Studies on Single-phase and Multi-phase Heat Pipe for LED Panel for Efficient Heat Dissipation

Vyshnave K C¹, G Rohit¹, D V N S Maithreya¹, Rakesh S G¹#
Department of Mechanical Engineering
Amrita School of Engineering, Bengaluru
Amrita Vishwa Vidyapeetham, Amrita University, India

¹#e-mail: sg_rakesh@blr.amrita.edu

Abstract. The popularity of LED panel as a source of illumination has soared recently due to its high efficiency. However, the removal of heat that is produced in the chip is still a major challenge in its design since this has an adverse effect on its reliability. If high junction temperature develops, the colour of the emitted light may diminish over prolonged usage or even a colour shift may occur. In this paper, a solution has been developed to address this problem by using a combination of heat pipe and heat fin technology. A single-phase and a two-phase heat pipes have been designed theoretically and computational simulations carried out using ANSYS FLUENT. The results of the theoretical calculations and those obtained from the simulations are found to be in agreement with each other.

Keywords- Heat Pipe, Heat Dissipation in LED Panel, Single Phase Heat Pipe, Multi Phase Heat Pipe

1. Introduction

Light sources contribute to around 20% of the total electric energy consumed worldwide. Since LEDs are one of the most efficient light sources, it is of paramount importance to improve its reliability and life time. The reliability and life time is limited by the heat produced inside the chip, which results in the increase of junction temperature.

Studies have been carried out by Amrutha Thomas et al. [1] to determine the effect of junction temperature on the performance of LEDs. Experiments are conducted using Edison C series 1W cool white power LEDs. Three such LEDs are placed in series and two more such series combinations are connected in parallel to form a 6W LED. On applying a voltage of 9.3V, the effect of the junction temperature on LED current and light intensity is studied using a photometric integrator. The results show that there is a significant decrease in current when the temperature is increased. This also contributed to a sharp decline in light output when the temperature is increased. The authors have thus concluded that limiting the junction temperature is an important parameter in the design of LED panels.
Heat fins have also been considered for the development of cooling techniques. Chi-Chang Hsieh et al. [2] have developed a novel fin type heat sink to achieve this. The hollow rectangular fin design is able to achieve a significant reduction in the maximum temperature of the LED panel. Though heat fins can be effective, it is necessary to take the heat away from the chip as quickly as possible so that the junction temperature is under permissible limits. D.V. Kozak et al. [3] have developed a two phase heat transfer device to perform this function. The study suggests that gravitational heat pipe with threaded capillary structure is more advantageous than thermosyphon systems. Use of fine pitch thread capillary structure can also increase the manufacturability of the heat pipe.

To design an effective thermal management system, it is important to know the amount of heat that needs to be removed from the LED panel. Kaya M. et al. [4] have shown that about 80% of the power rating of the LED panel is converted into heat. Heat pipe may not always be the solution for the removal of heat. In fact, for lower heat loads, the working of the heat pipe maybe fairly unstable resulting in lower velocities of the working fluid. This increases the thermal resistance of the heat pipe due to which they become less effective. J.C. Wang et al. [5] have shown that for a LED of less than 30W power rating, heat pipe is not required for heat dissipation. Different types of heat pipes may be used for LEDs of 30W rating and above. The wick structure and the orientation can also have considerable effect on the performance of the heat pipe. Loh C.K. et al. [6] have shown that in heat pipes with wick structures of lower capillary limit, gravity assistance is important for good performance.

Alizadehdakhel A. et al. [7] in their study have modelled a simultaneous evaporation and condensation phenomena in a thermosyphon. The volume of fluid (VOF) technique is used in this model. The CFD predicted temperature profile in the thermosyphon has been compared with the experimental measurements and a good agreement has been observed. They have concluded that CFD is a useful tool to model and explain the complex flow and heat transfer in a thermosyphon. The fill ratios also have a significant impact on heat pipe performance. B. Fadhl et al. [8] have shown that higher fill ratios can result in larger heat transfer from evaporator wall to the working fluid enhancing the evaporation. But this can also cause bubble formation at the evaporator due to which the heat transfer to the evaporator will reduce. Hence an optimum value of fill ratio has to be found out.

2. Theoretical Calculations
Following equations [10] and [11] have been used in theoretical calculations in our study.

Heat associated with internal energy, \( Q_1 = mC_p(T_1 - T_2) \)

Convection Heat, \( Q_c = hA_s(T_1 - T_2) \)

Heat associated with fin, \( Q_f = (hpKA_c)^{0.5}(T_1 - T_2)\tanh(Ml) \)

Where, \( M = \left( \frac{(hp)}{(kA_c)} \right)^{0.5} \)

Heat associated with hollow cylinder, \( Q_{cy} = \left( \frac{2\pi K_{cy}(T_1 - T)}{\ln \frac{R_2}{R_1}} \right) \)

Heat Associated with sensible and latent heat, \( Q_{sp} = m_aC_{pa}(T - T_1) + m_lC_p(T_2 - T) \)

Where, \( A_s \) is the surface area of the top face of the aluminium panel, \( T_1 \) and \( T_2 \) are final and initial temperatures of the LED panel, \( h \) is the convective heat transfer coefficient, \( p \) is the perimeter of the fin, \( K \) is the thermal conductivity of aluminium, \( l \) is the length of the fin, \( A_c \) is the c/s area of the fin,
$K_{cu}$ is the thermal conductivity of copper, $R_2$ and $R_1$ are the outer and inner radius of the copper pipe, $T$ is the temperature of evaporator region, $m_w$ and $m_v$ are the mass of water and water vapour, $l_h$ is the latent heat of water, and $C_{pw}$ and $C_{pv}$ are the specific heat values of water and water vapour respectively.

3. Methodology

The heat pipe design has been carried out using theoretical and computational methods for both single phase and two phase phenomena. The standard Aluminium LED panel (Figure 1) of 30W power, with dimensions 45.6mm x 45.6mm x 4.3mm thickness, having a central chip of dimension 13.5mm x 13.5mm x 1mm thickness is used in the study.

![Figure 1. Depiction of LED panel](image)

As per the literature, the amount of heat produced in an LED Panel is around 80% of the power rating [4]. The power rating of the LED panel under study is 30W and hence the amount of heat produced will be 24W, which needs to be effectively dissipated to keep the LED panel chip at a safe temperature of 80°C. The ambient temperature is assumed to be 25°C. C.Y. Ho et al. [9] have reported that steady state conditions are achieved in about 20 minutes after the LED panel is powered on. The total heat produced during this time is found to be 28.1kJ, of which 1kJ is utilized in increasing the internal energy (raising the temperature to 80°C) of the panel, 6kJ is dissipated due to natural convection through the panel surface and remaining 21.1 kJ is to be dissipated by external means which in this case will be a combination of heat fins and heat pipes.

For the available panel size, 25 aluminium short fins (Figure 3), with adiabatic tip of dimensions 45.6mm x 5mm x 0.5mm thickness with a calculated value of $M=20.83$ have been used. These fins will dissipate 14.9kJ of heat naturally and the remaining 6.2 kJ of heat has to be removed using other means. This additional heat can be effectively removed by incorporating compact heat pipes into the LED panel. Keeping in mind the size of the LED panel and the compactness required, commercially available copper pipe of 12mm internal diameter and 1.5mm thickness has been chosen for the design. The working fluid in the pipe is taken as water at atmospheric pressure. By using thermal resistance of the copper pipe and the energy balance between the hot chip and the working fluid, the inner wall temperature of the copper pipe and also the length of the copper pipe are calculated. The length of the copper pipe thus calculated is 871mm. As the length seems to be very large compared to the panel dimensions, the design of two phase heat pipe has been carried out. Though the diameter of the copper pipe used is the same, the working fluid (water) is filled under vacuum with a fill ratio of 0.8.
The pressure of the water inside the heat pipe is assumed to be 31.202 kPa, which will bring down the saturation temperature of water to 70°C. The length of the heat pipe required for this case is found to be 202mm. In both the cases, the chip temperature is maintained at a constant value of 30°C.

**Figure 2.** LED achieves steady state in 20 min
(Source : Internet)

**Figure 3.** Arrangement of the Heat Fins on the LED panel

4. **Numerical Computations**

Numerical computations are carried out in the present study to complement theoretical studies. The numerical computations are performed using the commercial code FLUENT from ANSYS 18. LED panel and fins are modelled in ANSYS 18 by associating the heat flux (11.54kW/m²) to the chip and the heat transfer coefficient to the panel and to the fin surfaces. The results are taken once the steady state is reached i.e., after about 20 minutes. The chip temperature is found to be more (93.16°C) than the safe temperature (80°C), indicating that heat fins alone cannot dissipate the entire heat generated. Simulation results are shown in Figure 4.

**Figure 4.** Analysis of Heat Fins Using Computational Method

**Figure 5.** Heat Pipe Geometry

The single phase heat pipe is modelled in pressure based, relative velocity, transient planar module with evaporator section of 96.8mm, adiabatic section of 704.2mm and condenser section of
70mm (Figure 5). The temperature at evaporator is specified as 80°C and the temperature at condenser has been found out after the simulation.

The mesh used is proximity and curvature with minimum size of $2.39 \times 10^{-5}$m and maximum size of $10^{-4}$m. Energy and RNG k-epsilon model with scalable wall function, full buoyancy effects (boussinesq equation) and Curvature correction have been used. The temperature at the condenser section for a heat pipe length of 871mm has been found to be around 30°C.

The two phase heat pipe is modelled in density based, relative velocity and transient planar module with evaporator length of 22.45mm, adiabatic section of 163.3mm and condenser section of 16.25mm. The boiling point is changed to 70°C to enable phase change. Boiling and condensation are also applied during simulation. The temperature at the condenser section is found to be around 30°C for a heat pipe length of 202mm, which was determined by theoretical calculations.

5. Results
The theoretical calculation suggested that a combination of heat pipe and heat fins are required for heat dissipation of a compact 30W LED panel. For single phase heat pipe, after solving thermal resistance and energy equation, the length of the heat pipe is found to be 871mm while for two phase heat pipe the length is found to be 202mm. This shows that multiphase heat pipes are better than single phase because of effective removal of heat due to the phase change process. The results from single phase simulation suggested that the condenser temperature reaches ambient temperature thereby no heat accumulation takes place at the chip (Figure 6). The static temperature contours for single phase heat pipe and two phase heat pipe as obtained in numerical simulation is shown in Figure 7 and Figure 8 respectively.

![Figure 6. Static temperature plot for condenser region](image_url)
Two phase simulation results suggested that the condenser temperature reaches ambient temperature enabling 100% heat dissipation. It also suggested that the vapor fraction is highest at the evaporator section and liquid fraction is highest at the condenser section. The respective solutions as obtained in numerical simulations are shown in Figure 9 and Figure 10.

6. Conclusions
Heat pipes are required for LED panels of power rating more than 30W, as the convection heat dissipation is less compared to the heat generation. Heat fins can improve the dissipation drastically but cannot fully solve the heat accumulation problem. Multiphase heat pipes are more efficient than single phase heat pipe as latent heat during phase change absorbs huge amount of heat that is to be dissipated. Multiphase heat pipes are also very compact, which takes care of space constraints in LED panels.
References

[1] Amrutha Thomas and Aju S. Nair 2015, Experimental study on the effect of junction temperature on power LED's, *Int J Curr Eng Sci Res.* 2015, 2(9):14–9.

[2] Chi-Chang Hsieh and Yan-Huei Li 2015, The Study for Saving Energy and Optimization of LED Street Light Heat Sink Design, *Advances in Materials Science and Engineering*, Volume 2015, Article ID 418214.

[3] Kozak D.V. and Nikolaenko Y.E. 2016, The working characteristics of two-phase heat transfer devices for LED modules, *Electronics and Information Technology (EIT), 2016 International Conference on. IEEE*; 2016, p. 1-4.

[4] Kaya M. 2014, Experimental study on active cooling systems used for thermal management of high-power multichip light-emitting diodes, *Sci World J.* 2014.

[5] J.C. Wang, R.T. Wang, T.L. Chang and D.S. Hwang 2010, Development of 30 Watt high-power LEDs vapor chamber-based plate, *International Journal of Heat and Mass Transfer*, vol. 53, no. 19-20, pp. 3990–4001.

[6] Loh C.K., Harris E. and Chou D.J. 2005, Comparative study of heat pipes performances in different orientations, *Semiconductor Thermal Measurement and Management Symposium, 2005 IEEE Twenty First Annual IEEE. IEEE*; p. 191–5.

[7] Alizadehdakhel A., Rahimi M. and Alsairafi A.A. 2010, CFD modeling of flow and heat transfer in a thermosiphon, *Int Commun Heat Mass Transf.* 2010; 37(3):312–8.

[8] B. Fadhil, L.C. Wrobel and H. Jouhara 2014, Modelling of the thermal behaviour of heat pipes, *Heat Transf XIII Simul Exp Heat Mass Transf.* 2014; 83:377.

[9] C.Y. Ho , W.C. Wu, C.S. Chen1, C. Ma1 and Y.H. Tsai1 2016, Measurement for Temperature on a LED Lamp, *International Conference on Consumer Electronics, Taiwan*

[10] Nag P.K. 2003, *Engineering Thermodynamics* - Second Edition, Tata McGraw Hill 2003.

[11] Cengel Y.A. 2013, *Heat transfer* - Tata McGraw-Hill Education 2013