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Thermal performance of heat sink with fluid pockets for high power light emitting diode

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ABSTRACT

In this study, a novel heat sink which has many fluid pockets in its base was designed and fabricated. An experimental setup was built to study the heat transfer characteristics of the novel heat sink while cooling a high-power light emitting diode (LED). In this investigation, an attempt has been made to increase the heat transfer rate by adopting passive cooling. This study reports the effect of parameters such as fill ratio, orientation, type of cooling liquid, and the geometry of fluid pockets on the junction temperature of the LED. The fluid pockets were filled with various heat transfer fluids on % Vol basis. Parameters were optimised for the optimal thermal performance of the heat sink. To compare, the novel heat sink was found to record temperatures at least 19% lesser than a conventional heat sink of the same configurations. The experimental results indicated that the novel heat sink acts as an economical supplement for effective heat transfer and that liquid cooling is a powerful technique for heat dissipation of high power LEDs. Introducing the fluid pockets in heat sinks is feasible and useful for outdoor street light applications.

Keywords: Heat transfer; fluid pocket; passive cooling; tilt angle; liquid cooling.

INTRODUCTION

The energy saving, long life, environmental protection, and high luminance output characteristics of LEDs have long attracted the lighting community to develop LED lighting solutions for various applications from household to commercial purposes. The thermal management of LED module is a key design parameter as higher operating temperatures can directly affect the LED's maximum light output, quality, reliability and lifespan. In previous literature, it was observed that increased electrical inputs used to drive LEDs have led to thermal issues [1]. In an LED street light device, the temperature of a high-power LED is an important parameter that affects the performance of the system. The maximum light output, quality, reliability, and the life span of LEDs are all closely related to the junction temperature. Thus, thermal management has become a key reliability issue for LED modules for which various solutions have earlier been proposed. Different means of cooling systems can be used to reduce the operating temperature of

LEDs: a simple one is the use of an extruded fin heat sink. Heat sinks are essential for the dissipation of heat. These are normally found in devices where heat augmentation is necessary. Different types of heat sinks have been employed in many engineering applications. Such devices depend upon the desired heat flow [2-4]. They may be active or passive in nature [5-10]. Active devices are generally not preferred unless they are inevitable as they consume additional energy. Passive cooling solutions are preferred in the industry for its structural simplicity and cost-effectiveness. Fins are the most popular passive heat transfer structure. They provide increased surface area for enhanced heat transfer [11-15].

A numerical investigation was carried out by Ahmed et al. on a heat sink model for various fin lengths using three different configurations, namely copper, aluminium, and steel in order to find out their ability to dissipate heat from the junction [16]. The results showed that aluminium performed better than copper and was found to be cost effective. Arularasan [17] conducted a numerical investigation for an optimal design of the heat sink. The effect of geometric parameters was found to be significant for low thermal resistance in the heat sink. A finite volume-based computational fluid dynamics (CFD) code and theoretical investigation on the effects of fin spacing, fin height, fin length, and temperature difference between fin and surroundings was conducted by Senol Baskaya et al. [18]. The results showed that the variables have pronounced effects on the overall heat transfer. Raj Bahadur et al. [19] studied the geometric dependence of heat dissipation, and the relationships between the pin fin height, pin diameter, horizontal spacing, and pin fin density for a fixed base area and temperature. Experimental results indicated that a pin finned thermally conductive polyphenylene sulphide (PPS) heat sink displays high thermal performance in natural convection. Royston Marion Mendonca et al. [20] investigated different fin geometries to determine their influence on thermal performance and airflow around them. It was reported that the rate of heat dissipation is greatly dependent on the geometrical parameters of the heat sink. Kou et al. [21] did theoretical investigations to maximise the heat dissipation of a heat sink with the least material cost for various fin cross-sections. They found that the heat sink with the maximum effective heat transfer surface area had the lowest thermal resistance when the ratio of convective heat transfer coefficient was set as 1. Vitor Costa et al. [22] investigated the enhancement of heat transfer by using numerical simulations for conjugate laminar steady-state natural convection, including heat transfer by radiation. The results demonstrated that the improvement in performance can be attributed to the number of fins, fin height, fin length, and fin thickness. Hou Fengze et al. [23] conducted a simulation of plate fin, in-line, and staggered-pin fin heat sinks for a high power LED lighting system which was compared under the same test conditions. The author reported that the staggered-pin fin was found to perform better than the other fins. An experimental study was conducted by Sung Jin Kim et al. on plate-fin and pin-fin heat sinks subject to a parallel flow of air using a blower [14]. It was found that the optimized plate-fin heat sinks possess lower thermal resistances than those for the optimized pin-fin heat sinks when the dimensionless pumping power is small and the dimensionless length of heat sinks is large. On the other hand, the reverse was true; when the dimensionless pumping power is large and the dimensionless length of heat sinks is small. Mostafa Awad [24] studied experimental investigations for enhanced heat transfer using plate-fins, cylindrical, solid pin fins, hollow pin fins and convergent-divergent fins. The results showed that the performance of the convergent divergent fins was relatively lower than that of solid pin fins and higher than that of hollow pin fins. Ren-Tsung Huang et al. [25] studied the influence of orientation on heat transfer for square pin fin heat sinks subjected to natural convection. The test results demonstrated that the upward facing orientation yielded the highest heat transfer coefficient, followed by the sideward facing and then the downward facing ones. Wadhah Hussein et al. [26] performed an experimental study of circular perforations in the heat sink to enhance heat transfer. It was found that enhanced heat transfer was obtained for the perforated fin with a larger number of perforations compared to with a small number of perforations. Elshafei [27] performed experimentation on the dependence of heat dissipation from heat sinks on the geometry of widely spaced solid and hollow/perforated circular pin fins with staggered combinations. The test results found lower temperatures for the hollow/perforated circular pin fin heat sink than that of the solid pin fin heat sink. Hyunjong Kim et al. [28] investigated the thermal resistances of smart heat sinks (SHS) and hybrid pin fins (HPF). The parametric study found that the thermal resistances of the SHSs were typically smaller than those of the pin fin heat sinks (PHSs). The results showed that the thermal resistance value of the HPF had decreased with increases in the declination angle. Kyoung Joon Kim [29] studied the thermal performance of the hybrid fin heat sink (HFH) under natural and forced convection conditions. The performance was compared with that of a pin fin heat sink (PFH). The results demonstrated that the thermal performance of the HFH was found to be better than that of the PFH. Lian-Tuu Yeh [30] investigated three different types of heat sinks which are extrusion fin, plain fin, and cell fins. It was found that the cell fin heat sink had the lowest heat transfer coefficient.

Jin-Cherng Shyu et al. [31, 32] investigated the effects of shroud clearance and obstructions at entrance or exit on the overall performance of LEDs. The result indicated a local minimum Nusselt number occurring near the exit of the LED panel. Congshun Wang et al. [33] introduced short pin fins on the surfaces of plate-fin heat sinks in his study. The results demonstrated that micro-pin-fin fabrication is effective in improving the thermal performance of air-cooled plate-fin heat sinks. Maw Tyan Sheen et al. [34] studied a micro-tube water-cooling system employed to cool high power LEDs. It was demonstrated that the micro-tube water-cooling system was more effective for heat dissipation in LEDs. Lei Liu et al. [35] investigated the heat dissipation of heat pipes with fins and compared to heat sinks with fins. The experiment data and simulation results demonstrated that heat pipes with fins had better cooling capability than normal heat sinks. Xiang-you Lu et al. [36] studied the heat release characteristics of high power LED packages for flat heat pipe heat sinks. The impact of the different filling rates and inclination angles of the heat pipe was studied and evaluated. The obtained results indicated that the junction temperature of LED had decreased and attained a lower heat transfer coefficient. From the literature, it was found that numerous studies have been reported on conventional heat sinks and their parametric design characterisation. However, studies on composite fin heat sinks using fluids as a passive cooling means have yet to be reported in the literature. Thus, the present experimental study is aimed at investigating the heat transfer characteristics of a heat sink with fluid pockets filled with different heat transfer fluids subjected to natural convection

METHODS AND MATERIALS

Experimental Set Up

In this study, a novel heat sink which has many fluid pockets in its base is proposed. The fluid pockets were produced by drilling holes through the base of the heat sink. Three types of novel heat sinks were designed and fabricated (HSHF0, HSHH02 and HSHH03). The detailed configurations of HSHF01, HSHH02, and HSHH03 are shown in Table 1.

The material of the heat sink is Aluminum 6061 T6. In the HSHF01 and HSHH02 heat sinks, 6 mm holes were made while 4mm holes were drilled at the base in the case of HSHH03. An experimental setup was built for studying the heat transfer characteristics of the novel heat sink for cooling a high power light emitting diode (LED). The experimental setup consists of an LED, a heat sink, and a data acquisition system. The schematic diagram of the experimental setup is shown in Figure 1. Conventional heat sinks (CHS01 and CHS02) with parallel rectangular fins with lengths of 100 and 50 mm were designed and developed. The properties of aluminum 6061 T6 (jindal make) are ρ = 2700 kg/m^3, C =896 J/KgK, and K=167 W/mK. The typical designations and configurations of the heat sink used in the current study are shown in Table 1 [37, 38].

Figure 1. Experimental setup of the present study.

The LED chosen in this study has 9 strips, each having 3 LEDs (CREE Make- X lamp XP-G) of 3W each, totaling to 27 LEDs with its wattage being equal to 80W. The arrangement of LED strips is shown in Figure 2. Thermodynamic hotspots were identified using a Sonel-made KT 140 infrared thermal image camera with an accuracy of ±2°C. Two critical points were located at the junction. The identified critical points over the MCPCB were placed with T type thermocouples to measure the junction temperature. The thermocouples were placed precisely at the critical points (0 and 1) on the LED array as shown in Figure 2.

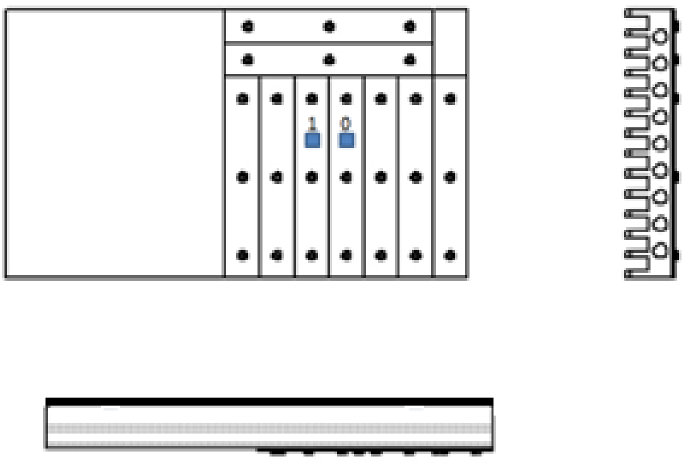
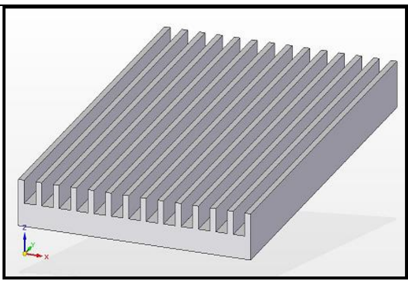
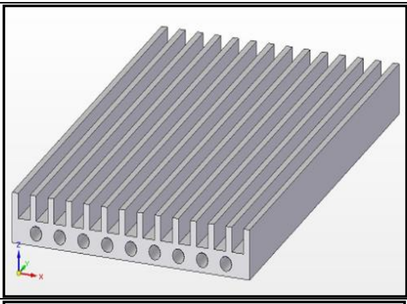
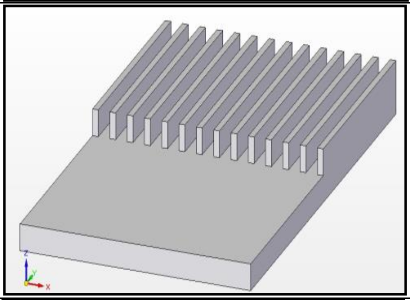
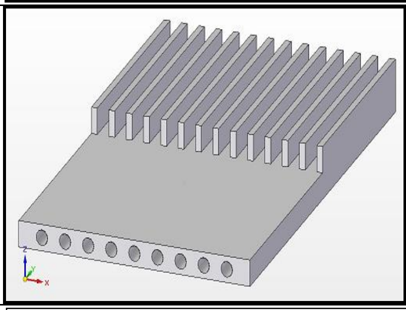
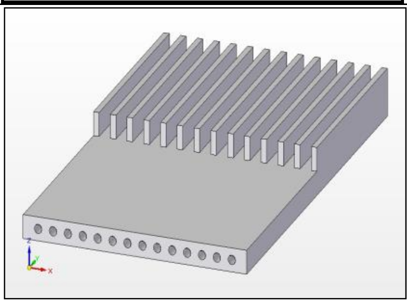


Figure 2. CAD views of the LED with heat sink, showing the location of thermocouples.

Table 1. Typical configurations and designations of various heat sink models.

Sl No	Heat Sink Type	Heat Sink Designation	Image	Geometry
1	Conventional Heat Sink without holes and full-length fins	CHSO1		200 x 120 x 10 mm 14 fins, with Pitch=6 mm Height= 10mm Thickness=3 mm Length=200 mm
2	Heat Sink with holes and full-length fins	HSHF01		200 x 120 x 10mm Ø6 x9 holes drilled for a length 200mm 14 fins, with Pitch=6 mm Height= 10mm Thickness=3 mm Length=200 mm
3	Conventional Heat Sink without holes and half-length fins	CHS02		200 x 120 x 10 mm 14 fins, with Pitch=6 mm Height=10mm Thickness=3 mm Length=100 mm
4	Heat Sink with holes and half-length fins	HSHH02		200 x 120 x 10 mm Ø6 x9 holes drilled for a length 200mm 14 fins, with Pitch=6 mm Height= 10mm Thickness=3 mm Length=100 mm
5	Heat Sink with holes and half-length fins	HSHH03		200 x 120 x 10 mm Ø4 x14 holes drilled for a length 200mm 14 fins, with Pitch=6 mm Height= 10mm Thickness=3 mm Length=100 mm

A suitable thermal interface material, ANABOND 656C was used between the LED strip and heat sink to minimise thermal resistance and avoid air bubbles. The data acquisition system (TRACER make) with a resolution of 10^{-5}°C connected to a signal conditioning circuit and an analog to digital converter was used. The sampling rate was 1/s. Figure 3 shows a typical plot of raw data generated by the DAQ (data acquisition system).

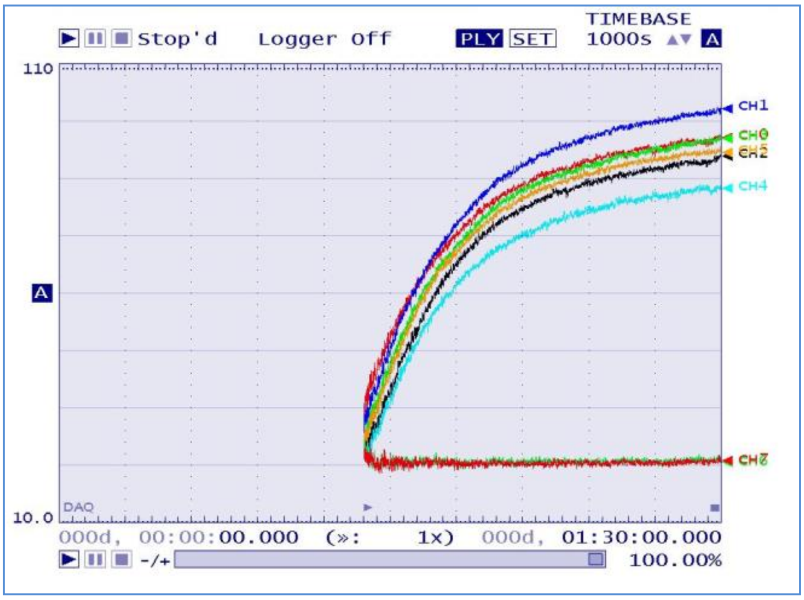


Figure 3. Typical plot produced by the DAQ.

The selection of a suitable heat transfer fluid for increased heat transfer would ideally depend upon the fluid's thermal stability, latent heat, thermal conductivity, liquid and vapor viscosities, surface tension, freezing point and compatibility with wall materials. The selection is also based on thermodynamic considerations such as heat sink design, capillary and a high value of surface tension desirable in order to enable the heat sink to operate against gravity and generate a high capillary driving force. This study explores the use of liquid cooling using various heat transfer fluids for heat removal and compares its performance with the conventional heat sink of the same configurations but without fluid pockets. Experiments were conducted using different fluids, viz. acetone, ethanol, methanol and De-ionized water [39]. Table 2 shows the properties of the fluids chosen for the current study.

Table 2. Physical properties of heat transfer fluids.

Working Fluid	Saturation Temperature T_b (°C)	Latent heat h_{fg} (kJ/kg)	Density ρ (kg/m³)		Kinematic Viscosity μ(10^{-7}Ns/m²)		Thermal Conductivity K(W/m-K)		Surface Tension σ (10^{-3} N/m)	Specific Heat C_p (kJ/kg-K)	
			Liq	Vap	Liq	Vap	liq	Vap		Liq	Vap
Methanol	64.7	1119.5	750.8	0.566	3291.4	109.6	0.201	0.0018	18.8	2.52	1.601
Ethanol	78.3	962.45	758.1	1.372	4452.6	102.3	0.169	0.0197	17.4	0.73	1.604
Acetone	56.2	520.56	748.5	2.123	2340.6	89.25	0.169	0.0140	19.0	2.28	1.385
Water	100	2251.2	958.7	0.597	2790.0	121.0	0.680	0.0248	58.9	4.22	2.034

Experimental Procedure

The chosen heat transfer fluid was filled into the holes made in the base of the novel heat sink. All holes were sealed to prevent any leakages. The LED MCPCB was placed over the heat sink with thermal interface material. The experiments were carried out with variations in parameters such as fill ratio, orientation effect, liquid cooling and effect of fluid pockets on junction temperature of LED for all configurations of the novel heat sink. The transient and steady state experiments were conducted, and the junction temperatures of the LED were measured. Experiments were conducted using different working fluids, viz. acetone, ethanol, methanol and de-ionized water. The fluid pockets were filled with various types of heat transfer fluids on a % vol. basis. The heat sink with fluid pockets was tested for different fill ratios (volume of the fluid in the hole/total volume of the same hole). 50%, 75%, and 100% fill ratios were chosen to test the fluids for effective heat transfer. The heat dissipation of the heat sink was measured at three different orientations with the horizontal (tilt angle) using water as the cooling fluid. The test results were compared with those of a conventional heat sink. A constant power input of 80W was maintained throughout the experiment. The hotspots were identified using infrared camera and were placed with T type thermocouples. The junction temperature was recorded using the data logger. Data was recorded for both transient and steady states at a given test condition. In the course of experimentation, five trials were taken at each test condition for repeatability of data, and the arithmetic average of temperature recorded by these two thermocouples was considered as the junction temperature. The average temperature has been plotted against the power input. The standard deviation was computed to locate the bandwidth. The test duration was 100 min. All experiments were conducted under ambient conditions to match practical applications of the LED.

RESULTS AND DISCUSSION

Effect of Orientation on Junction Temperature

The heat transfer characteristics of the novel heat sink were analysed for three different orientations (Ө). The effects of orientation on the heat dissipation rate in terms of junction temperature of the LED were investigated. Table 3 shows the variation of junction temperature as a function of time for the 0°, 15°, 30° and 45° orientations when water was used as the coolant for HSHH02. It was observed that the junction temperature increased with increases in power supplied, till it reached a steady state. Figure 4 shows the minimum junction temperature when tilted 15° horizontally among all the orientations tested. For the 0°, 30° and 45° orientations, the junction temperature remained virtually unaltered or had slightly decreased. It can be noticed from Figure 4 that the junction temperature was found to be optimum for the 15° horizontal orientation. This is mainly because of variations in fluid density. With gains in the thermal energy, the fluid starts to flow against gravity when the capillary driving force has a larger magnitude than the gravity force. With further increases in the tilt angle (30° and 45°), the upward driving force decreases. Hence the junction temperature remains unaltered or decreases slightly. The results indicated that a heat sink with fluid pockets at a slightly tilted angle improves heat transfer. It can be seen from the results which show that the LED panel with a heat sink positioned at 15° is most suitable for street light applications. Additionally, with the 15° tilted angle of the LED panel, the heat transfer rate increases and becomes more pronounced with the use of lower viscosity cooling fluids [8].

Table 3. Variations of junction temperature as a function of time for tilted angle ϴ and using water for HSHH02.

Time in Sec	Junction Temperature in °C			
	0°	15°	30°	45°
500	58.12	53.54	53.98	56.12
1000	71.23	67.61	68.01	70.02
2000	87.94	84.4	85.32	86.84
3000	95.13	91.92	93.45	94.12
4000	100.68	95.96	97.89	98.07
5000	103.92	97.33	99.98	100.3
5500	103.92	97.33	99.98	100.3

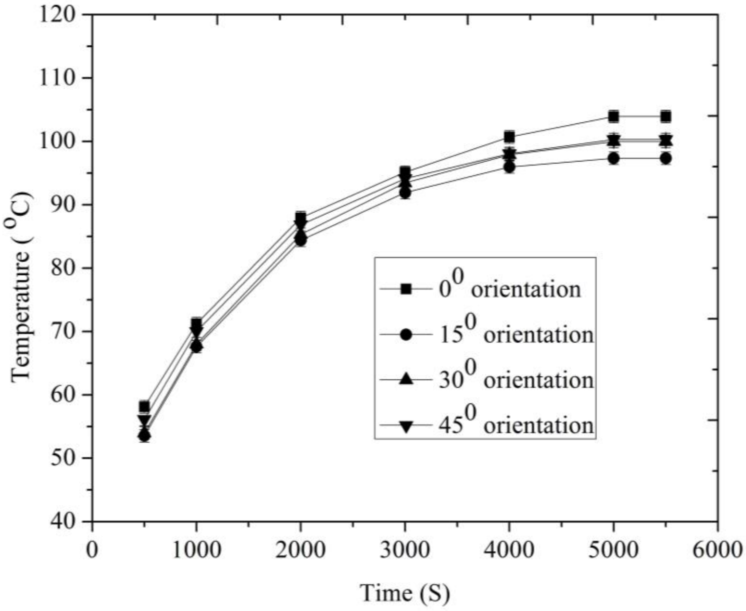


Figure 4. Variations of junction temperature as a function of time for tilt angle ϴ and using water for HSHH02.

Effect of Fill Ratio on Junction Temperature

The junction temperature of the LED was measured to find the optimum fill ratio. Experiments were done on the HSHF01 and HSHH02 configurations with water as the cooling fluid for three different fill ratios and 15° orientation with the specified power input. Water was filled and sealed inside the heat sink HSHF01 at 50%, 75%, and 100% fill ratios, and comparisons were made to locate the optimum filling ratio as shown in Table 4. The same data with standard deviation is shown in Figure 5. It is evident from Figure 5 that the junction temperature for the 100% fill ratio is the minimum when compared to other fill ratios. The results were compared with CHS01 and CHS02. It was found that the junction temperature was at the minimum when the filling ratio was about 100% for water. For other filling ratios, the experiment results indicated that the junction temperature was slightly higher than that of the filling ratio of 100% for water. The difference in junction temperature between CHS01 and HSHF01 with water was found to be nearly 10°C. Therefore, a 100% fill ratio was selected for further experiments. The temperature recorded in each case is presented in Table 4 and the same data with standard deviation is shown in Figure 5.

Table 4. Variations of junction temperature as a function of time for different fill ratios of water for HSHF01.

Time in Sec	Junction Temperature in °C		
	50% fill ratio	75% fill ratio	100% fill ratio
500	65.36	61.01	58.46
1000	81.57	77.00	73.53
2000	98.09	94.56	90.06
3000	103.24	100.54	97.61
4000	104.65	102.10	99.29
5000	105.11	102.75	100.23
5500	105.11	102.76	100.23

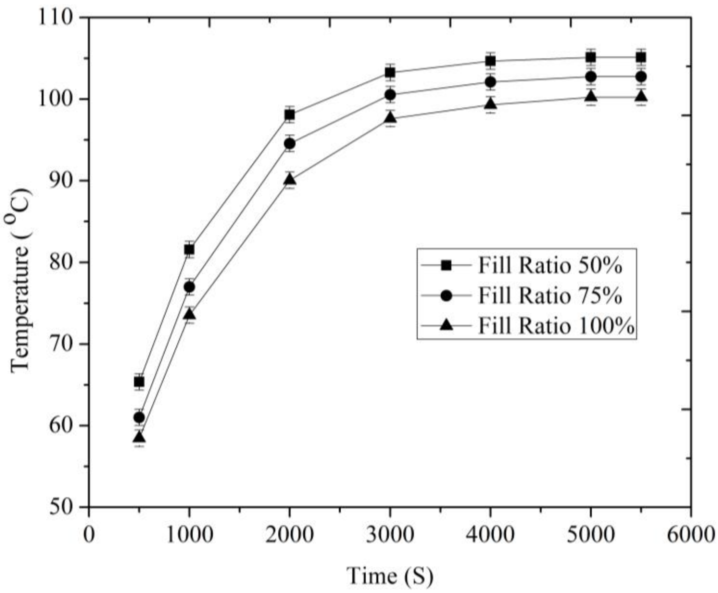


Figure 5. Variations of temperature as a function of time for different fill ratios for water for HSHF01.

The experiments done on HSHF01were repeated on HSHH02 with the same test conditions. The results were also compared with the conventional heat sink CHS02. The junction temperature of an LED with the conventional heat sink CHS02 attained 116.53 °C. In the case of HSHH02 too, experiments were repeated using different heat transfer fluids in order to minimise the junction temperature. The results revealed a positive effect for water at 100% vol. of fluid compared to other filling ratios for HSHH02. When the volume of liquid was increased, the heat dissipation from the junction increased because of its ability to conduct heat. The measured data indicated that the junction temperature of the LED decreased with the increasing quantity of fluid in the fluid pockets [40]. Larger volumes of liquid result in faster heat dissipation. The temperature recorded in each case is presented in Table 5 and the same data with standard deviation is shown in Figure 6.

Table 5. Variations of junction temperature as a function of time for different fill ratios of water for HSHH02.

Time in Sec	Junction Temperature in °C		
	50% fill ratio	75% fill ratio	100% fill ratio
500	56.85	56.31	53.54
1000	71.70	70.26	67.61
2000	89.17	87.12	84.40
3000	97.04	94.85	91.92
4000	100.19	98.65	95.96
5000	100.58	99.82	97.33
5500	100.84	99.93	97.33

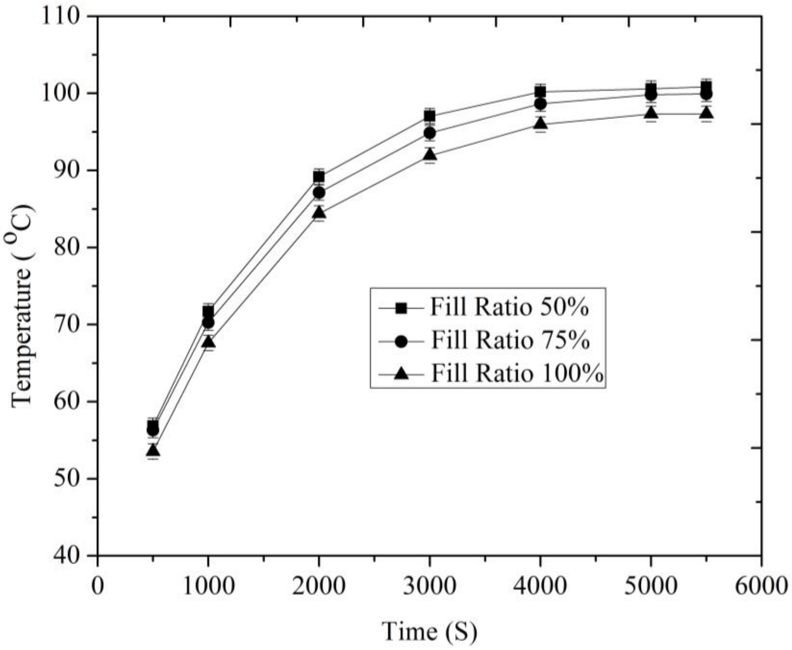


Figure 6. Variations of junction temperature as a function of time for different fill ratios of water for HSHH02.

Effect of Temperature on Fluid Flow

The fluid in the heat sink gained heat, leading to a temperature rise which caused the fluid to flow upward i.e. against gravity, while the reverse flow was due to the gravity effect. Under the same operating conditions, the conventional heat sink had not shown significant thermal performance. The heat sink with fluid pockets gave better thermal performance than that of the conventional heat sink. This is due to the fact that the cooling fluids have a large thermophysical property. As a result, the junction temperature of the LED was lower than that of the conventional heat sink of the same configurations. This suggests that the fluid filled in the fluid pockets had transferred heat faster, leading to cooler LED junctions through enhanced heat transfer. The variation of junction temperatures of the LED for different cooling fluids was compared with the conventional heat sink. From the results, it was observed that the heat sink filled with water recorded the lowest junction temperature. The same data with standard deviation are shown in Figures 7 and 8.

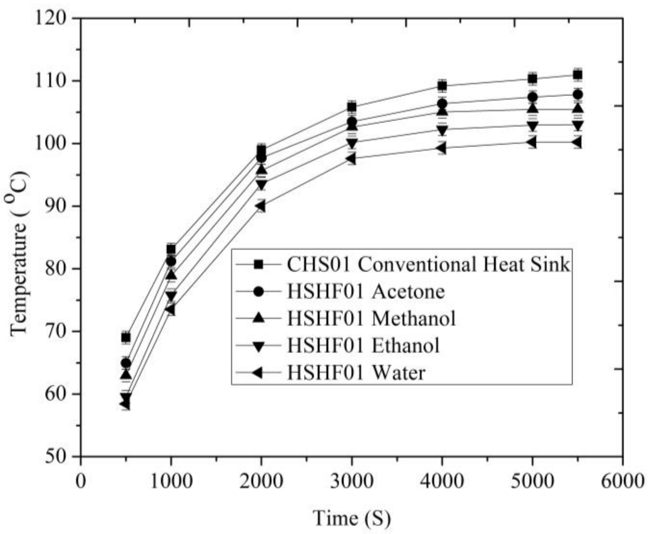


Figure 7. Variation of junction temperature of LED for heat sink (HSHF01) filled with different cooling fluids for 100% fill ratio and the conventional heat sink (CHS01).

Table 6. Temperature as a function of time for different fluids with a fill ratio of 100% for HSHF01.

Time in Sec	Junction temperature in °C				
	Conventional Heat Sink CHS01	Heat Sink with fluid, HSHF01			
		Acetone	Methanol	Ethanol	Water
500	69.02	64.96	62.99	59.57	58.46
1000	83.09	81.18	78.89	75.80	73.53
2000	98.98	97.72	95.70	93.60	90.06
3000	105.81	103.50	102.63	100.2	97.61
4000	109.19	106.38	105.05	102.25	99.29
5000	110.33	107.41	105.46	102.95	100.23
5500	110.33	107.41	105.46	102.95	100.23

Table 7. Temperature as a function of time for different fluids with a fill ratio of 100% for HSHH02.

Time in Sec	Junction Temperature in °C				
	Conventional Heat Sink CHS02	Heat Sink with fluid, HSHH02			
		Acetone	Methanol	Ethanol	Water
500	72.00	60.70	64.85	60.19	53.54
1000	89.66	77.31	78.68	76.86	67.61
2000	107.63	96.07	94.75	94.72	84.40
3000	113.30	103.62	100.84	102.04	91.92
4000	115.20	105.79	103.46	105.11	95.96
5000	116.53	107.73	104.92	106.75	97.33
5500	116.53	107.75	104.92	106.75	97.33

The junction temperatures attained under the 100% fill ratio for all fluids tested for HSHF01 and HSHH02 configurations are shown in Tables 6 and 7 respectively. The junction temperature of the LED at the steady state was found to be the least for water compared to acetone, ethanol and methanol, keeping the other parameters same as in the case of HSHF01 and HSHH02. The reason for this is that water has a larger surface tension, latent heat, and thermal conductivity compared to other fluids for a given heat sink configuration. Another reason is that acetone performs better at lower power density as it vaporises at very low temperatures. On the other hand, ethanol, and methanol produced moderated junction temperatures as they have low thermal conductivity compared to water [41]. Based on the results obtained in this study, water can be considered as the coolant to be used in electronic device cooling applications. This effective mechanism of cooling using fluid pockets may be considered as one of the options for cooling high power LEDs and other electronic cooling applications.

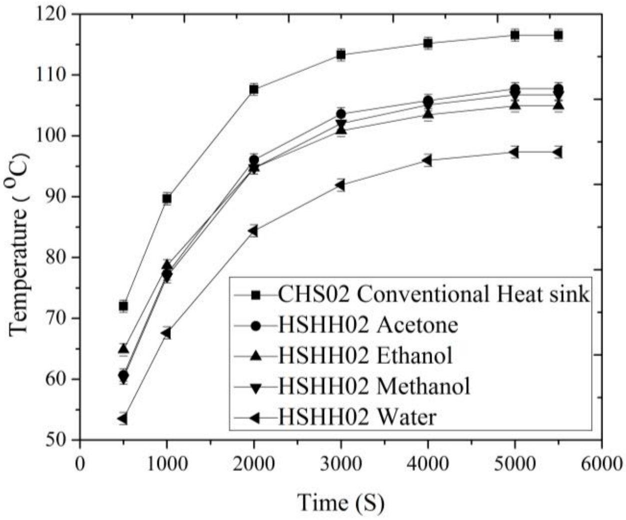


Figure 8. Variations of junction temperature of LED for heat sink (HSHH02) filled with different cooling fluids at the 100% fill ratio, and the conventional heat sink (CHS02).

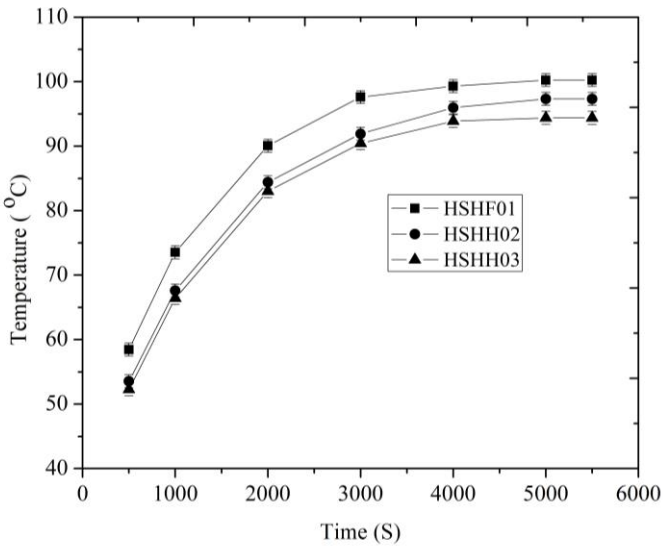


Figure 9. Variations of junction temperature of LED for heat sink (HSHF01 and HSHH02) and heat sink HSHH03 filled with water at 100% fill ratio.

Effect of Fluid Pockets on Junction Temperature

Another major consideration is the selection of the fluid pockets' diameter as they are directly responsible for effective heat dissipation. The experiments were carried out on HSHH03 with the same test conditions to verify the accuracy of HSHF01 and HSHH03. In HSHH03, the fluid contact area was maintained constant by increasing the number of fluid pockets and decreasing the diameter of the fluid pockets. It was observed that the increased number of water pockets in the heat sink rendered further improvement in reducing the junction temperature effectively and provided very good heat dissipation as shown in Figure 9.

Table 8. Temperature as a function of time for different heat sinks.

Sl No	Heat Sink Type	Heat Sink Designation	Junction Temperature in °C
1	Conventional Heat Sink without fluid and full-length fins	CHS01	110.33
2	Heat Sink with fluid and full-length fins	HSHF01	100.23
3	Conventional Heat Sink without fluid and half-length fins	CHS02	116.53
4	Heat Sink with fluid and half-length fins	HSHH02	97.33
5	Heat Sink with fluid and half-length fins(diameter of hole 4mm)	HSHH03	94.37

Observations

It was also observed from Figures 7 and 8 that the junction temperature increases with increases in time up to 3600 seconds; beyond which, it attained a steady state. Lower values of thermal resistance and higher values of heat transfer coefficient were observed in the case of water compared to acetone, ethanol and methanol. Table 8 shows the lowest junction temperatures recorded by different heat sink configurations. The conventional heat sink (CHSO1) reported a junction temperature of 110˚C and the heat sink with water pockets (HSHF01) reported a junction temperature of around 100˚C. The conventional half-length fins (CHS02) were found to give nearly the same results as that of full-length fins, and the difference in junction temperature was found to be nearly 6˚C. The 10˚C of difference in junction temperature between CHS01 and HSHF01 of the LED may be attributed to the various properties of the fluids used (Table 3). When the conventional heat sink CHS02 reported a temperature of 116˚C, the corresponding novel heat sinks HSHH02 and HSHH03 reported temperatures of 97˚C and 94˚C, respectively. It is evident from the fluid properties that water has the highest boiling temperature, latent heat, liquid density, thermal conductivity, surface tension, specific heat, and viscosity in comparison to other heat transfer fluids. This has resulted in a more effective heat transfer, leading to minimum junction temperatures. Higher boiling temperatures increase the sensible heat which causes the heat transfer rate to increase. Even if it boils, as the latent heat is also high, heat transfer would increase. Higher density, thermal conductivity, surface tension, and specific heat add to the improved heat transfer. Moderate viscosity assists in improved circulation of water due to the density variation inside the hole. This is a sign of effective heat transfer. Increased number of holes with the area being constant would ensure better and uniform contact of fluid with the metal surfaces. By providing holes in the heat sink, the mass of the heat sink will reduce, which in turn reduces the quantity of material consumed.

CONCLUSIONS

The junction temperature increases with increases in time and attains a steady state after 60 minutes. Tests done at 100% fill ratio using water for both full-length and half-length fins were found to be optimal. Amongst the various heat transfer fluids tested, water was found to be better than other fluids. Deionised water was observed to be a more suitable working fluid for high power LEDs under different operating conditions. In these configurations, the gravity effect plays a major role in minimising the junction temperature. Conventional half-length fins were found to give nearly the same results as that of full-length fins, and the difference in junction temperature was found to be nearly 6˚C. The difference in junction temperature between the conventional heat sink (CHS02) and the heat sink with fluid (half-length fin) (HSHH02) is substantial at 19 ˚C, and increasing the number of fluid pockets for the experiment with half-length fins further reduced the junction temperature by close to 3˚C, which is very significant. The results of the experimentation demonstrated that water pockets in heat sinks are very effective for pronounced heat dissipation in outdoor applications. For all configurations, the optimal heat dissipation occurred at the 15 degree inclination for the heat sink with fluid pockets. The study has established that half-length fins (rectangular cross section) with a maximum number of fluid pockets yield the best result. Hence, considering the experimental investigations, it is recommended to use half-length fins with water pockets to minimise material volume to increase the lifespan of LED lighting loads due to cooler junctions.

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