the maximum temperature in the condenser of LHP is115ºC. Also on an average the T_C is found to be is 104.23 ºC.

V. CONCLUSIONS

Following the results of the simulations, following conclusions can be made:

A. The average enhanced COP_I &COP_{II} are 2.09 and 0.4571 respectively.
B. The percentage increase in COP_I &COP_{II} can be observed to be 75.82 and 28.2 respectively.
C. The COP_{II} has a sharper rise over the range when compared to the COP_I for the range of Q_{Cond}.
D. The COP I shows a increasing slope for the entire range while the COP II shows a decreasing slope for the entire range of the T_G and T_C.
E. Increase in the temperature T_G provides the desirable results such as reduction in the Q_{Leak} and increase in Q_{Cond} and average T_C is found to be is 104.23 ºC .

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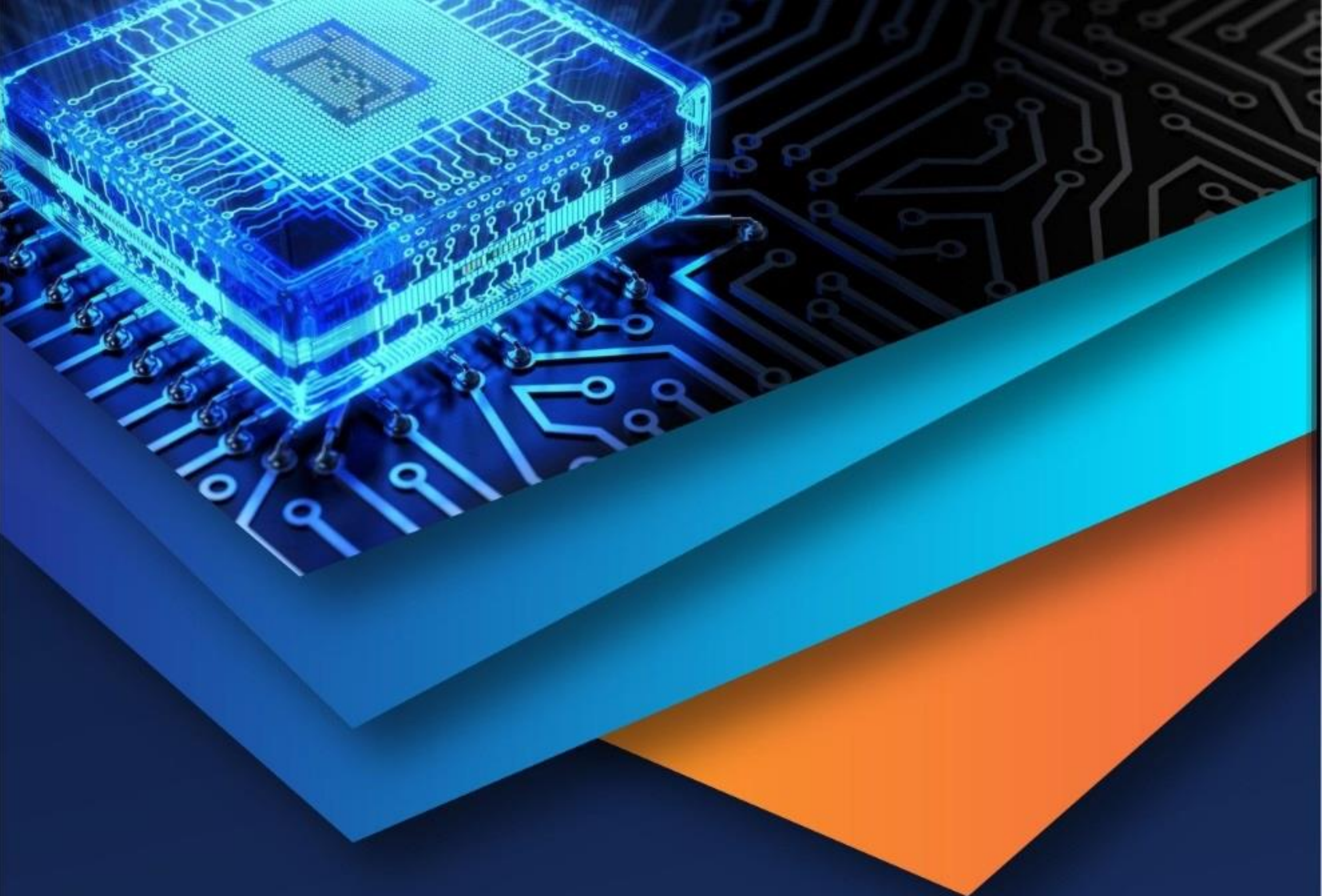

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