iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 6 **Issue:** I **Month of publication:** January 2018

DOI: http://doi.org/10.22214/ijraset.2018.1131

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor :6.887
Volume 6 Issue I, January 2018- Available at www.ijraset.com

Performance Enhancement of Simple Vapour Absorption System Using Loop Heat Pipes

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Abstract: A Vapour Absorption Refrigeration System is able to use waste heat, which makes it very useful in the Energy Crisis. In this research work, as beginning a loop heat pipe (LHP) with different specifications are employed to re-use the heat that has been rejected in the widely used conventional condensers. The condensation after the generator occurs in as a flow condensation as it rejects heat to the evaporator of LHP. Hence by removing the conventional condenser or by reducing its size, it will drastically result in cost reductions. This research work finds that COP $_I$ increases by up to 80% due to the re-use of heat. Also due to the removal of the bulky anergy creating parts, the exergy losses are reduced and the COP $_{II}$ increases up to 30%. The size of the system reduces and the system becomes easy to operate.

I. INTRODUCTION

In a LHP**,** heat enters the evaporator and vaporizes the working fluid at the wick outer surface. Vapors then flow down the system of grooves and the vapor line towards the condenser, where it condenses while the heat is removed. A LHP is a Two-phase cooling device composed of an evaporator, a tubular condenser and connecting lines. It contains a working fluid which transfers heat through continuing cycles of vaporization and condensation. This three key physical phenomenon is involved:

A. Capillary Pumping. Evaporators include an inner capillary prepared of metallic foam with micron level pores. The foam generates a natural pressure head that maintains fluid circulation. Pumping occurs without any consumption of external energy.
B. Vaporization. Due to the latent heat of vaporization, high heat loads (with heat fluxes up to 100W/cm²) can be easily transferred, as working fluid in the LHP evaporates.
C. Condensation. The vapors of working fluid condense in the condenser part and are sent back to the evaporator, completing the loop

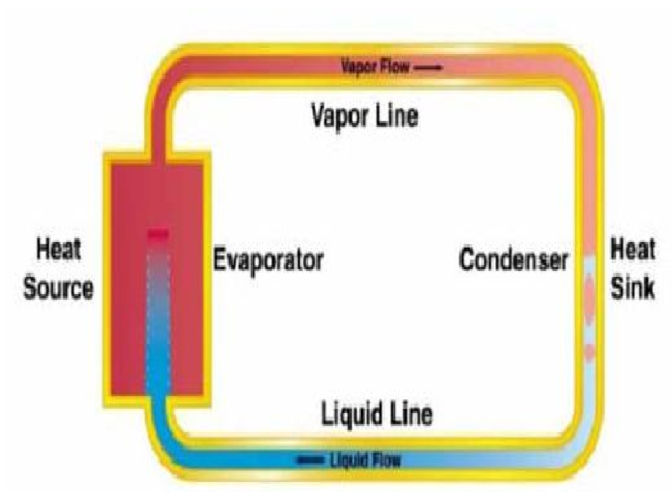

Fig 1: Circular process of a Loop heat pipe [30]

On the other hand, the VARS works on the only low grade energy i.e. Heat. It is always preferred if there is some scope of waste heat from industries or some other sources. It can be combined and used with power plants where there is a huge scope of waste heat. VARS contains a generator that heats up the mixture of weak and strong refrigerant. It eliminates the energy consuming device of VARS called compressor, which has moving parts and requires maintenance. Ammonia-Water (NH_3-H_2O)is commonly used as a working fluid for the cycle.

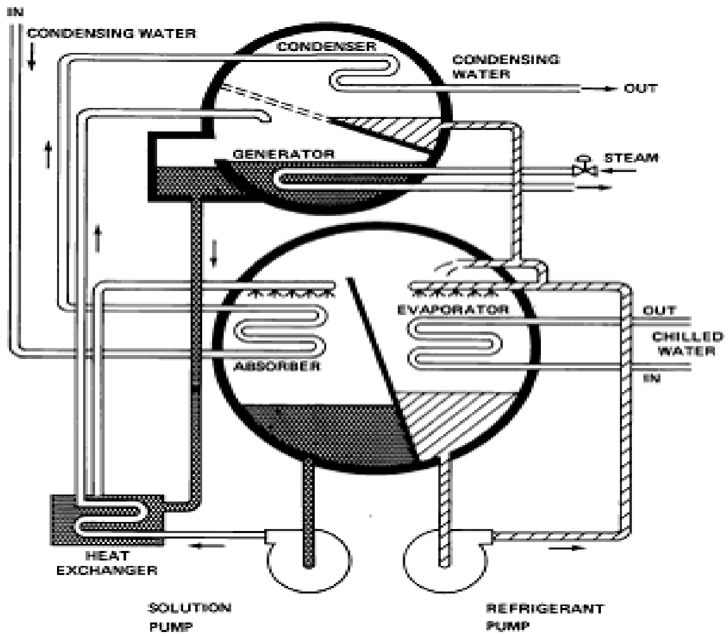

Fig 2: Vapour Absorption Refrigeration System.

VARS has a lower COP $_{I}$ and COP $_{II}$ because it works on the low grade energy when compared to Vapour Compression Refrigeration System. The scopes to improve the performance of the VCRS are being researched upon.

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 effectWater–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. Guilherme B. Ribeiro et al. (2010) investigated a novel evaporator design for a small-scale refrigeration system whose function is to assist the existing heat pipe technology currently used in chip cooling of portable computers. Chengchu Yan et al. (2015) presented a seasonal cold storage system that uses separate type heat pipes to charge the cold energy from ambient air in winter automatically, without consuming any energy. Dr. R.E. Critoph et al. observed carbon - ammonia refrigerators driven by the heat of steam condensing in a thermo-syphon heat pipe. The heat source can be such as solar energy, biomass, or combinations of the two.

In various researches performed, LHPs are being used directly to maintain temperature of several cold storages around the world. It has high heat flux capacity. After reading available research papers following gaps can be identified: There are types of VAR systems such as Single Effect, Double Effect, and Triple Effect etc. in which First Law and Second Law have been studied. But Heat Pipes can be made an integral part of the system and these valuable analyses can be executed on this new system and results can be studied in a comprehensive manner. Waste heat going to the environment from condenser has never been used, which can be supplied back to the generator, requiring low grade energy for its operation. Also the VAR system can be coupled with other systems may be refrigerating or power generating, in which heat is released. The Loop Heat Pipes will make the system compact, and that effect must be studied to optimize the performance of the VAR systems.

The VAR system uses low grade energy for its operation, which can be obtained from several cheaply available sources (solar, waste heat etc). The COP is low and irreversibility related to heat transfer in the cycle is associated. With the use of a Loop Heat Pipe, external heat sources can be connected which will increase the COP of the system. For optimizing a VAR system a LHP can be used to utilise the waste heat for intra-cycle heat exchange, which will eventually increase the First Law COP, Second Law COP and will reduce the irreversibility connected with the operation of a VAR system.

III. SYSTEMS DESCRIPTION

Fig 3 below shows a simple VARS system that works between the temperature range 373K and 278K and its condenser and absorber are at surrounding temperature. It has a generator, absorber, evaporator and a condenser. The system follows the standard VAR cycle.The refrigeration capacity of the system is 90kW. The heat input in generator is107kW. Heat being rejected in the Condenser to the surrounding is 85kW.

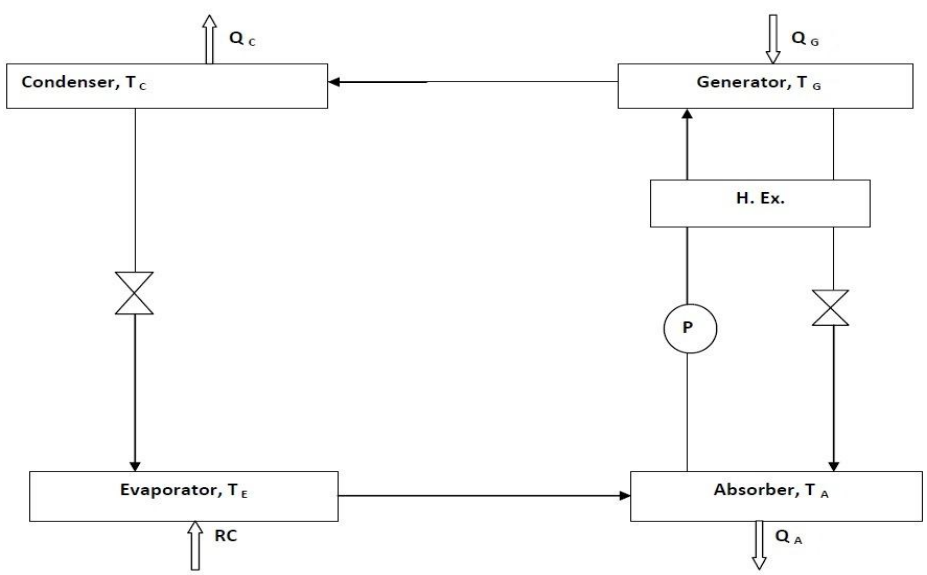

Fig 3: Simple Vapour Absorption System

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The Fig 4 exemplifies a modification in the simple VARS with using a LHP. This LHP will perform the Intra-Cycle heat exchange in the system by absorbing the heat from the condensing strong refrigerant exiting the generator and using that heat to be supplied to the mixture exiting the absorber and before entering the generator, reducing the requirement of heat input in generator. Considering different materials in the LHP the amount of the heat re-usable in the system can be varied and thus simulation will show the changes in the COP_I& COP_{II}. Improvements in the performance and there comparison is also plotted with the help of simulation. The heat leaks in LHP also has some impact on the performance of this system, hence the plots are developed for Q_{Leak} and Q_{Cond}.In this system several bulky components like Heat Exchangers are removed saving cost and irreversibility connected to it. Heat exchange will also become faster as the heat transfer rate is very good with LHP.
The table 1 has the list of the terms used in the research work.

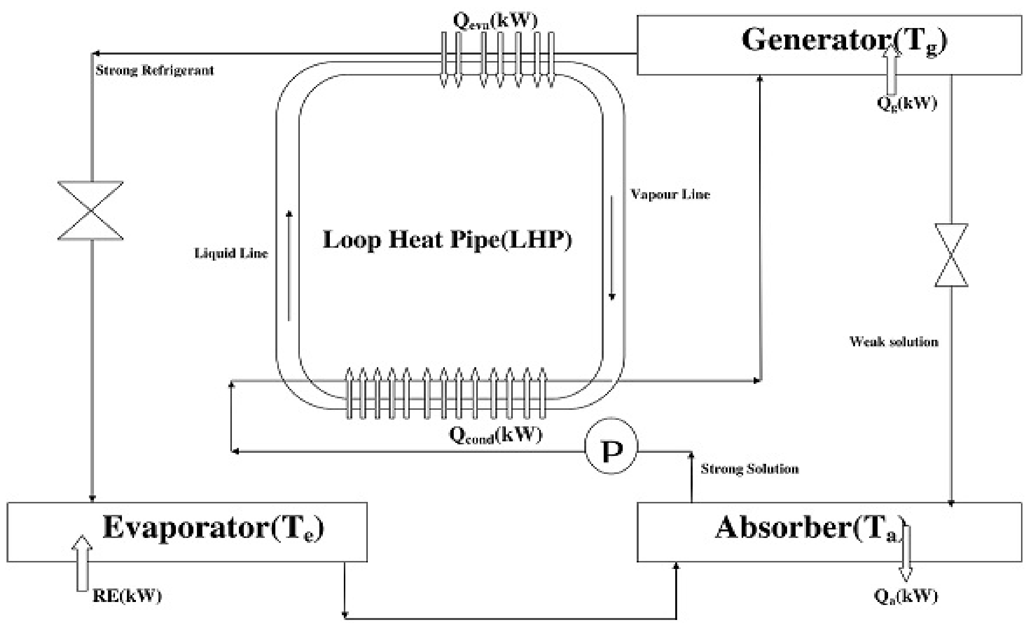

Fig.4: Modified VARS with a LHP [34].

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 K	T_a,T_A(K)
Generator Temperature in K	T_g, T_G (K)
Condenser Temperature in K	T_c (K)
Evaporator Temperature in K	T_E,T_e(K)
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	$\%COP_{I\ imp}$

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Performance	
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	$COP_{II\ imp}$

IV. RESULTS AND DICSUSSIONS

The Fig 5 & Fig 6 show the variations of COP_I and Improved COP_I in the modified system with the heat utilised through the condenser of LHP, $Q_{Cond}$and the total heat leaked from the LHP, Q_{Leak}. The amount of heat utilized in the condenser can be improved by the materials used in the LHP as they improve the Effective Wick Area, Figure of Merit, Pore radius, Wick Angle and Capacity as a whole. [33]

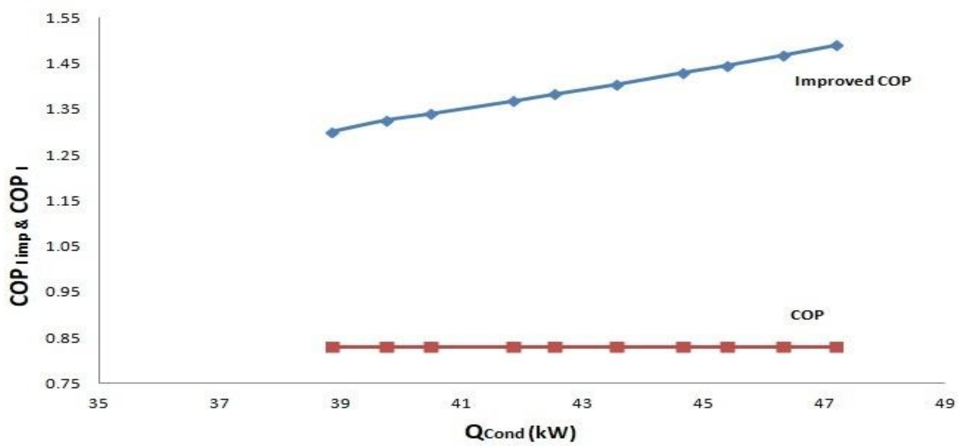

Fig 5: Comparison between COP_I and $COP_{I\ imp}$ plotted with Q_{Cond}

Also the leakage of heat from LHP will also be controlled. The above mentioned figures show that as the Q_{Leak}increases, Q_{Cond}reduces and hence reduces the improvement of COP_I and vice-versa. The relation between the Improvement of COP_I and the Q_{Leak}&$Q_{Cond}$is more or less linear. By reducing the leakage the COP can be increased. The average COP_Iforthe improved system is 1.4 where as the simple cycle had a COP_I of 0.83.

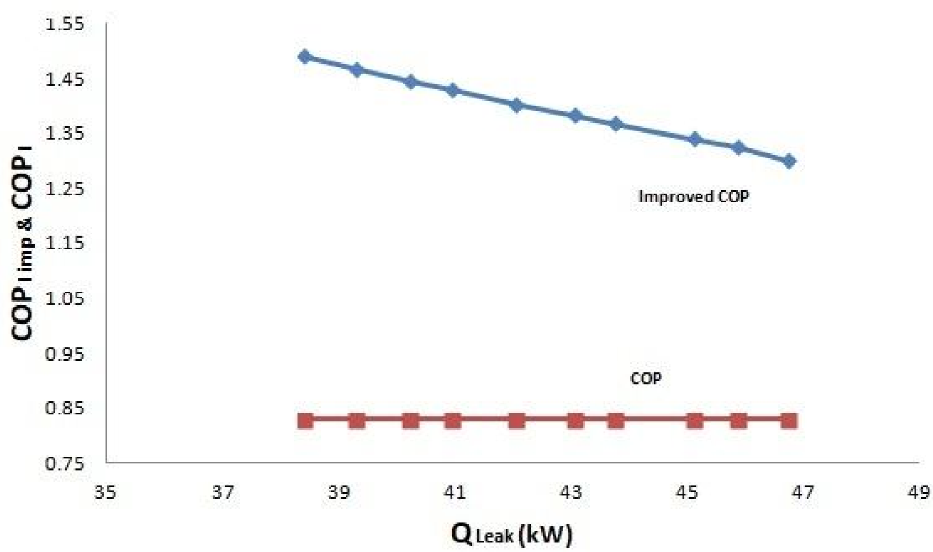

Fig 6: Comparison between COP_I and $COP_{I\ imp}$ plotted with Q_{Leak}

Similarly Fig 7 and Fig 8 show the variations of COP $_{II}$ and Improved COP $_{II}$ in the modified system with Q_{Cond}andQ_{Leak}. As the Q_{Leak}increases, the exergy losses increase and the Improved COP $_{II}$ decreases along with it. After the improvement, COP_{II} is 0.51, whereasfor simple VARS the COP_{II} is 0.42.

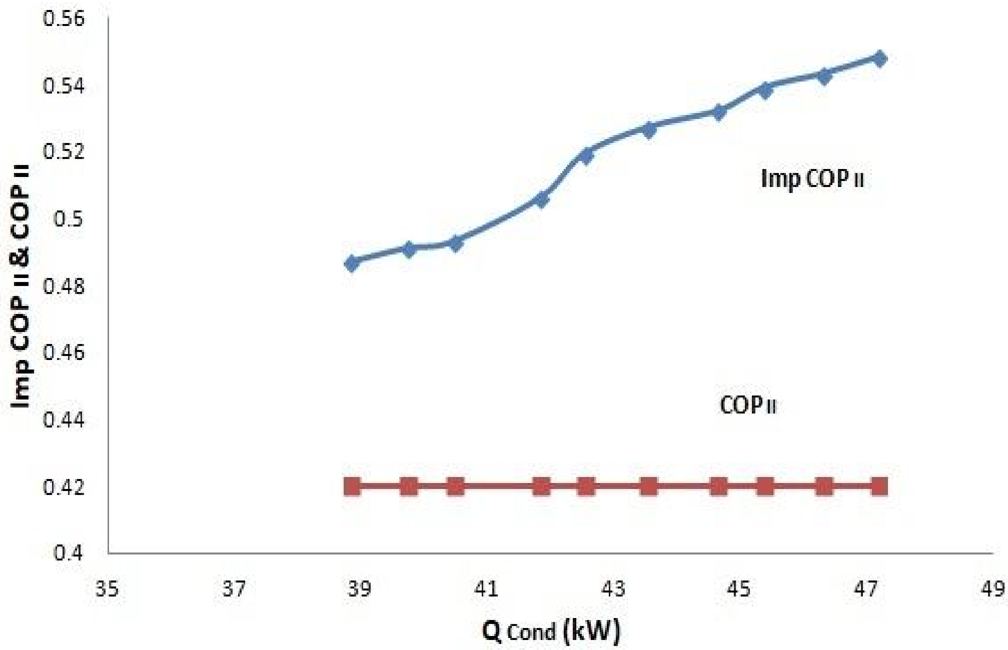

Fig 7: Comparison between COP $_{II}$ and COP $_{II\ imp}$ plotted with Q $_{Cond}$

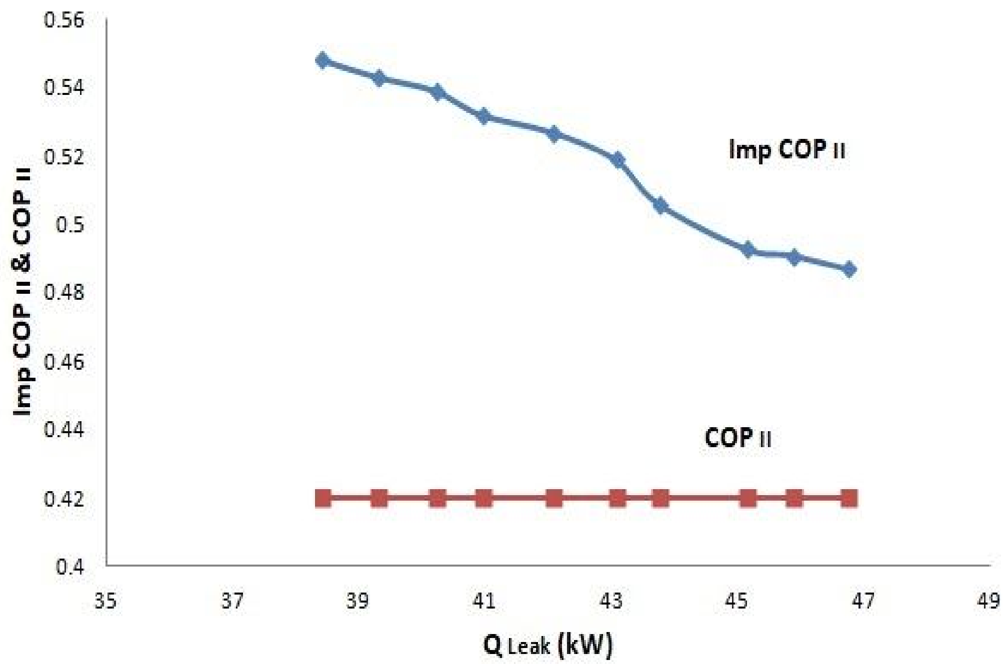

Fig 8: Comparison between COP $_{II}$ and COP $_{II\ imp}$ plotted with Q_{Leak}

In Fig 9 & Fig 10, the COP $_{I}$ and COP $_{II}$ of the modified system are analysed with varying Q_{Cond}andQ_{Leak}. The COP $_{I}$ has larger fluctuations with the $Q_{Cond}$and$Q_{Leak.}$ on the other hand this comparative plot shows that the COP $_{II}$ variations are more are less smooth and linear.

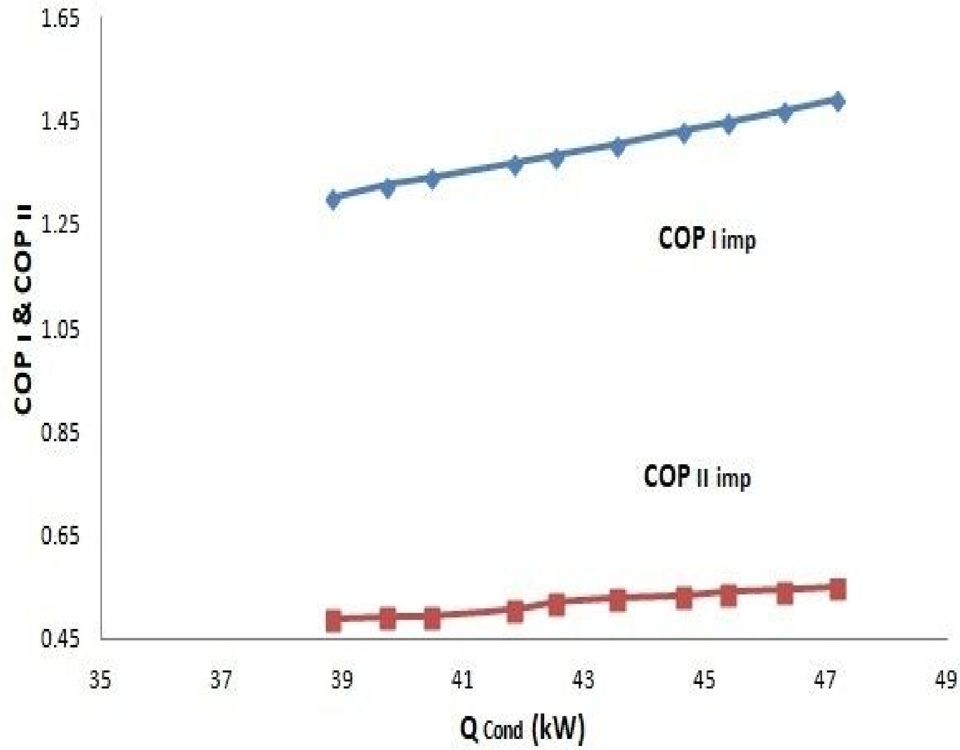

Fig 9: COP $_{I\ imp}$ and COP $_{II\ imp}$ plotted with Q_{Cond}

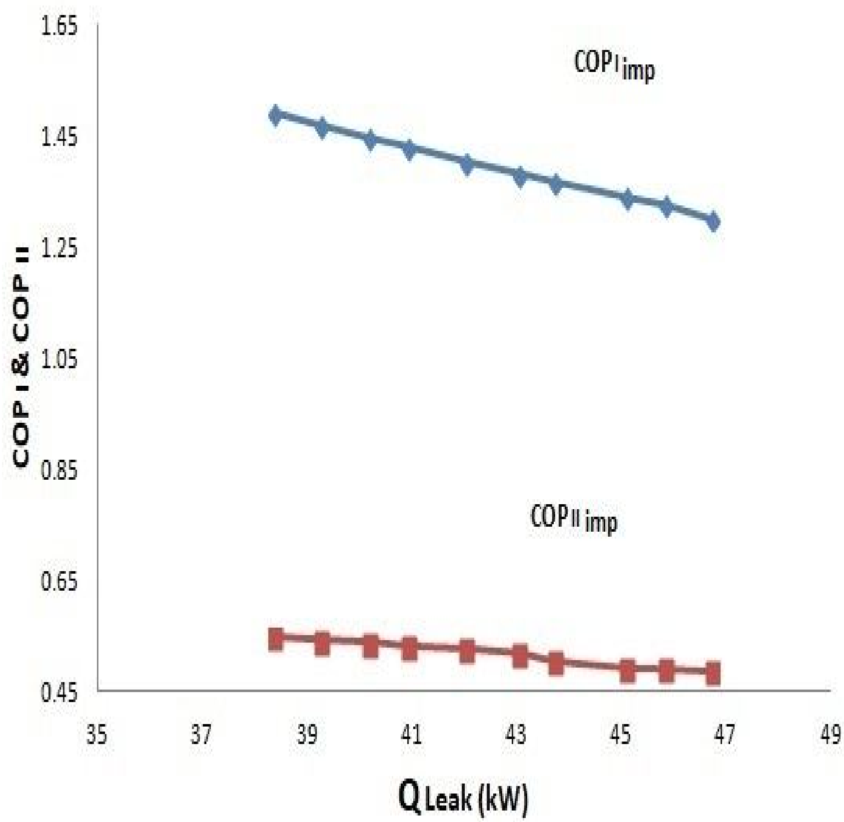

Fig10: COP $_{I\ imp}$ and COP $_{II\ imp}$ plotted with Q_{Leak}

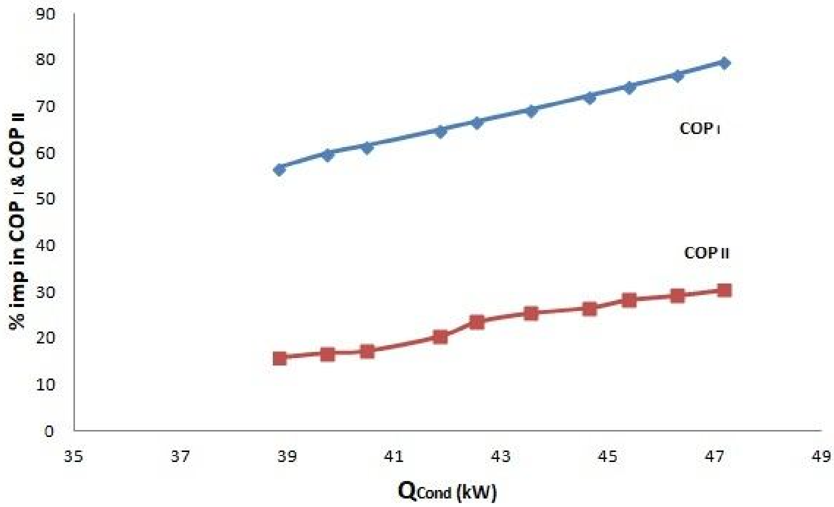

Fig 11: Variation of %COP $_{I\ imp}$ and % COP $_{II\ imp}$ plotted with Q_{cond}

The fig 11 & fig 12 deals with the % improvement in the COP_I and COP $_{II}$ while using the heat from the LHP. The average improvement in COP $_I$ is 68% and that for the COP $_{II}$ is 23%. Gradual and steady increase can be seen in the performance as the heat utilization increases.

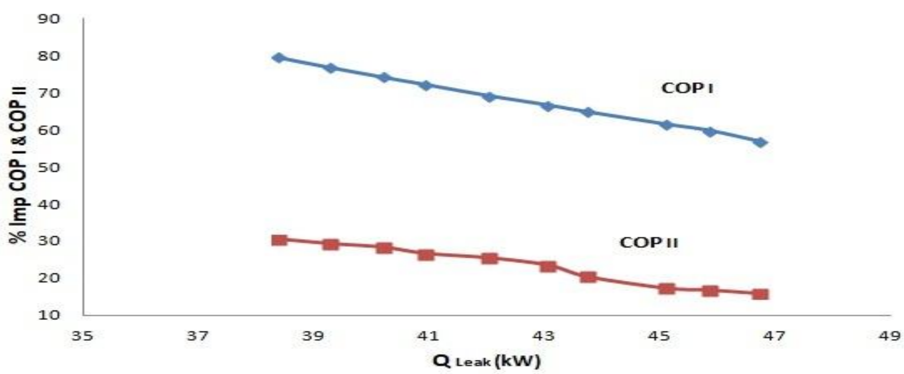

Fig 12: Variation of %COP $_{I\ imp}$ and % COP $_{II\ imp}$ plotted with Q_{Leak}

V. CONCLUSIONS

After the study of the results and inferring from them, the following conclusions can be made:

A. The utilization of heat increases with the change in design and materials of the LHP.
B. By reducing the $Q_{Leak}$the COP_I increases. The average COP $_I$ forthe improved system is 1.4 where as the simple cycle had a COP $_I$ of 0.83.
C. After the improvement, COP $_{II}$ is 0.51, whereas for simple VARS the COP_{II} is 0.42.
D. COP $_I$& COP $_{II}$ increase by good margin of 68% and 23% respectively.
E. The size of the system is reduced and the parts having anergy are reduced.
F. Further improvements can be achieved if more heat pipes are incorporated at various.

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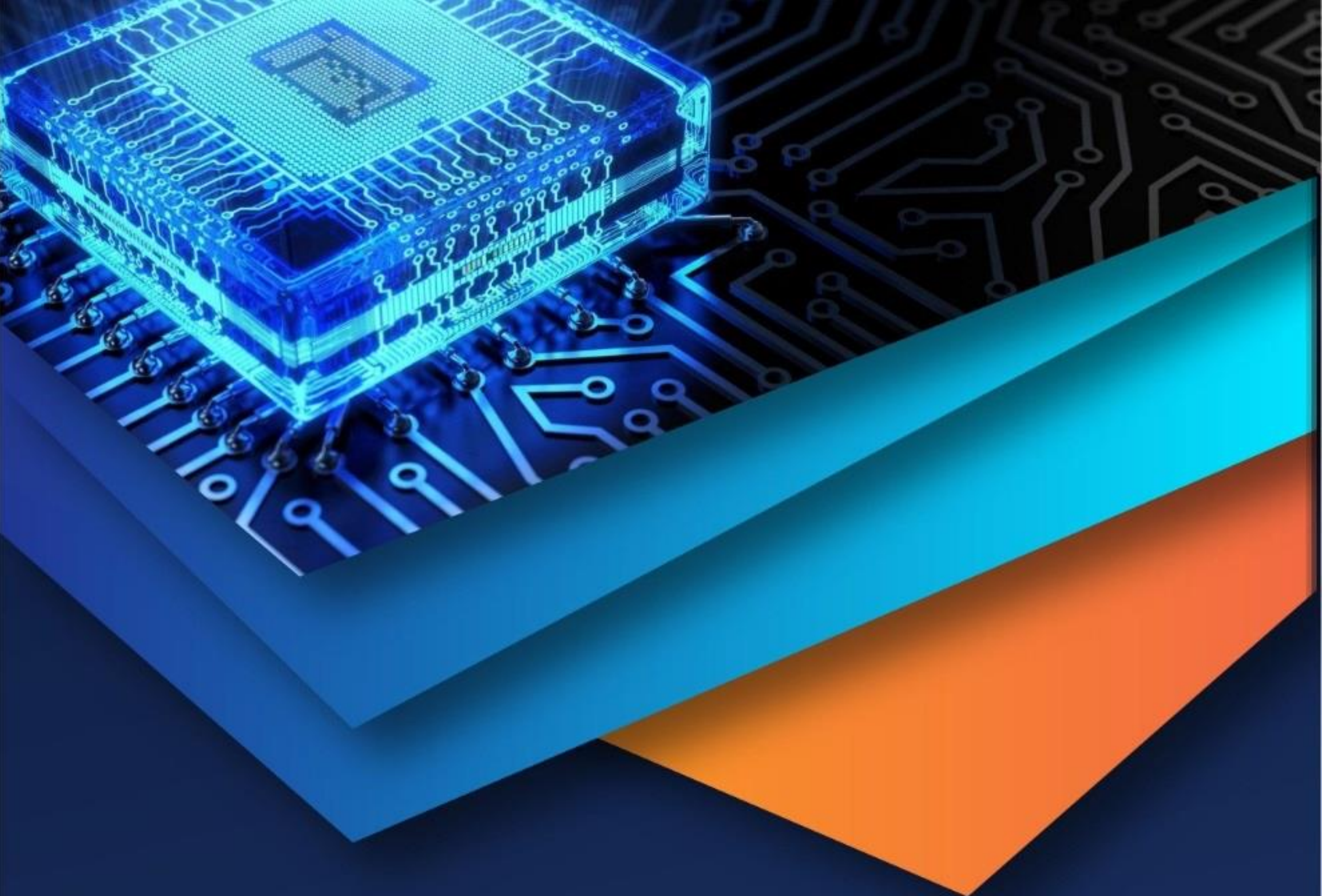

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