Heat Transfer Analysis on Laptop Cooling System Using Loop Heat Pipe Technology

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ABSTRACT

Science and Technology has prompted a new rebellion in humanoid life. Due the growth in technology, microelectronic tools especially laptops trail to be slighter, lighter and faster. As a high dispensation unit is complicated, laptops are exposed to statement a lot of heat, and in turn crafting hot spots on the dispensation unit. Since the cooling system presently working is not much disciplined to determination absent the heat in hot acnes, it is replaced with contemporary small Loop Heat Pipe (mLHP) knowledge for improved chilling. In totalling, this new inactive chilling solution has so many compensations similar to the present vigorous chilling solutions such as the noise-free action, inferior liveliness ingesting and advanced dependability. In this exploration, aalphanumeric archetype of laptop with the new cooling system is intended and examined using Computational Fluid Dynamics software Fluent. This examination is approved out with numerous heat debauchery rates of the heat source 30 W, 32 W, 43 W for dissimilar working conditions such as standard use of the notebook, standard use while charging the battery and 100% CPU load respectively. The heat dissipation and distribution for different working conditions are investigated. Based on the results obtained, a contemporary cooling solution is proposed for the overheating problem of laptops.

Keywords: *Heat Transfer, Computational Fluid Dynamics, Heat, Contemporary Cooling Solution*

I. INTRODUCTION

Loop heat pipes (LHPs) are highly efficient heat-transfer devices with a considerable potential for development and application in various fields. At present LHPs are successfully employed in space engineering. Usually these devices have a cylindrical evaporator or rectangular evaporator. The shape and the size of the condenser may be quite different depending on the means and conditions of its cooling. The length of the vapour and the liquid lines connecting the evaporator and the condenser can reach a distance of 10 m and more.

In order to expand the field of LHPs application, for instance, for cooling electronics, personal computers and notebook computers, it is necessary to miniaturizethese devices. LHPs have more developed evaporator structure with the well-distributed system of vapour channels that provide high-heat transfer rate from the heated wall of the evaporator to the evaporating meniscus inside the wick.

As a result, LHP evaporators are able to handle very high-heat fluxes with low-heat transfer resistances. Latest laptop models are equipped with more than one high processing chipset (e.g., memory chip, graphics chip) that increases the cooling requirements. This project focuses on using miniature Loop Heat Pipes (mLHPs) for effective cooling of laptops.

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II. LHPSASTHERMALMANAGEMENT DEVICES

At present, different cooling alternatives are available for the thermal management of the electronic devices. An optimum choice depends on the number of factors such as thermal performance, reliability index, acoustic issues, cost of manufacturing, future potential and scope for miniaturization. In the domain of two-phase technology, a Loop Heat Pipe (LHP) can be considered as one of the potential candidates for cooling compact electronics with high-powered microprocessors. A LHP consists of an evaporator, with fine pored wick structure, and a condenser section connected with separate vapour and liquid flow lines. It uses latent heat of evaporation and condensation to transfer heat, and relies on the capillary pressure generated by the wick structure for the circulation of the working fluid around the loop.

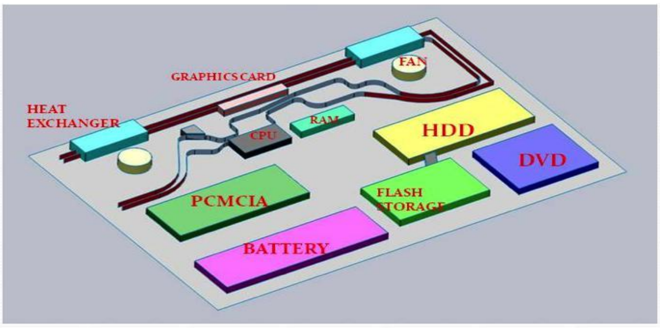
For laptop cooling, miniature versions of LHPs can be considered as potential alternatives to convectional heat pipes because of their high-heat transport capacities and flexible design structures.

III. CFD BASE DESIGN MODEL

The base model for CFD analysis is taken from the reference [1]. The new cooling model, is equipped with miniature Loop Heat Pipes (mLHPs) that consists of two rectangular flat evaporator of area 47 mm x 37 mm (length x width). It consists of a flow channel where the working fluid flows and condenses with air-cooled fin and tube condenser. A pump of capacity 0.43 m^3/min is attached in order to support the return water flow to the evaporator. The fan speed is set to 0.1 m^3/min to radiate the heat from the condenser liquid. The working fluid in this set up is water.The selection of materials for the cooling system is given. The heat pipe and base plate are made with copper has high thermal conductive of 398 K. Hence copper is universally preferred as the spreader material that actively transfers heat to the cooling system.The design parameters for the new miniature Loop Heat. The CFD model with the boundary block of components and the novel-cooling model as shown in Figure 1 are obtained from a series of steps.The individual components and position of different units of laptops are understood from the Figure 1, which is under the section Studies on Cooling System of Laptops.

- Two evaporators of area 47 mm x 37 mm as given in Table 4.2 are designed for the following evaporator considerations.
- The evaporator is rectangular in shape with 20 microchannels, and with an individual cross-section of 0.7 mm deep and 0.5 mm wide, were machined on the inside of the active zone of area 22 x 22 mm.

Both evaporators are placed in between CPU, graphics card and RAM where a large portion of heat is generatedMicrochannels heat sink design includes a 10 x 10 mm^2 copper base on which 49 rectangular channels with individual Pipe cooling system is given. It is necessary to define the boundary conditions in CFD analysis.



IV. CFD MODEL

The significant part in designing a CFD model is the prior planning of assigning boundary condition for complex systems. In this project, the cooling system itself has a complex structure, and as the cooling unit is priority of analysis, the other components are treated as boundary condition blocks. The isometric view of CFD modelled component is shown in figure 1.

- Depth, width, spacing, and length of 1.3 mm, 0.1 mm, 0.1 mm, and 7mm were fabricated
- Microchannels with their high-aspect ratio provide large surface to volume ratio for efficient heat transfer from the active heated zone to the working fluid Two fan cooled fin and tube condensers of length, width, thickness, 50 mm, 18 mm and3 mm respectively are designed
- Fan condition with the air outlet of 0.1 m^3/min is setup for condensing units
- The inlet and outlet of pump to heat pipe is left as the discontinuity as CFD software has the pump condition that can be defined for the desired flow rate.
- The cooling unit is assembled similar to the CFD base model shown in Figure 4.6
- The entirely assembled cooling system with two evaporators, one microchannel, two condensers are set as a single unit along with the surrounding laptop component blocks
- Such as CPU, RAM, Graphics card, HDD drive, Flash storage, Battery, DVD, etc.

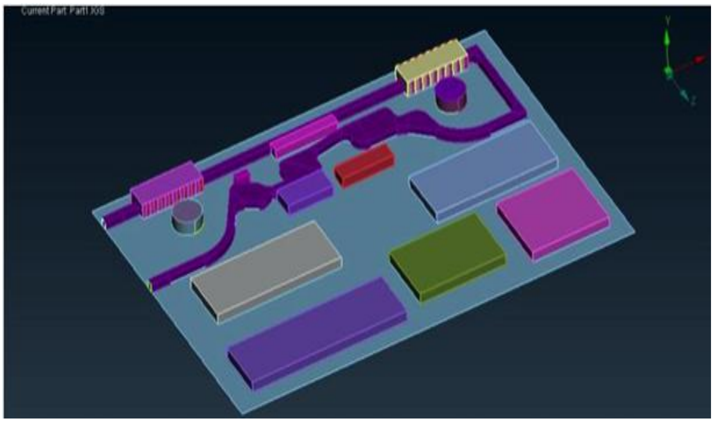
V. CFD PROCESSING

5.1 CFD Domain Extraction of the Modelled Cooling System

The first and foremost step is CFD pre-processing of the modelled loop heat pipe cooling system is geometry clean up. This clean-up has been done using the ANSA meshing tool which is very robust clean up tool. Extracting the fluid region is the next step in which all the surfaces which are in the contact of fluid are taken alone and all other surfaces are removed completelyExtracted domain of the cooling system is shown in figure 2.

5.2 Meshing

After cleaning up the geometry, the surface mesh is generated in ANSA tool itself. All the surfaces are discretized using tri surface element. As the geometry has some complicated and skewed surfaces tri surface elements are used to capture the geometry. The figure 6.5 shows the mesh of extracted domain.The volume mesh for the static zone of the extracted domain of the cooling system is generated using ANSYS-TGRID which is a robust volume mesh generator. The volume of the static zone of the extracted domain is discretized using tetrahedron and prism elements. The prism elements are wedge shaped elements in which the higher order differential form of the navier-stokes system of equations are solved at each and every cell centroid of the elements for high accuracy results. Prism elements are also used to capture the boundary layer and recirculation in the static flow domain. Fine meshes are enabled at high working condition zones. The Mesh component of the cooling system is characterized with following properties. Nodes: 14147, Faces: 109346, Cells: 49423 with 10744 Boundary nodes, 21596 boundary faces and 29 boundaries face zones. The total elements available in the cooling system mesh domain are 59756 elements.



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5.3 Solver Set Up and Methodology

- ANSYS-FLUENT is used as the solver for this case.
- The solver is set for pressure based type, absolute velocity formation and steady time.
- Energy equation is activated to solve thermal distribution.
- The model with energy equation is activated for laminar viscous fl
- The materials for solid are set as: cooperforheat pipe and nickel for the wick.
- The material for fluids is set as: water and air are the cooling working fluids.
- The reference values of the cooling system analysis are marked as per the desired component and the working conditions

5.3 Initial and Boundary Conditions

The whole notebook chassis is the computational domain that consists of CPU, CPU heat sink, heat pipes, heat exchanger, fans; aluminium heat dissipation plates, RAM, DVD, battery, PCMCIA card, HDD, speakers, ventilation holes, PCB, and miscellaneous cards attached to PCB are modelled according to measured dimensions and manufacturers' specifications. The heat pipes are represented as solid rods having the same physical dimensions with the actual heat pipes and a high thermal conductivity in the axial direction that is taken as 40,000 W/(m·K). The ambient temperature is taken as 25 °C and at steady state, since the table surface on which the notebook is placed will be at a similar temperature to the bottom surface temperature, irradiative transfer from the bottom.

5.5 CFD Simulation Approach

The apple Macbook Pro notebook is considered forthis project on which a hybrid thermal system is used. The whole notebook chassis is the computational domain, which is shown in Figure 4.8. In this chassis, CPU, CPU heat sink, heat pipes, heat exchanger, fans, aluminium heat dissipation plates, RAM, DVD, battery, PCMCIA card, HDD, speakers, ventilation holes, PCB, and miscellaneous cards attached to PCB are modelled according to measured dimensions and manufacturers specifications. The components, which have no or little effect on the fluid flow and heat transfer, are not modelled .The operating conditions of the components are not steady in aVentilation holes are neglected. Average heat transfer coefficients are defined for the top and side surfaces of the chassis separately. Finally an iterative CFD approach is used to obtain the heat transfer coefficients for each case using available correlations for the new miniature Loop Heat Pipe Cooling system. For a mesh involving 59756 elements, the iteration taken for the solution to get converged is 112,846 iterations.

VI. RESULTS AND DISCUSSION

6.1 CFD-Fluent Results

The Computational Fluid Dynamics analysis results for the new laptop cooling system are obtained for the following three different working conditions of laptop.

- Laptop working under normal condition
- Laptop working under normal condition while charging
- Laptop working under 100% CPU load

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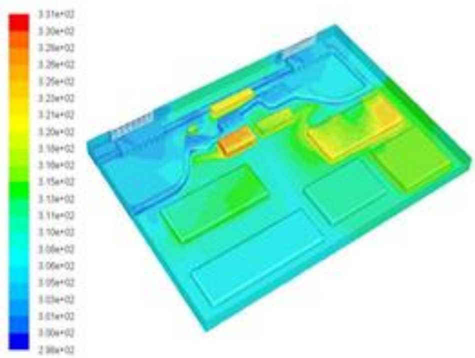
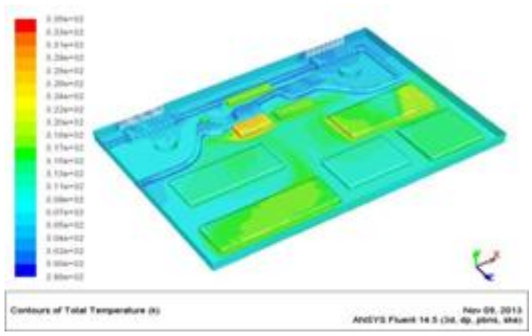
6.1.0 Laptop Working Under Normal Condition (NC)

The input and boundary condition values for the simulation are taken from Table 1. The thermal conductivity, pump condition, fan condition, ambient condition, density of working fluids, heat equation, etc. are defined. The wall conditions are setup and the solution is iterated.The results are obtained from graphics and animation tab, once the solution is converged. The temperature distribution plot for the first working condition is shown in Figure 3. The temperature distribution plot clearly shows that maximum heat is contributed on CPU, which is 325 K. Furthermore, the different components thatdissipate heat are also maintained at a temperature range within maximum operating temperature. The CFD average temperature (Tavg) values and CFD hot spot temperature individual components of laptops can be obtained from Figure 3. The values obtained from Figure 3 are noted down in Table 2 and Table 3 to check whether the cooling system is efficient enough to maintain the laptop components under their maximum operating conditionnotebook computer, which change the heat dissipation rates of the components. However, in this project, considering the specifications of the manufacturers, an operating condition is chosen for each component in each analysed case (Table 1) and the calculations are performed according to the steady state assumption.Transient thermal management of a notebook is a different issue requiring dynamic control strategies. No slip boundary condition is applied for the chassis and the component walls in the domain. The heat transfer mechanism outside the notebook chassis is assumed to be natural convection. The convective effects of the flow coming through the fan exits



6.1.2 Laptop Working Under Normal Condition While Charging (NCC)

The input and boundary condition values for the simulation for the laptop working under normal condition while charging are taken from Table 1. The thermal conductivity, pump condition, fan condition, ambient condition, density of working fluids, heat equation, etc. are already defined in previous simulation. Hence there is no necessity to define them again, unless the software is reset or set for another data. The wall conditions are setup and the solution is iterated.In a similar way, the results are obtained from graphics and animation tab, once the solution is converged. The temperature distribution plot for the second working condition is shown in Figure 4. It is observed that the temperature distribution is almost similar to the first condition but in the second case battery contributes to the heat dissipation condition as the charging unit heats the battery. The temperature distribution plot clearly shows that maximum heat is contributed on CPU, which is 326 K. Furthermore, the different components that dissipate heat are also maintained at a temperature range within maximum operating temperature. The battery that dissipates 2 W heat reduces the heat dissipation of hard disk drive while charging. This improvement in HDD component is because the laptops are modeled to perform better while charging.In an analogous way, the CFD average temperature (Tavg) values and CFD hot spot temperature individual components of laptops can be obtained from Figure 4. The values obtained from Figure 4 are noted down in Table 2 and Table 3 to check whether the cooling systemfor the second case is efficient enough to maintain the laptop components under their maximum operating condition.



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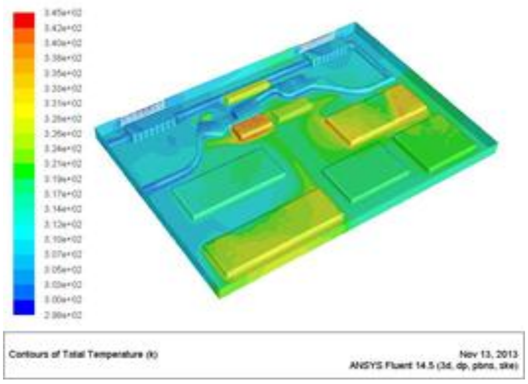
6.1.3 Laptop Working Under 100% CPU Load (100% CPU Load)

Laptops when worked continuously for a long time with many rouge applications in process, then it takes a full CPU load (100% CPU load). The input and boundary condition values for the simulation for the laptop working under 100% CPU load are taken from Table 1. The thermal conductivity, pump condition, fan condition, ambient condition, density of working fluids, heat equation, etc. are already defined in previous simulation. Hence there is no necessity to define them again, unless the software is reset or set for another data. The wall conditions are setup and the solution is iterated.

Similarly, the results are obtained from graphics and animation tab, once the solution is converged. The temperature distribution plot for the full CPU working condition is shown in Figure 5. It is noted that the temperature distribution is maximum at CPU and secondly the HDD and battery throw in for the temperature distribution from the CPU. HDD at 100% CPU load, sometimes, work above the maximum operating temperature. Hence it is better for a notebook computer to operate at normal working conditions.



The temperature distribution plot clearly shows that maximum heat is contributed on CPU, which is 335 K. In addition, the different components that dissipate heat are also maintained at a temperature range within maximum operating temperature. The battery, even though, does not dissipate heat; it generates heat due to the effect of 100% CPU load working condition

Table 1. Temperature Factors

Component	Dissipation at Normal Condition (W)	Dissipation at Normal Condition while charging (W)	Dissipation at 100% CPU load (W)	Maximum Operating Temperature T_{max} °C
CPU	21	21	30	100
RAM	0.5	0.5	0.5	70
HDD	5	5	9	60
Graphics card	2	2	2	85
South Bridge	0.5	0.5	0.5	85
PCMCIA	1	1	1	85
Battery	0	2	0	70
Total	30	32	43	35

6.2 Discussion

Table 2.Temperature Distribution at Its Minimum

Component	Tavg at Normal Condition °C	Tavg at Normal Condition while charging °C	Tavg at 100% CPU load °C	Maximum Operating Temperature Tmax °C
CPU	50	51	62	100
RAM	40	44	52	70
HDD	46	43	55	60
Graphics card	47	44	52	85
South Bridge	40	42	47	85
PCMCIA	38	39	43	70
Battery	33	44	49	55

Table 3. Temperature Distribution to Hot Spots

Component	T at Normal Condition °C	T at Normal Condition while charging °C	T at 100% CPU load °C	Maximum Operating Temperature Tmax °C
CPU	55	55	65	100
RAM	43	46	54	70
HDD	48	48	59	60
Graphics card	48	45	53	85
South Bridge	42	43	48	85
PCMCIA	40	40	45	70
Battery	35	45	54	55

From Table 2 and Table 3, it is clear that the temperature distribution on all individual components is within the maximum operating temperature range, even when there is a hot spot created on the component.It is also observed that hard disk drive that usuallyIn all the three cases, the temperature distribution in components is maximum at the Central Processing Unit and it is made sure the CPU does not reach the maximum operating temperature. Since water is used as a working fluid in normal heat pipe cooling, and when CPU reaches the maximum temperature, the might get converted in steam, which in turn damages the total system of cooling unit. But the usage of Loop Heat Pipe cooling drives away maximum heat from CPU and ensures a safe operationexceeds the maximum operating temperature during 100% CPU load, also works within the maximum temperature, even if there is a hot spot exists. Thus this contemporary cooling solution is more efficient than the present cooling system available.

6.3 Comparison of Results with Standard Results

The standard result of the conventional cooling solution mentioned in section 4.2 of the report, obtained from [7], records the maximum temperature in the case 100% CPU load. Some of the temperature values of the components are obtained from the real time usage of laptop with the help of Temperature Monitor Software. The temperature readings of the standard conventional cooling system are tabulated.

Table 4. Temperature Distribution to Hot Spots

Component	Temperature Distribution at 100% CPU load °C (conventional)	Temperature Distribution at 100% CPU load °C (mLHP)	Maximum Operating Temperature Tmax °C
CPU	81	65	100
RAM	63	54	70
HDD	68*	59	60
Graphics card	61	53	85
South Bridge	56	48	85
PCMCIA	51	45	70
Battery	62*	54	55

The results obtained from the project shows that the miniature loop heat pipe cooling system an economical cooling solution even when laptop is working under 100% CPU load. The maximum temperature recorded at the individual component is the hotspot temperature of that component.

Hence the hotspot temperature of the component is tabulated in Table 4 and the results are compared with the standard results obtained from the existing cooling solution.From the Table 4, it is clear that the Hard Disk Drive and Battery are exposed to work at a higher temperature, exceeding the maximum operating temperature, under 100% CPU load condition. But the usage of miniature Loop Heat Pipe cooling system enables more efficient cooling and also helps the components of laptops to work below the maximum temperature range. Hence the mLHP cooling solution is considered as the better cooling system when compared to the existing cooling system.

VII. CONCLUSION

The thermal management of a typical notebook computer passive heat dissipation path is investigated with the help of a commercial CFD software package, ANSYS Fluent.From the obtained CFD results, the usage of miniature loop heat pipe for cooling system is a better cooling solution for the notebook computers. It is also showed that the performance for high-powered chip cooling application and can be easily integrated into thecompact enclosures of modern laptops.Finally, it is concluded that this passive cooling solution is better in heat dissipation and cooling the system, compared to the existing active cooling solutions; and it also has additional advantages such as the noise-free operation, lower energy consumption and higher reliability.

REFERENCES

[1] Randeep Singh et al “Thermal Potential of Flat Evaporator Miniature Loop Heat Pipes for Notebook Cooling”, Components and Packing Technologies, IEEE Transactions on (Volume: 33, Issue 1)

[2] Ilker Tariet al “CFD Analyses of a Notebook Computer Thermal Management System and a Proposed Passive Cooling Alternative”, Components and Packing Technologies, IEEE Transactions on (Volume: 33, Issue 2)

[3] S. H. Moon et al "Improving thermal performance of Miniature Heat Pipe for Notebook PC Cooling", Microelectron. Rel., Vol. 42, No. 1, pp. 135 – 140

[4] Randeep Singh et al “Miniature Loop Heat Pipe With Flat Evaporator for Cooling Computer CPU”, Components and Packing Technologies, IEEE Transactions on (Volume: 30, Issue 1).