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Study of Improvement in the Performance of Triple Effect Vapor Absorption System Using Loop Heat Pipes

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Abstract: The triple effect vapor absorption refrigeration system (VARS) works at higher temperatures (>150-160°C).This high temperature working of the cycle helps in achieving higher COP $_I$ and COP $_{II}$. This research analysis works on reducing the heat input in the generators by use of two Loop Heat Pipes (LHPs) installed in the high and medium temperature levels. The simulations have found that the improved COP $_I$ &COP $_{II}$ are 2.545 and 0.588 respectively. Also the percentage increase in performances of the modified system has been recorded as 61.112 % and 25.146% respectively. Simulations also found that the average T_C can be maintained at 151.18 °C. The increase in the performance characteristics shows a positive gradient with the increase in the temperature of operation of LHP. The average Q_{Leak} and Q_{Cond} are found to be 89.44 kW and 71.68 kW respectively.

I. INTRODUCTION

Loop Heat Pipe (LHP) is an evaporator-condenser that works on the thermo-siphon effect. It operates and transfers heat without any requirement of input work. It acts as a super-conductor owing to the high heat transfer rates related to the evaporation and condensation. The heat pipe is a wicked structure, outside of which the heat is absorbed by the working fluid of the LHP from the ambient and the fluid gets vaporized. This vapor passes through the porous wicked structure and moved towards the condenser of the LHP through the Vapor Line. The vapor rejects heat in the condenser and gets condensed. These condensates then move towards the Compensation Chamber (CC) connected to the evaporator of the LHP and gets accumulated there.

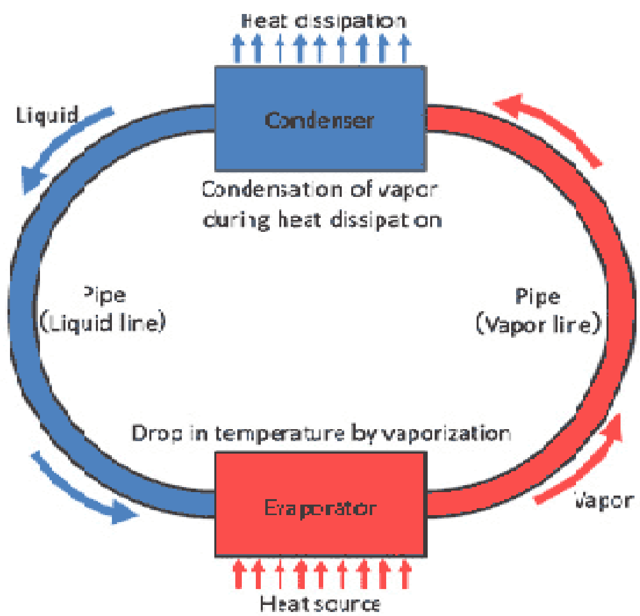

Fig 1: Cyclic process of a Loop Heat Pipe [35]

There is some leakage of heat of associated with the LHP from CC, Liquid and Vapour Lines, From the wick etc. These losses are although negligible but can be reduced up to an extent by the proper selection of materials and designs.

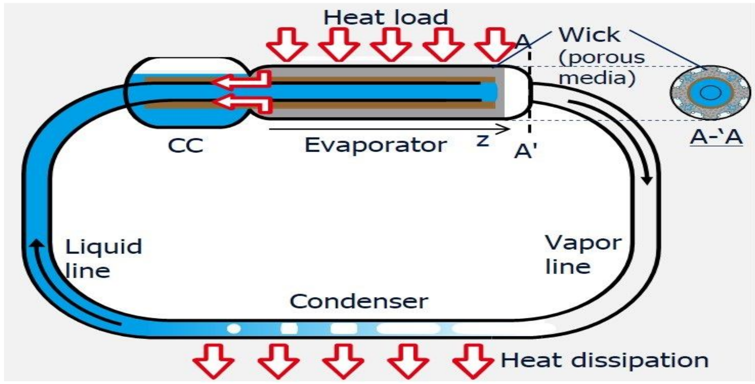

Fig 2: Schematic of LHP [36].

A triple effect vapor absorption system refrigeration system (VARS) is used when the source temperature is high(>140-150 °C). The high temperature also corrodes the material of the generator and connecting lines. The parallel flow type heat exchanger is shown and explained in fig 3. This VARS system is very useful in utilizing a waste heat. The efficiency of the triple effect system is also relatively higher as the operating temperature is very high comparatively.

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, PatrikNemecet 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].PrachaYeunyongkul 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 vapour 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/LiBr vapour 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 vapour absorption cooling system .The prototype is designed for 1 kW cooling capacity using HFC based working fluids (R134a as refrigerant and DMAC as absorbent). RabahGomri 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 et al. (2008) developeda 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. Ankit Dwivedi et al. (2018) through computer simulations of the replacement of condensers from single, double and half effect VARS, showed the improvements in the performance in COP_I and COP_{II} .Waste heat is being utilized in the cycle from some outside source, while the cycle itself rejects heat at the saturation temperature of the refrigerant which in case is as high as the generator. This heat is taken away by the working fluid of the condenser (Air, Water etc). It can be taken away by the mixture of refrigerant from the absorber as well which already works at the condenser temperature. The LHP can be used for this purpose. It can replace the condenser and help in the intra cycle heat exchange. The two condensers working at higher temperatures (>100°C) can be replaced in the triple effect cycle by LHPs. The bulky condensers will be removed and flexile heat pipes will take its place. Also as mentioned earlier the LHPs will act as a superconductor with having higher capacity and higher heat transfer coefficient. Some of the research works have showed the options for more analysis in these aspects.

III. SYSTEMS DESCRIPTION

It can be explained by the fig 3 what are the basic components and cycle processes of the triple effect VARS. This is a parallel flow triple effect system which has 3 condensers (Low(LC), Medium(MC) and High(HC)), 3 generators (Low(LG), Medium(MG) and High(HG)), an absorber, an evaporator, 3 Heat Exchangers (Low H.E x, MedH. Ex, HighH. Ex), pumping devices and throttle valves. The mixture is pumped to the high temperature generator HG (>working at 150°C) through the 3 heat exchangers. A major part of the rich refrigerant then gets separated from the mixture and is transferred through HC to the evaporator to produce the refrigeration. The remaining mixture from the HG then is throttled to the MG(>120°C) where it is heated and the separated strong refrigerant is transferred to the evaporator through MC and throttle valves. The remaining mixture from MG is then throttled to the LG(>80-90°C) where the above process takes place. Finally the remaining mixture is throttled to the absorber. This 3 stage process helps the separation strong refrigerant well administered.

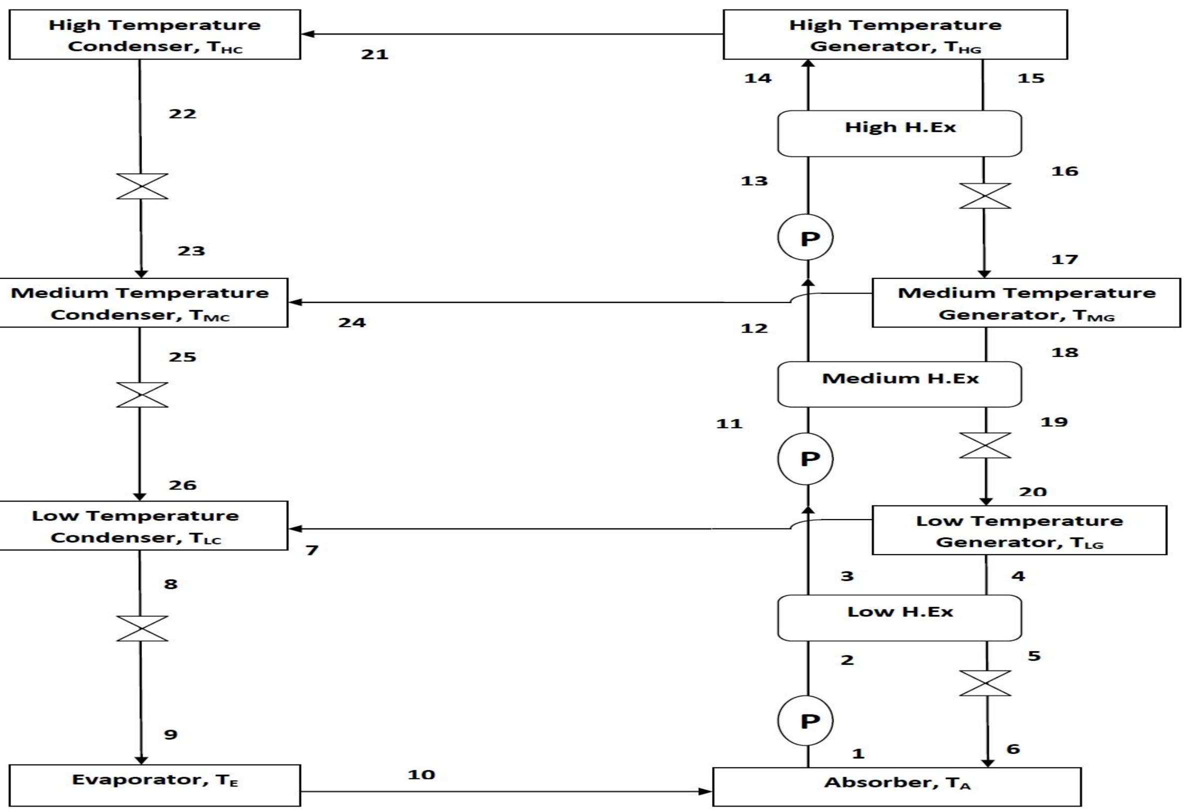

Fig 3: A Triple Effect (Parallel) Vapour Absorption System

The proposed modifications can be well described in fig 4. Here HC, LC , Low H.Ex and Med H.Ex are to be removed from LHPs. Understanding that the temperature is sufficiently high at this level(i.e. 120°C -150°C), LHPs will perform the tasks of condensers and H.Ex reduces the size and complexity of the Heat Exchangers. The cost associated can also be reduced. The design of the LHP will be very simple when compared with that of H. Ex. Heat is removed at the evaporator size on the LHP from the condensing strong refrigerant. This heat will be transferred to the mixture coming from the absorber. The effectiveness on the the LHP will be higher than the other heat exchangers owing to the high heat transfer coefficients. The simulations are executed and the results are as follows. The table 1 consists of the terminology used in the analysis.

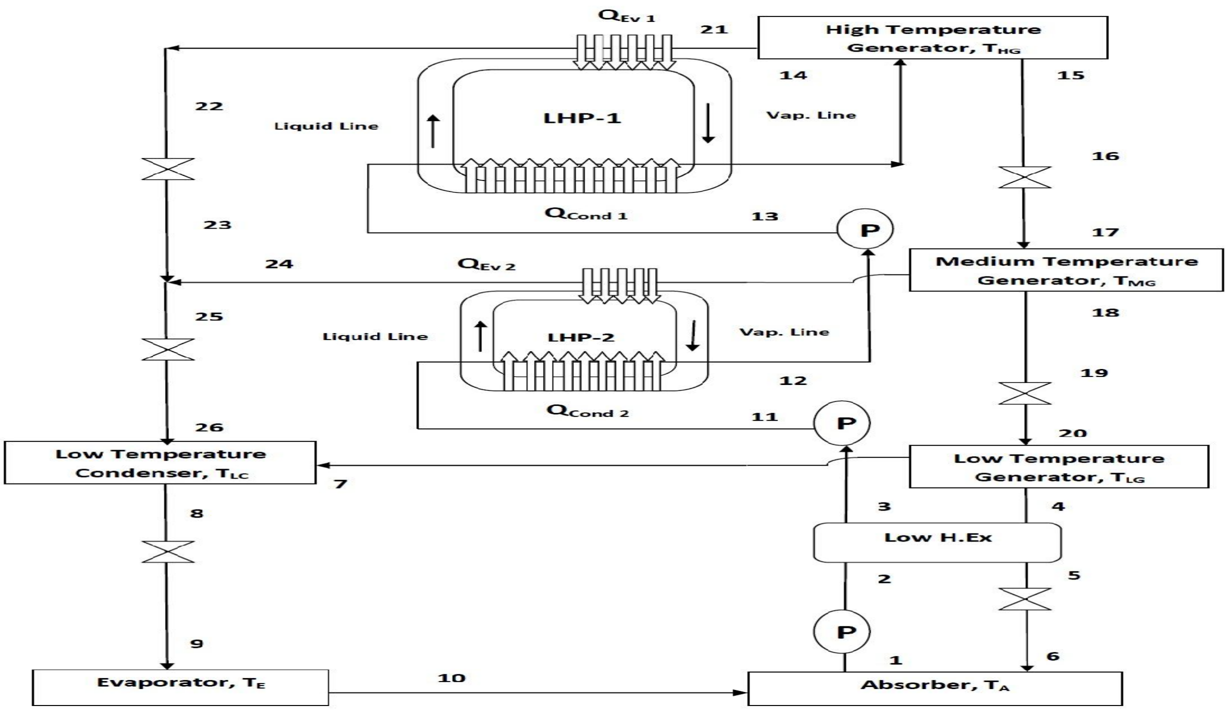

Fig.4: Modified Triple Effect Vapour Absorption System

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},T_{MG}(°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	$COP_{\ I\ imp}$

Performance	
Improvement in Second Law Coefficient of Performance	$COP_{II\ imp}$
Low Temperature Generator, Condenser	LG,LC
Medium Temperature Generator, Condenser	MG, MC
High Temperature Generator, Condenser	HG, HC

IV. RESULTS AND DICSUSSIONS

From Fig 5 to Fig 8 shows the various variations in COP_I& COP_{II}. Fig 5 describes the comparison of COP_I improvement in the modified system and the COP_I in the basic triple effect cycle. The average COP_I of modified system can be observed to be 2.545.

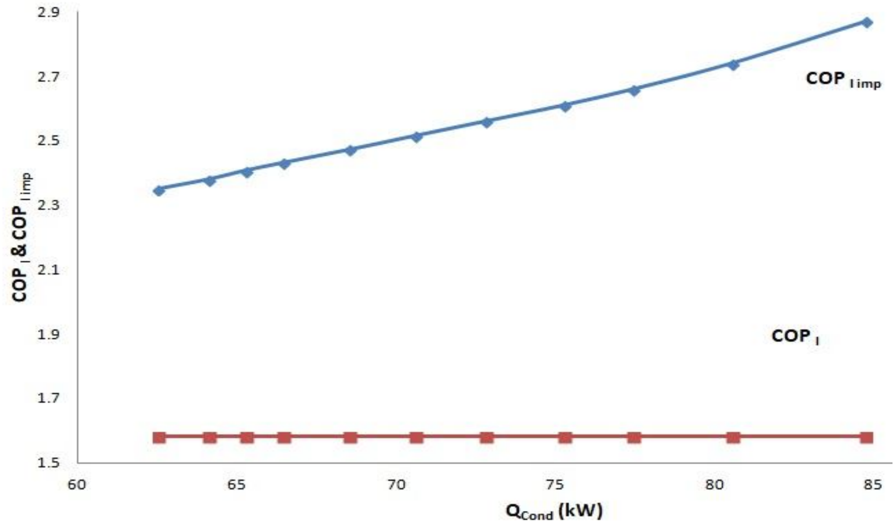

Fig 5: Comparison between COP_I and $COP_{I\ imp}$ plotted with Q_{Cond}

It can be seen in the fig 6 how COP_{II} of the proposed modified system stands against the original system. There's a continuous increase in the COP_{II}, as the slope in the beginning is positive and in the later stage the increase in Q_{Cond} may not yield in higher rises in COP_{II}. The average COP_{II} of modified system can be 0.588.

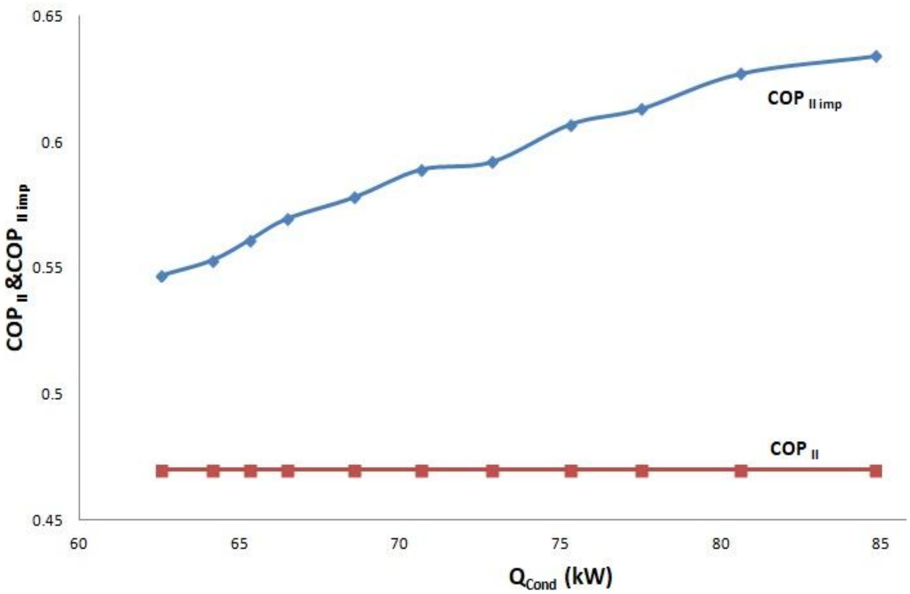

Fig 6: Comparison between COP_{II} and $COP_{II\ imp}$ plotted with Q_{Cond}

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Fig 7 shows the increase in COP $_I$& COP $_{II}$ relatively over the range of Q $_{Cond}$. It can be seen that COP $_I$ has a higher and direct effect of Q $_{Cond}$ as its being used in improving it directly. The COP $_{II}$ on the other hand doesn't show a sharp rise as COP $_I$ does. The reduction of heat wastage in the system no doubt helps in decreasing the exergy loss. Both external and internal irreversibility are reduced.

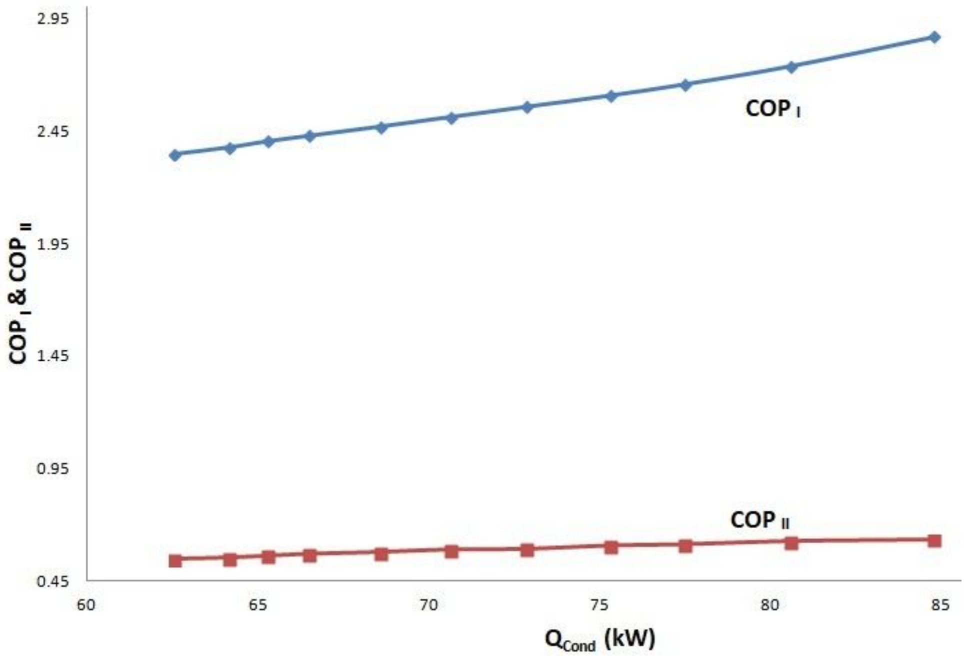

Fig 7: COP $_I$ and COP $_{II}$plotted with Q_{Cond}

Fig 8 in a way is developed to show the percentage rise in the COP_I and COP $_{II}$ owing to the use of LHPs. As discussed earlier the COP $_I$ is directly affected by the Q $_{Cond}$. Here the average percentage rise in COP $_I$is found to be around 61.112 % and the average rise in COP_{II} is 25.146%. Also if the designs can be changed so that LHPs are able utilize more heat and the leaks are reduced the COP $_I$ can be further improved.

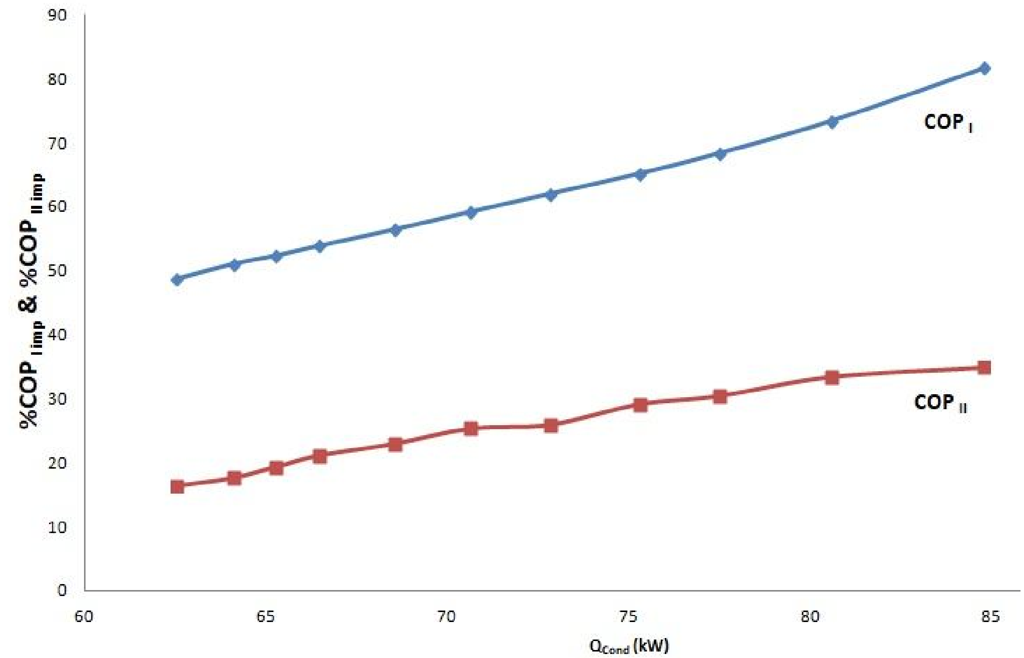

Fig8: Variation of %COP $_{I\ imp}$ and % COP $_{II\ imp}$ plotted with Q_{Cond}

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The Fig 9 & Fig 10 shows the percentage improvements in the performance with the range of LHP condenser temperature T_C and HG temperature T_G. With the ranging T_C rise in COP $_I$ has a positive slope as discussed earlier and as the T_C increase further the availability also increases. Increase in the availability helps in increasing COP $_I$ as the heat to be utilized increases. COP $_{II}$ also follows, and increase in the COP $_{II}$ is recorded by the simulations.

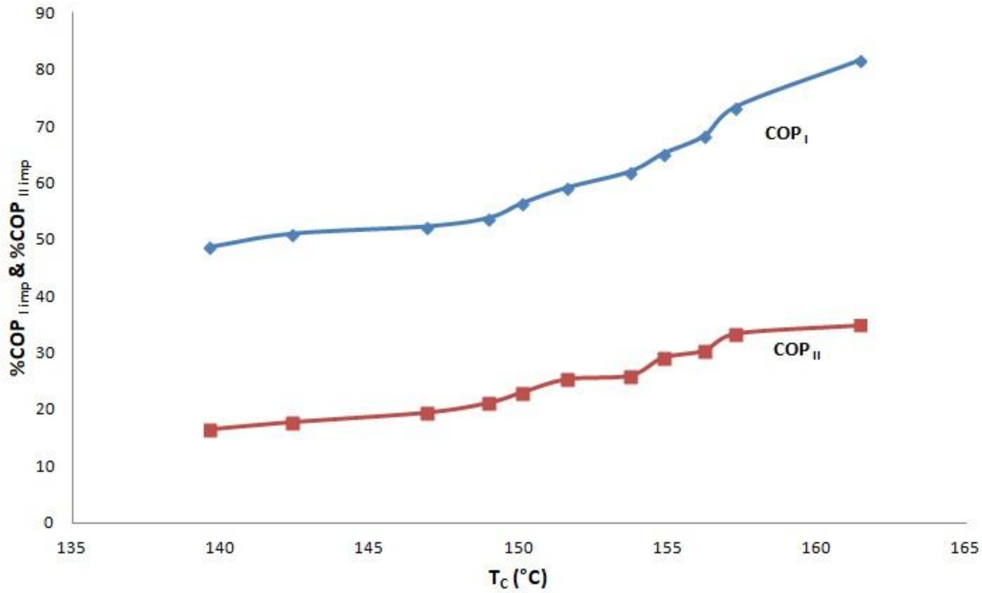

Fig9: Comparison of %age improvements in COP $_I$& COP $_{II}$ varying the T_C

Fig 10 describes the variations of performance with the range of T_G. With rise in T_G the COP_I has a sharp increase, whereas the COP_{II} has a gradual increase.

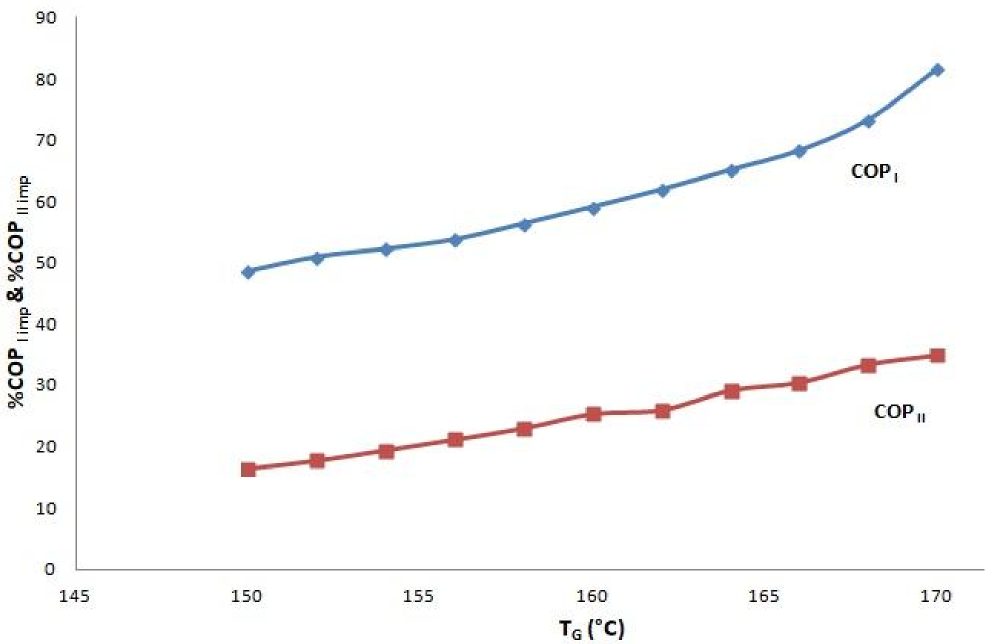

Fig 10: Comparison of %age improvements in COP $_I$& COP $_{II}$ varying the T_G

The Fig 11 & Fig 12 show the improved performance with the temperature range.

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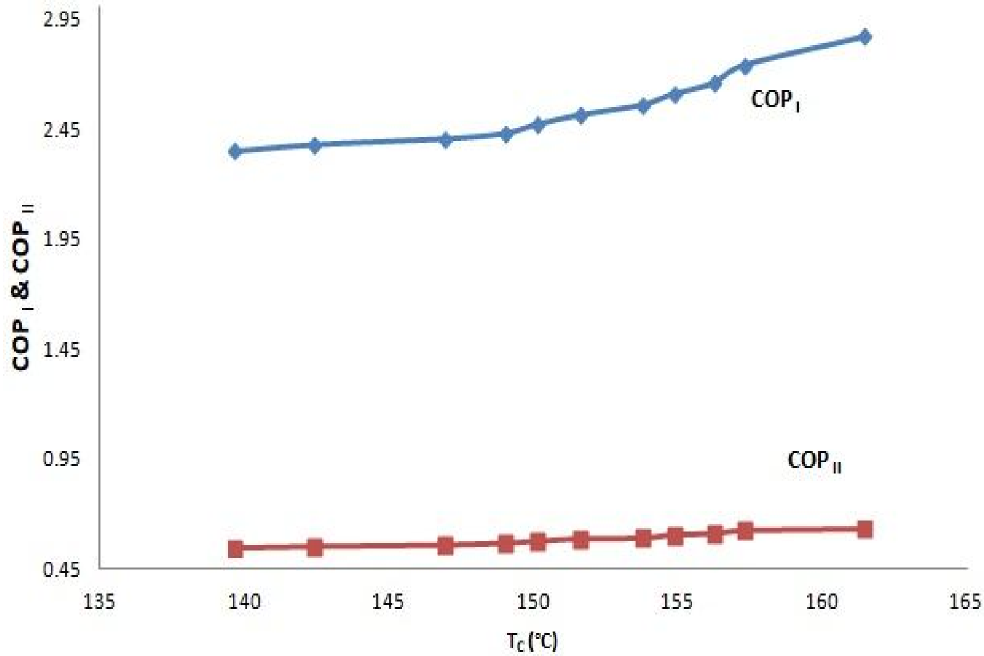

Fig 11: Comparison of COP $_{I}$& COP $_{II}$ varying the T_C

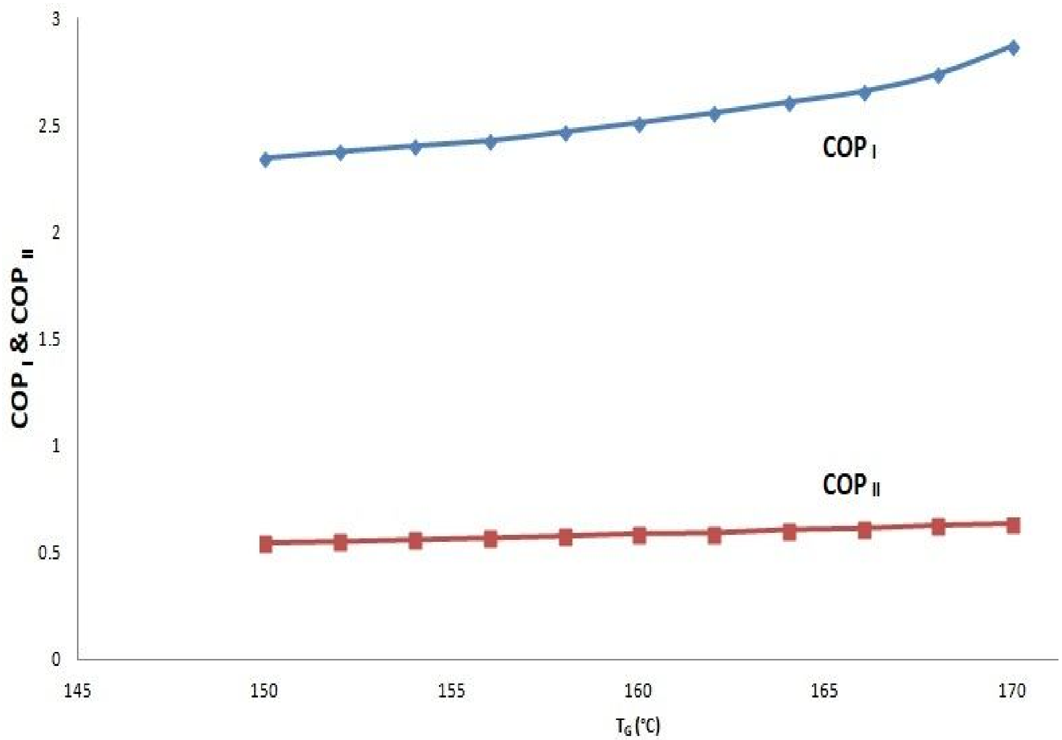

Fig 12: Comparison of COP $_{I}$& COP $_{II}$ varying the T_G

Fig 13 and Fig 14 describe the variations in Heat Leaked and Heat Utilized in the LHPs along the temperature. In the figure as the temperature of the LHP condenser increases it can be observed that heat utilized in condenser increases. The average heat utilized in the LHP condenser is 71.68 kW.

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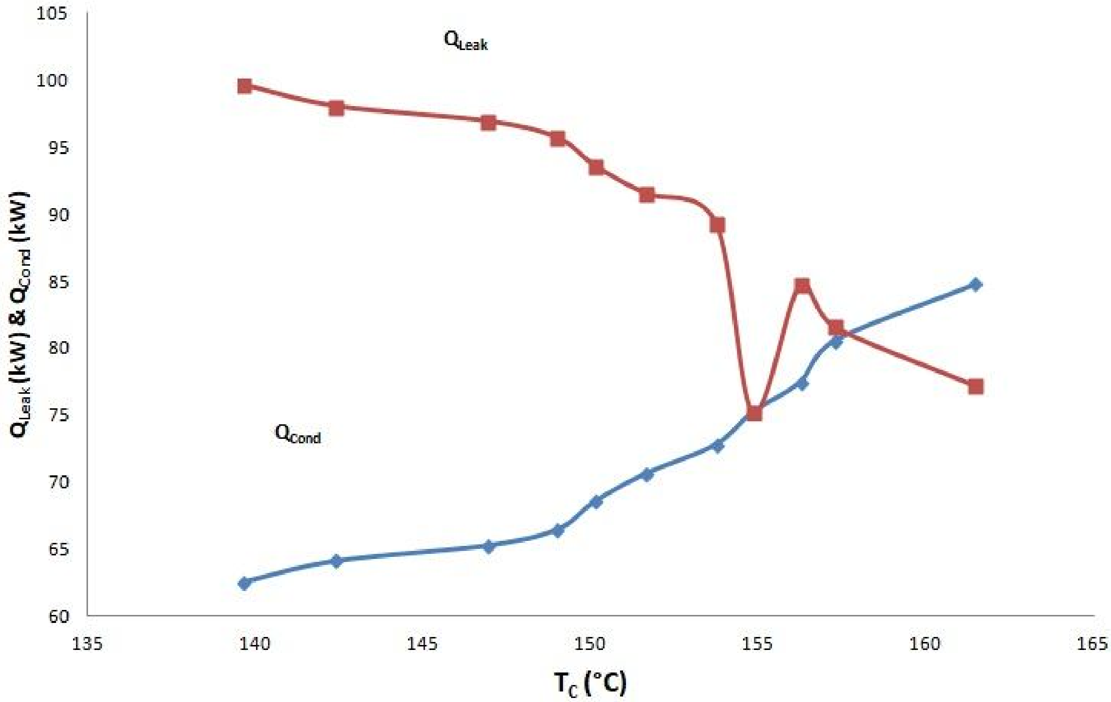

Fig 13: Comparison of Q_{Leak} & Q_{Cond} varying the T_C

On the other hand, the figure below shows the same variation with temperature of HG. The heat leak Q_{Leak} is decreasing with the increase in T_G. The average heat that has leaked the LHP is 89.44 kW over the ranges of temperatures.

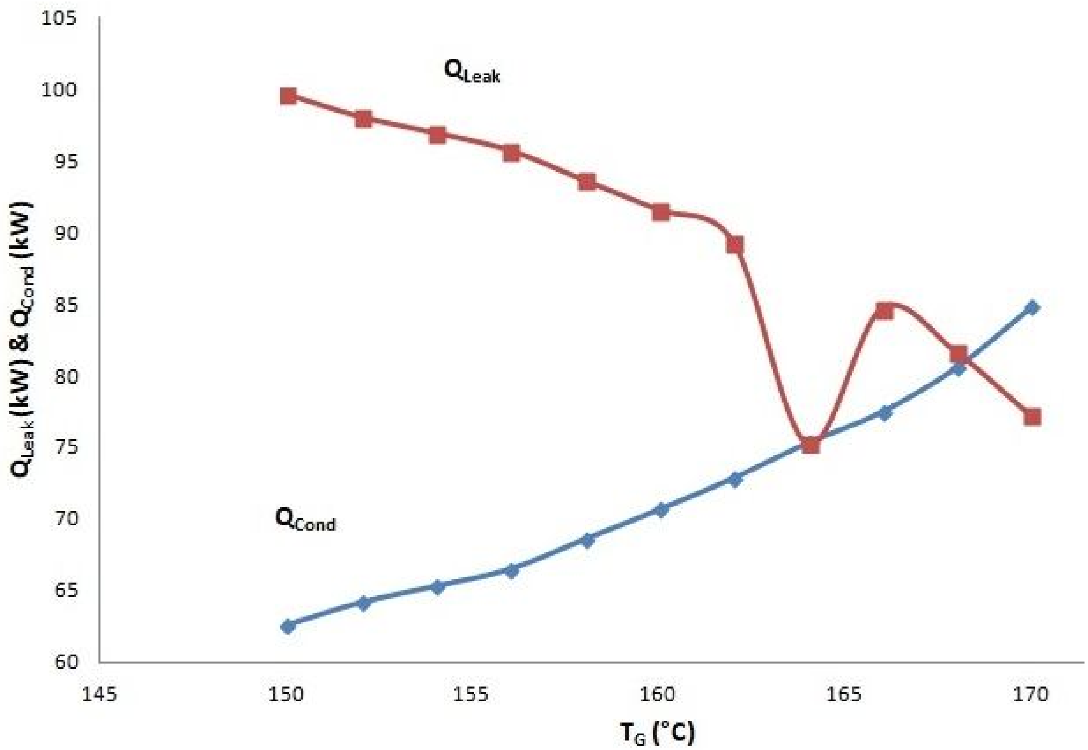

Fig 14: Comparison of Q_{Leak}&Q_{Cond} varying the T_G

Fig 15 shows the dependency of TC on TG.As the TG increases TC also increases. Direct dependence can be observed from the figure below. The average temperature can be managed to be achieved in the condenser of LHP is 151.18 °C.

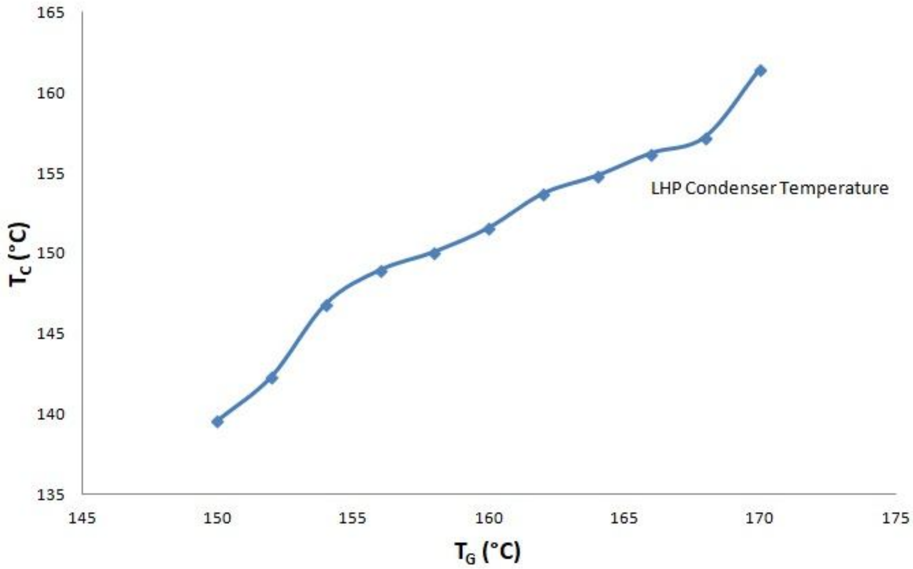

Fig 15: Variation of T_C with the T_G

The Figure 16 to 19 the performance of the modified system can be studied with the variations in the working temperatures.

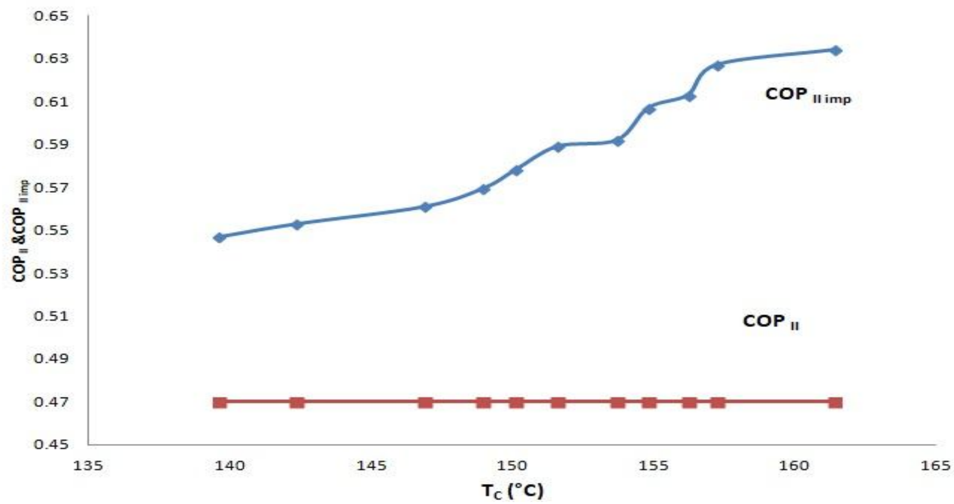

Fig 16: Variation of improvement in COP $_{II}$ with the T_C

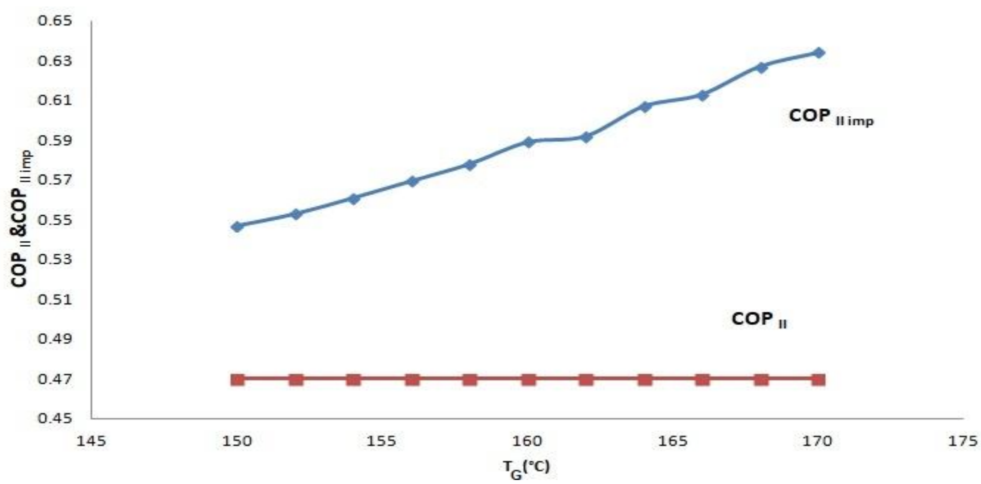

Fig 17: Variation of improvement in COP $_{II}$ with the T_G

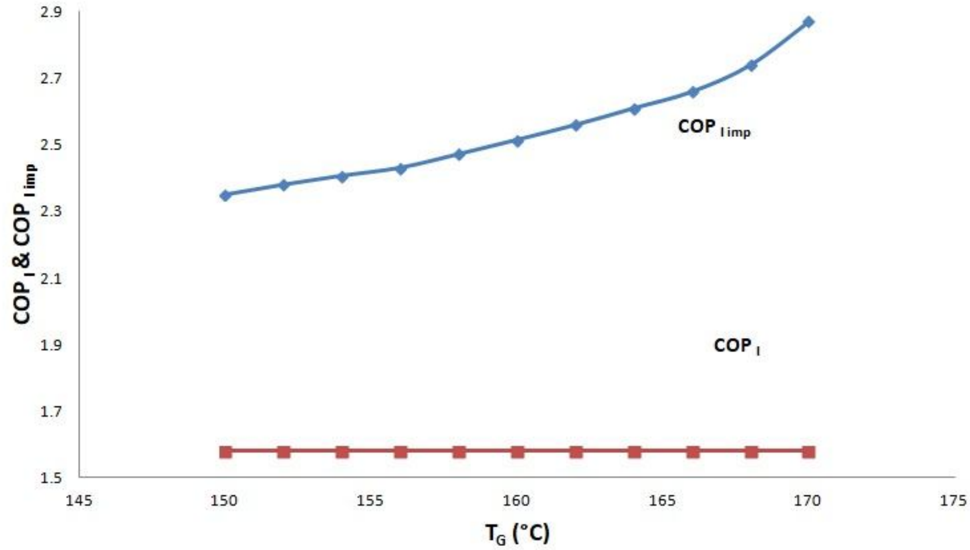

Fig 18: Variation of improvement in COP $_I$ with the T_G

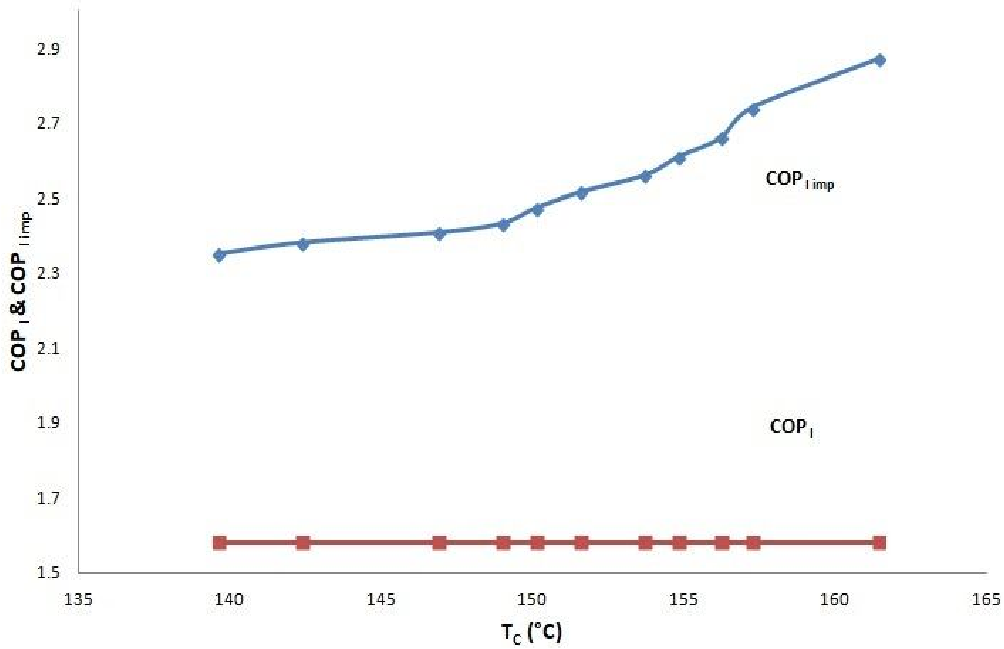

Fig 19: Variation of improvement in COP $_I$ with the T_C

V. CONCLUSIONS

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

A. The average improved COP $_I$ &COP $_{II}$ are 2.545 and 0.588 respectively.
B. The percentage increase in COP $_I$ &COP $_{II}$ can be observed to be 61.112 % and 25.146% respectively.
C. The COP $_I$ has a sharper rise over the range when compared to the COP $_{II}$ for the range of Q_{Cond}.
D. The COP $_I$ shows an 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 151.18 °C.
F. Average Q_{Leak} and Q_{Cond} are found to be 89.44 kW and 71.68 kW respectively.

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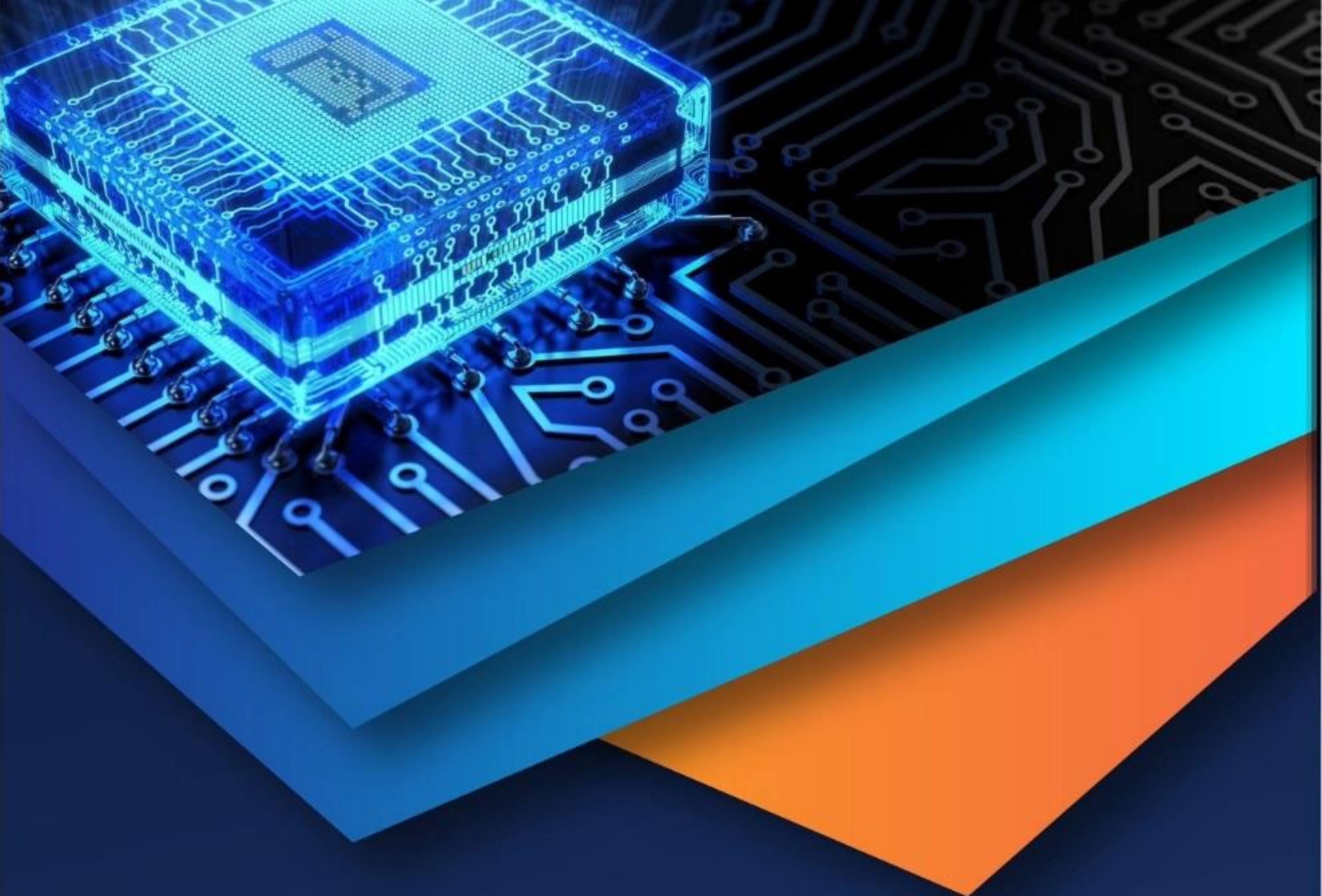

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