J Ther Eng, Vol. 12, No. 1, pp. 16–28, January, 2026

Journal of Thermal Engineering
Web page info: https://jten.yildiz.edu.tr
DOI: 10.14744/thermal.0001055

Research Article

Performance investigation of high-powered light emitting diodes using copper and silicon-oxide based nanofluid filled heat pipe

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ARTICLE INFO

Article history
Received: 27 January 2025
Revised: 10 June 2025
Accepted: 26 June 2025

Keywords:
Cooling System; Heat Pipe; LEDs; Nanofluid

ABSTRACT

Thermal management of light-emitting diodes (LEDs) significantly reduces the chances of failure due to overheating and provides a better lifespan. The most efficient, compact, and low-cost cooling system must be developed for better heat dissipation. Researchers have conducted major investigations on LED performance for low-wattage applications. The current work focuses on the high-wattage real-life application of LEDs. Researchers have considered investigations for 100 W, 200 W, and 400 W capacity high-wattage LEDs in street, stadium, and high-mast tower applications. Copper-made, cylindrical, two-layered heat pipe with screen mesh wick has been designed and fabricated to cool LEDs. Dispersed copper and silicon oxide nanoparticles in distilled water are used as a working medium in a heat pipe. Types of working medium, filling ratio, and LED capacities were considered input variables during the experiment. The resultant variables are the evaporator and condenser temperature difference, thermal resistance, energy consumption, effective thermal conductivity, and overall heat transfer coefficient. Researchers have developed a dedicated experimental setup for testing, with all required measuring and controlling devices. A superior performance was observed with the Cu/DI water-filled heat pipe, considering a 60% filling ratio in the tested LEDs. Cu/DI water with a 60% filling ratio has a 15.2% and 3.5% lower temperature difference, contrasting with DI water and SiO_2/DI water for 100 W LED.

Cite this article as: Khudaiwala A, Patel R. Performance investigation of high-powered light emitting diodes using copper and silicon-oxide based nanofluid filled heat pipe. J Ther Eng 2026;12(1):16–28.

INTRODUCTION

In recent years, the scientific community has been seriously debating the development of sophisticated and effective heat transfer devices for the thermal management of electrical devices. Several lighting solutions are being examined to address the rise in temperature during working cycles. The issue continues despite varying working

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This paper was recommended for publication in revised form by Editor-in-Chief Ahmet Selim Dalkılıç

conditions and ambient temperatures [1]. An experimental attempt is essential for the thermal management of Light Emitting Diodes (LEDs) due to the complicated and non-linear performance of LED cooling.

The utilization of light-emitting diodes, also known as LEDs, is widespread in every aspect of our lives. LED chips are liable for facilitating light and heat generation [2]. In addition to enabling an expanded selection of colour temperatures, LEDs offer a more excellent range of operation temperatures, ranging from -20 ° C to 85° C [3]. Three

researchers earned the Nobel Prize in Materials Science in 2014 for their work in developing blue LEDs that are both productive and efficient, using Gallium nitride (GaN). Researchers experimented to recognize that LEDs are committed to human culture [4]. Even though LEDs benefit society since they provide an alternative lighting solution for both industries and society, the junction temperature thermal management of LEDs continues to be an issue for society and requires urgent attention [5]. It has been demonstrated through experimentation that regulating LED junction temperatures within an appropriate range using heat pipes can improve the lifespan of the LEDs and reduce the amount of power consumed by a notable amount.

This experiment uses a heat pipe as a cooling device. This experiment primarily focuses on the efficient cooling trends of heat pipes and the space considerations related to the LEDs used in the experiments. Out of the many types of heat pipes available, we have chosen cylindrical ones mainly for their easy manufacturing, low cost, and high efficiency [6]. The evaporator, the adiabatic, and the condenser sections comprise three sub-sections that comprise the overall construction [7]. Observations also showed that the temperature of the LED exhibit was not in line with the brightening force, and a high filling proportion can degrade the enlightenment power of LED chips. The planned Oscillating Heat Pipe (OHP) for high-power LED cooling favored a low % filling proportion of 30%. Bumataria et al. [8] concluded with their experiments that the heat pipe is an essential component in the thermal management of high-power LEDs because it ensures that the junction temperature remains within the acceptable temperature window

Kim et al. [9], LEDs convert 80 to 90% of electrical power to heat at the flow-watt level, while 10 to 20% is exclusively converted to electro-optical energy. If the surface space varies between 1 and 2.5 mm², a functional LED›s hotness scattering change can reach 100 W/cm². LEDs require a converged temperature below 110 °C to function more effectively and last longer.

Gunnasegaran et al. [10] experimented with diamond-H_2O nanofluid with concentrations ranging from 0% to 3%, with heat input ranges between 20W and 60W. They decreased thermal resistance from 5.7% to 10.8% for mass concentrations ranging from 0.5% to 3%. Kahani and Vatankhah [11] predicted the thermal performance of wickless heat pipes using Al_2O_3-water Nanofluid by an artificial neural network. The results indicated that the volume concentrations were the most crucial parameter for predicting the thermal performance of heat pipes. Zhen et al. [12] experimented with a 12W LED with fins and could restrict the temperature to 40°C while working for a 5-minute cycle. The findings also showed promising results for heat pipe readings, keeping the junction temperature at 25°C for the same working cycle. Tang et al. [13], explored high-power LEDs with chips directly connected to heat pipes. They have confirmed that the heat conductivity of the Closed Loop Heat Pipe (CHP) lead outline at 2800 mA is 0.23 °C/W and 1.65 °C/W. The CHP lead outline LED device›s iridescent efficiency is 66.23 m/W at 2800 mA. It is 19.2% more costly than the standard copper-lead outline. The CHP lead Casing›s Connected Variety Temperature (CCT) shift value is 108 °C (381 K), 23.5% lower than the standard copper-lead outline. Wang et al. [14], reasoned that the heat dispersal coefficient ought to be more critical than 1 W/cm²/°C to give an advantageous removal of the hotness made. Since LEDs are hot light sources, heat radiation cannot accurately represent how heat is absorbed. Design an adequate and effective dissemination system to heat the executives effectively. Pekur et al. [15], Experimentally studied the spiral heat exchangers and heat pipes for the cooling application of LEDs. They concluded that radially arranged heat pipes with spiral heat exchangers for 10.00w capacity LED emphasize the promising cooling system at ambient temperature.

Shekho et al. [16], investigated the compound microchannels using Al_2O_3 and CuO dispersed nanofluids with a 47 nm size and 4 vol% concentration. Employing the nanofluids decreased the total thermal resistance by 16.8% compared to water. Nasser et al. [17], investigated the SiO_2/H_2O nanofluids as a coolant in the container. They investigated with a concentration ranging from 0.1 wt% to 0.3 wt% and a 2 LPM flow rate. Increasing the mass concentration of the Nanofluid increases the thermal efficiency. For distilled water concentrations of 0.1 v%,0.2v%, and 0.3v%, the thermal efficiency for SiO_2 nanofluid was 35.56%, 79.91%, 91.04%, and 104.01%, respectively. Hasan et al. [18] investigated the heat transport characteristics of SiO_2/H_2O nanofluids with a particle size of 20 to 50 nm. The higher heat transfer rate is observed with smaller nanoparticles, as they have higher Nusselt numbers due to a large surface area, increasing the collision rate to improve heat transfer rates. Li et al. [19], investigated Cu/H_2O dispersed nanofluids to study the thermophysical properties of nanofluids. Increased surface area-to-volume ratio in nanoparticles greatly improved the thermal conductivity of nanofluids. The thermal conductivity rose from 11% to 30%. Guru et al. [20], studied the thermosiphon utilizing Boron/H_2O nanofluids with a concentration of 0.5 wt%, 1.0 wt% and 2.0 wt%. The heat pipe was tested for 200W,300W, and 400W heating power while the cooling water flow ranged from 5 g/s to 7.5 g/s and 10 g/s in the evaporator section. With 2% boron nanofluid at 400 W heating power and a cooling water mass flow rate of 10 g/s, the results demonstrated a

20% increase in efficiency. The improvement in heat resistance seen as a result of the Boron nanofluid was 28%.

Datta et al. [21], reviewed the possibility of tertiary nanofluids for the jet-impinging cooling process. They suggested the combination of Al_2O_3, CuO, and TiO_2 nanoparticles with a size of 20 nm. The addition of nanoparticles enhances heat transfer, and a smaller size is the optimum for maximum heat transfer, whereas the heat transfer decreases for bigger-sized nanoparticles.

In the open literature, various researchers have adopted methodologies such as heat pipes, heat sinks, fins, thermal paste, fan cooling, liquid spray, and others to manage the LEDs to keep the junction temperature lower. Significant work has been carried out for the performance analysis of low-capacity LEDs only. Researchers studied the effect of inclination angle, concentration, particle size, and shape on nanofluid-filled heat pipes. The current work mainly focuses on high-wattage LEDs with 100W, 200W, and 400W capacity. Researchers tested the real-life application of LEDs in a performance trial involving street lights (100W), stadium lights (200W), and high-mast towers (400W). Researchers investigated the effect of various feeling ratios on heat pipe performance using Cu/DI water and SiO_2/DI water as working mediums.

This paper focuses on the thermal management of the light-emitting diodes (LEDs) used for high-mask towers, stadium lights, and street lights. Various capacities of LED (based on application), filling ratio, and working medium are considered experimental variables. DI water, Cu/DI water, and SiO_2/DI water-filled, two-layered, screen mesh wick, copper-made, cylindrical heat pipe have been tested for the cooling application of LEDs by varying the filling ratio. The effect of variables on evaporator and condenser temperature difference, power consumption, thermal resistance, effective thermal conductivity, and overall heat transfer coefficient is calculated and discussed in the results and discussion section. A superior combination of heat pipe with working fluid and filling ratio has been suggested for the cooling application of high-wattage LEDs.

MATERIALS AND METHODS

Light Emitting Diodes (LEDs)

All the LEDs purchased for the evaluated applications, namely the street light, the stadium light, and the high mast tower, have been put through an eight-hour working cycle to ensure that the readings remain consistent. The specifications of the purchased LED are described in Table 3.

Heat Pipe

Cylindrical heat pipes made up of copper with an outer diameter of 6-8 mm have been proven to be a superior cooling appliance due to the higher thermal conductivity of the material, shape, and volume to surface area for the particular applications[22]. Three sets of fabricated heat pipes have been experimented with for LED cooling. The 8 mm OD copper tube with 0.6 mm thickness has been manufactured with a non-return valve at one end for evacuation and refilling purposes. Screen mesh wick has been inserted for the capillarity. The close contact between mesh wick and inner wall has been confirmed by releasing the wick tension[23]. Table 2 describes the heat pipes for all three types of LEDs under experimentation, with their dimensions.

The closed contact between the heat pipe and the LED surface ensures heat dissipation. As shown in Figure 1, the heat pipe has been inserted between the LED junction and the LED›s casing. The heat pipes are embedded in the LED.

Table 1. LED Specification

LED Power	100 W	200 W	400 W
LED Size (mm)	190*150	250*160	350*270
Trial Duration	08 Hours	08 Hours	08 Hours
Purpose	Street Light	Stadium Light	High Mask Tower

Table 2. Description of heat pipes

Types of LED	100 W	200 W	400 W
Heat Pipe Material	Copper	Copper	Copper
Total length (mm)	630	875	1225
Evaporator Section Length (mm)	180	250	350
Condenser section Length (mm)	270	375	525
Types of Wick Structure	Screen mesh	Screen mesh	Screen mesh

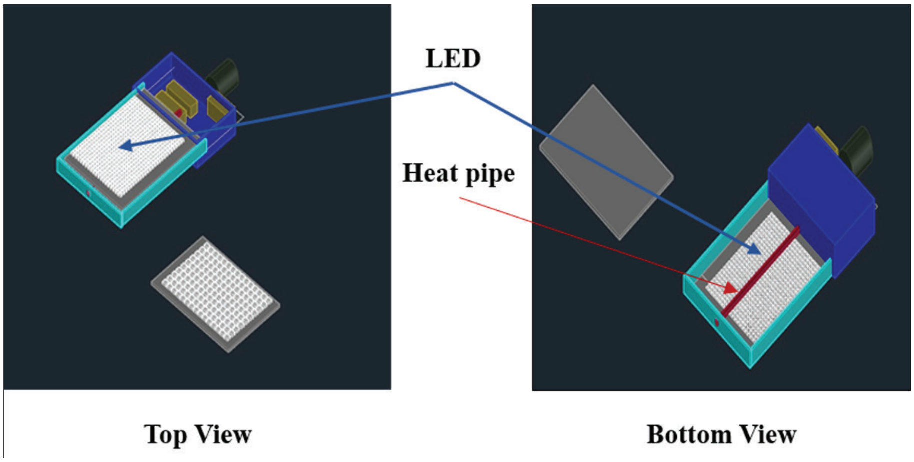

Figure 1. LED assembly along with Heat Pipe.

Nanofluids

Table 3. Properties of Nano-additives

Parameter	Cu	SiO_2
Density (g/cm3)	1.91	1.634
Particle size (nm)	30-50	30-50
Thermal Conductivity (W/mK)	383	10.4
Cost (Rs) per 10 gm	3500	1700

The researcher used a two-step method to prepare the nanofluids. Particles have been prepared using grinding. In the Second step, the particles are dispersed in the base fluid by stirring and ultrasonication [24]. As the investigation was associated with nanoscale molecule size, the possibility of eliminating molecule aggregation was considered. Suspend the molecule in a base liquid to prevent it from settling due to agglomeration [25]. The copper and silicon oxide particles used in this investigation are purchased in powder form from Platonic Nanotech Private Limited, Jharkhand (India). Table 2 shows the nanoparticle properties.

For the preparation of nanoparticles, the ultrasonic weight gauge was used by the researchers for 1.0 wt.% concentration particle weight, as significant studies had accounted that 1.0 wt.% is optimum[26], [27]. An attractive stirrer stirred the mixture of DI water and weighted particles for two hours, ensuring accurate scattering. After the mixing system was put through its paces, investigators subjected the nanofluids to a two-hour sonication process using an ultrasonic homogenizer. Both Cu and SiO_2 nanofluids were processed. The prepared nanofluids were stored in a glass bottle for testing and determining their stability.

Experimental Setup

Figure 2 describes an experimental setup prepared using various measuring and controlling devices. The evaporator area of the heat pipe is in the LED, which acts as a heat source[28]. The higher orientation, closure to vertical orientation retard the performance due to faster condensate return. It has been determined that the horizontal position of the heat pipe has the highest thermal resistance[29]. The current investigation implemented horizontal orientation for better LED orientation and lighting. The adiabatic section is exceptionally well insulated. The researchers used polyethylene foam (thermal conductivity = 0.032-0.034 W/mK, and linear coefficient of thermal expansion = 2×10^{-4} $°C^{-1}$ at 20 °C) to exhibit excellent thermal resistance, water resistance, and stability in different environmental conditions. A chamber is designed to cool the condenser component. Circulating water was utilized as a coolant to extract heat energy from the condenser and cycled within it simultaneously. PT-100 washer types thermocouples, the digital V-A meter records the total heat load capacity during the 08-hour working cycle. A rotameter records the mass flow of cooling water. Table 4 represents monitoring and measuring instruments› specifications, range, accuracy, and uncertainties.

All measuring devices have been calibrated at the Quality Calibration Centre, J2K LLP, Rajkot (Gujarat), India, a NABL (National Accreditation Board for Testing and Calibration Laboratories)- approved calibration centre. Thermocouples have been calibrated using a Multifunction process calibrator (3021131/MPC/ET/02). The thermocouple locations are as per Figure 2.

The experimentation is carried out by taking DI Water, Cu/DI Water, and SiO_2/DI Water as the working medium, and 20%, 40%, 60%, and 80% as the filling ratio. Figure 3 shows the actual experimental setup.

Uncertainty Analysis

Experimental uncertainties were calculated using the method developed by S. J. Kline and F. A. McClintock.[30] The calculations incorporate the estimated ones in experimental tests into the final results of interest as per Table 5.

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Table 4. Specifications of monitoring and measuring instruments

Measuring Device	Measuring property	Range	Uncertainty
Washer Type RTD (PT-100) Specifications: Probe type: Washer Type: RTD, PT-100 No. of terminals: 03 Length: 2 meters	Temperature	0 to 200°C	0.1°C
Probe type RTD (PT-100) Specifications: Probe type: SS Road with spring Type: RTD, PT-100 No. of terminals: 03 Length: 2 meters		0 to 200°C	0.1°C
Digital Temperature Display/ Scanner Specifications: No. of channels: 08 Relay contact: 230V AC, 2A Input type: PT100, Cu100, CU50 Dimensions: 96*96 mm		-	-
Digital Volt & Amp Meter Specifications: No. of channels: 08 Relay contact: 230V AC, 2A Input type: PT100, Cu100, CU50 Dimensions: 96*96 mm	Heat Load	A meter: 0-5A Voltmeter: 1-280 V	A meter: 0.01 A Voltmeter: 1 V
Rotameter Specifications: Material: Fibre body with metallic float. Maximum pressure: 8 bar Medium: Water Maximum temperature: 80 °C	Mass flow of cooling water	0 to 1200 LPH	50 LPH

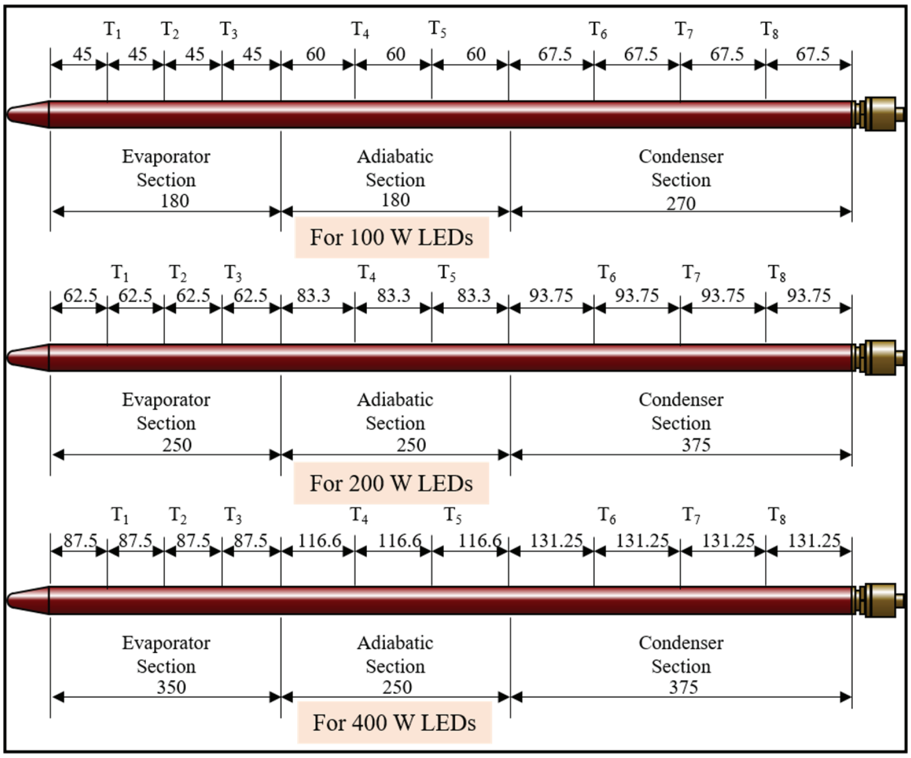

Figure 2. Thermocouple locations on the heat pipe surface.

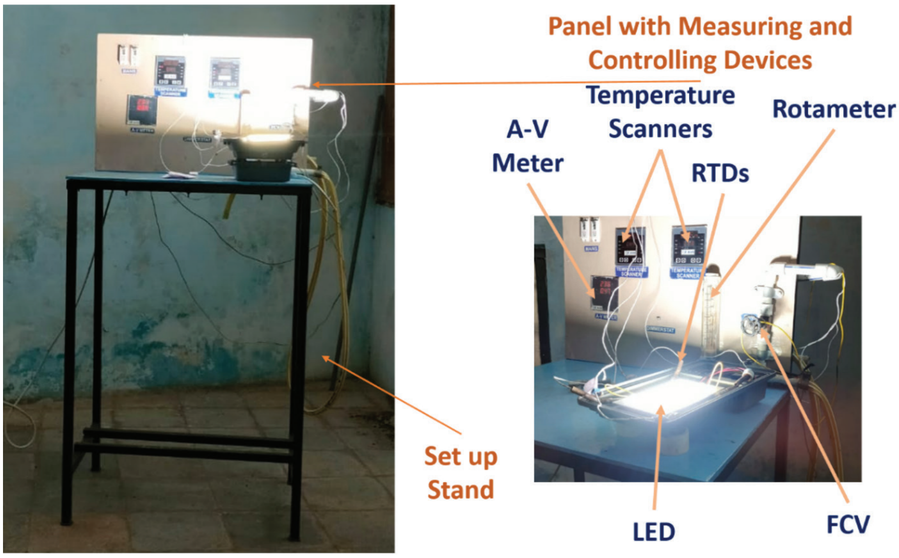

Figure 3. Experimental setup.

Table 5. Calculated uncertainty in final results

Result	% Uncertainty
Temperature difference	7.07%
Thermal resistance	7.05%
Effective thermal conductivity	6.82%
Overall HTC	7.06%

These results of uncertainty show that the uncertainty in the final parameters of interest is up to the expected level:

Evacuation and Refilling

The filling ratio is the ratio of the quantity of working medium poured inside the heat pipe and the total volume of the heat pipe[31]. Proposed filling ratios ranging from 20% to 80% have been used for the experimentation. The calculated quantity of working medium has been poured into the filling bottle and installed in the station. The appropriate insulation of the vacuum has been ensured by enveloping a Teflon tape. The specially designed evacuation and refilling station has been designed and developed for the evacuation and refilling of the fabricated heat pipe. Figure 4 shows the actual setup for evacuation and refilling. Heat pipes under experimentation for the thermal management of LED are first flushed with DI water and prepared nanofluids. Firstly, the heat pipe has been assembled with the station and evacuated with the help of an evacuation and refilling station. Valves V1 and V2 were opened during evacuation, and V3 was closed. The vacuum gauge has been installed to ensure the appropriate vacuum. After evacuation, the vacuum pump was cut off, and valve V2 was closed. Then, after the prepared mono nanofluids have been poured inside the heat pipe, valve V3 is operated.

Figure 4. Evacuation and refilling station.

The heat pipe was disassembled with the station and assembled with the LEDs for testing.

RESULTS AND DISCUSSION

The thermal performance analysis of LEDs using nanofluid-filled heat pipes has been investigated by varying the types of working fluid, filling ratio, and load capacity. The result of such variables has been analyzed by considering the temperature gap between the evaporator and condenser sections, effective thermal conductivity, and overall heat transfer coefficient.

The lower temperature difference between the evaporator and condenser sections implies better heat dissipation through the heat pipe. The surface temperature between the evaporator and condenser sections was [29].

$$\Delta T = T_e - T_c \quad (1)$$

The thermal resistance should be as low as possible. The thermal resistance has been calculated as[29],

$$R = \frac{Te - Tc}{Q} \quad (2)$$

The better effective thermal conductivity leads to better heat transfer from the evaporator to the condenser section. The effective thermal conductivity has been calculated as[29],

$$K = \frac{L_{eff}}{A_c \times R} \quad (3)$$

The overall heat transfer coefficient should be as high as possible for better heat transfer between the heat source and heat sink regions. The overall heat transfer coefficient has been considered with[29],

$$\frac{Q}{A_c \times \Delta T} \quad (4)$$

Temperature Difference Between Evaporator and Condenser Section

Effect of filling ratio on Te-Tc

Figure 5 describes the comparative results of the temperature difference between the evaporator and condenser sections by varying the filling ratio for 20%, 40%, 60%, and 80% for all three types of LEDs with a heat pipe under experimentation, i.e., 100W, 200W, and 400W. Researchers found the lowest temperature difference between evaporation and condenser sections in the 60% filling ratio for Cu/DI water-filled heat pipe and SiO_2/DI water-filled heat pipe in all LEDs. Cu/DI water with 60% filling ratio has 0.81%, 1.60%, and 7.16% lower temperature differences as

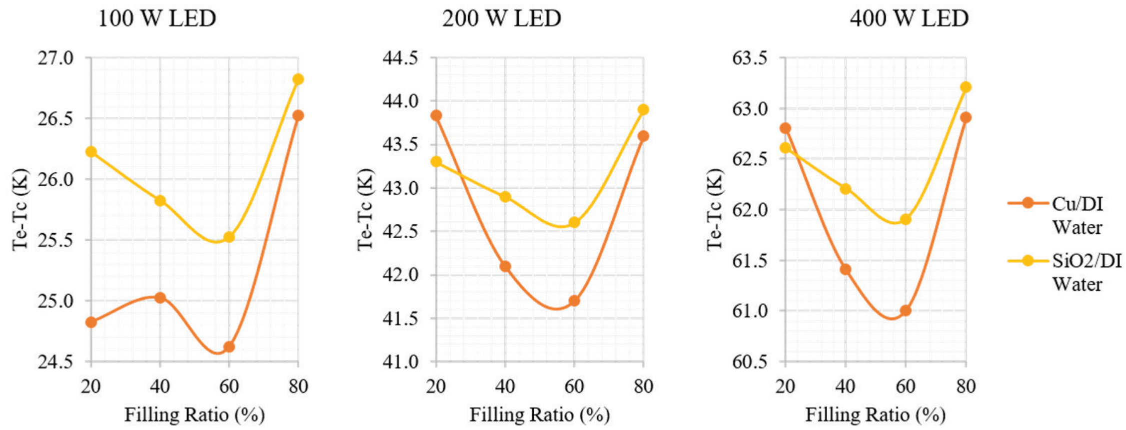

Figure 5. Effect of filling ratio on Te-Tc.

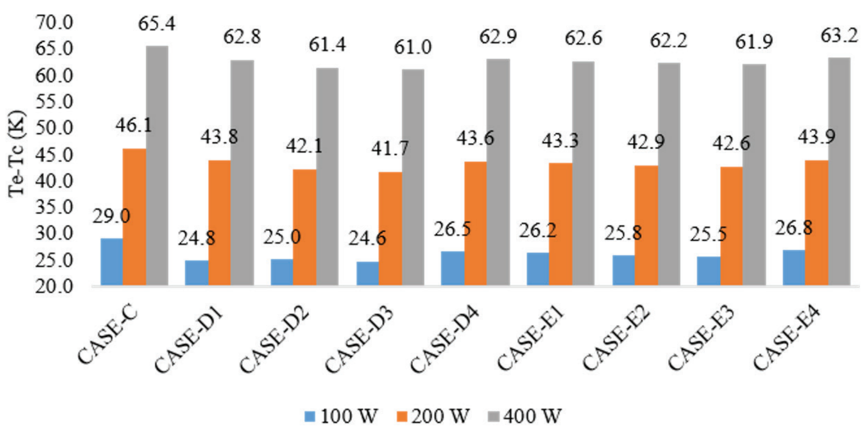

Figure 6. Effect of Working Mediums on Te-Tc.

compared to 20%, 40% and 80% filling ratio for 100 W LED. Cu/DI water with a 60% filling ratio has 4.87%, 0.95% and 4.36% lower temperature difference as compared to 20%, 40% and 80% filling ratio for 200 W LED. Cu/DI water with 60% filling ratio has 2.9 %, 0.7% and 3.0% lower temperature difference as compared to 20%, 40% and 80% filling ratio for 400 W LED.

Effect of working mediums on Te-Tc

Figure 6 describes the comparative results of the temperature difference between the evaporator and condenser sections by varying the working medium for all three types of LEDs with a heat pipe under experimentation, i.e., 100W, 200W, and 400W. The lowest temperature difference between evaporation and condenser sections has been found in case D3 (Cooling with Cu/DI water-filled heat pipe at 60% filling ratio) for all types of LEDs. Cu/DI water with 60% filling ratio has 15.2% and 3.5% lower temperature difference in contrast with DI water and SiO_2/DI water for 100 W LED. Cu/DI water with 60% filling ratio has 9.5% and 2.1% lower temperature difference in contrast with DI water and SiO_2/DI water for 200 W LED. Cu/DI water with 60% filling ratio has 6.7% and 1.5% lower temperature difference in contrast with DI water and SiO_2/DI water for 400 W LED. The temperature difference is lower in a 100 W LED than in a 400 W LED.

Heat Input

Effect of working mediums on heat input

Figure 7 illustrates the comparative results of heat input by varying working medium for all three types of LEDs with heat pipes under experimentation: 100W, 200W, and 400W. Cu/DI water-filled heat pipes with a 60% filling ratio have 6.5% and 8.5% lower power consumption, contrasting with fin and natural cooling for 100 W LEDs. The appropriate cooling reduces overheating, reducing power consumption.

Thermal Resistance

Effect of filing ratio on thermal resistance

Figure 8 demonstrates the comparative thermal resistance results by varying the filling ratio for 20%, 40%, 60%, and 80% for all three types of LEDs with a heat pipe under experimentation, i.e., 100W, 200W, and 400W. Researchers have found the lowest thermal resistance with a 60% filling ratio in Cu/DI water and SiO_2/DI water-filled heat pipes for

Figure 7. Effect of working mediums on Heat Input.

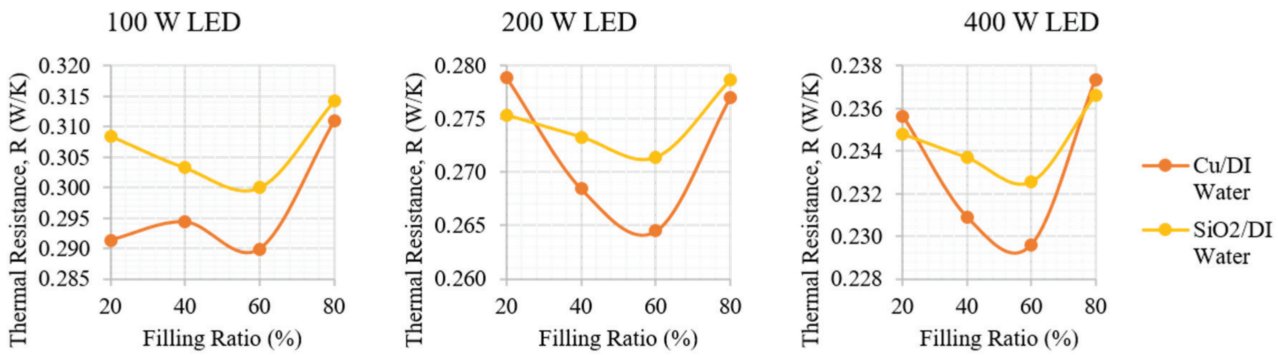

Figure 8. Effect of filling ratio on thermal resistance.

all types of LEDs. Cu/DI water with 60% filling ratio has 0.50%, 1.51% and 6.76% lower thermal resistance as compared to 20%, 40% and 80% filling ratio for 100 W LED. Cu/DI water with 60% filling ratio has 5.17%, 1.48% and 4.54% lower thermal resistance as compared to 20%, 40% and 80% filling ratio for 200 W LED. Cu/DI water with 60% filling ratio has 2.6%, 0.6% and 3.3% lower thermal resistance as compared to 20%, 40% and 80% filling ratio for 400 W LED.

Effect of working medium on thermal resistance

Figure 9 demonstrates the comparative results of thermal resistance by varying working mediums for all three types of LEDs with heat pipes under experimentation, i.e., 100W, 200W, and 400W. The lowest thermal resistance has been found in case D3 (Cooling with Cu/DI water-filled heat pipe at a 60% filling ratio) for all types of LEDs. Cu/DI water with 60% filling ratio has 14.6% and 3.4% lower thermal resistance in contrast with DI water and SiO_2/DI water for 100 W LED. Cu/DI water with 60% filling ratio has 9.5% and 2.5% lower thermal resistance in contrast with DI water and SiO_2/DI water for 200 W LED. Cu/DI water with 60% filling ratio has 6.1% and 1.3% lower thermal resistance in contrast with DI water and SiO_2/DI water for 400 W LED. The thermal resistance is lower in a 400 W LED and higher in a 100 W LED.

Effective Thermal Conductivity

Effect of filling ratio on effective thermal conductivity

Figure 10 demonstrates the comparative results of effective thermal conductivity by varying the filling ratio for 20%, 40%, 60%, and 80% for all three types of LEDs with a heat pipe under experimentation, i.e., 100W, 200W, and 400W. The highest effective thermal conductivity has been found with a 60% filling ratio for Cu/DI water and SiO_2/Di water-filled heat pipes, again for all types of LEDs. Cu/DI water with 60% filling ratio has 0.51%, 1.54% and 7.25% higher effective thermal conductivity as compared to 20%, 40% and 80% filling ratio for 100 W LED. Cu/DI water with a 60% filling ratio has 5.45%, 1.50% and 4.75% higher effective thermal conductivity as compared to 20%, 40% and 80% filling ratio for 200 W LED. Cu/DI water with 60% filling ratio has 2.6%, 0.6% and 3.4% higher effective thermal conductivity as compared to 20%, 40% and 80% filling ratio for 400 W LED.

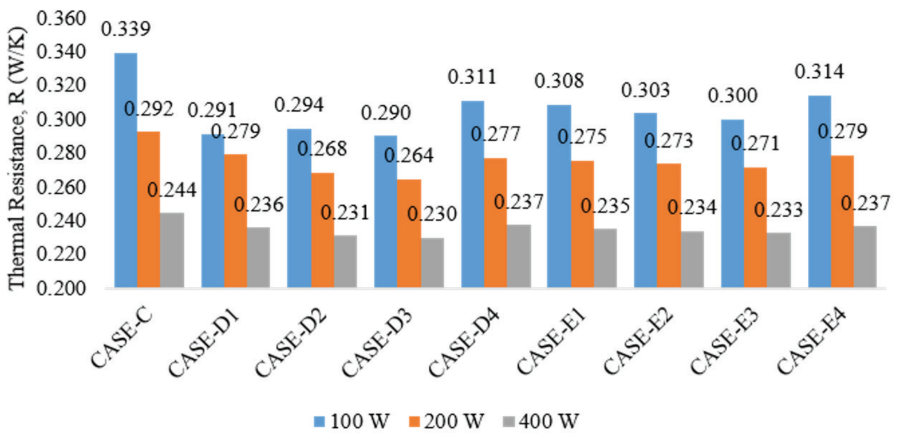

Figure 9. Effect of working medium on thermal resistance.

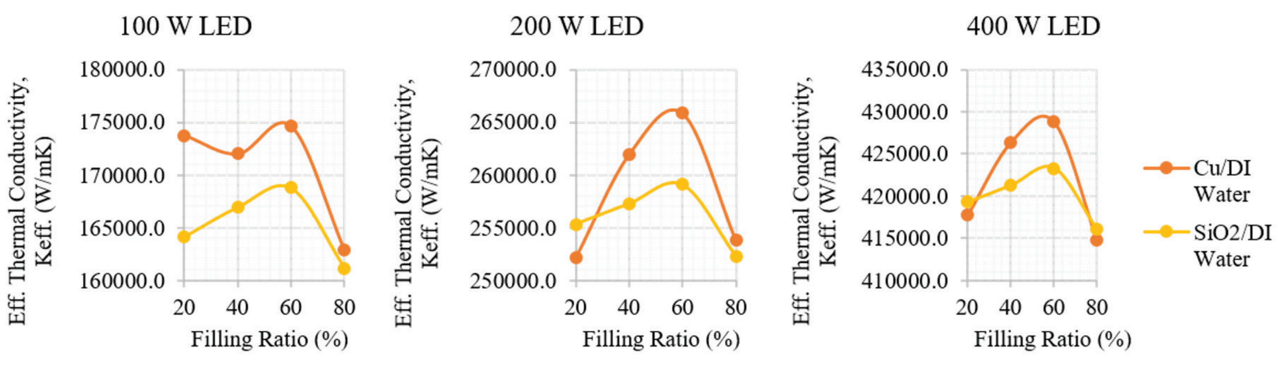

Figure 10. Effect of filling ratio on effective thermal conductivity.

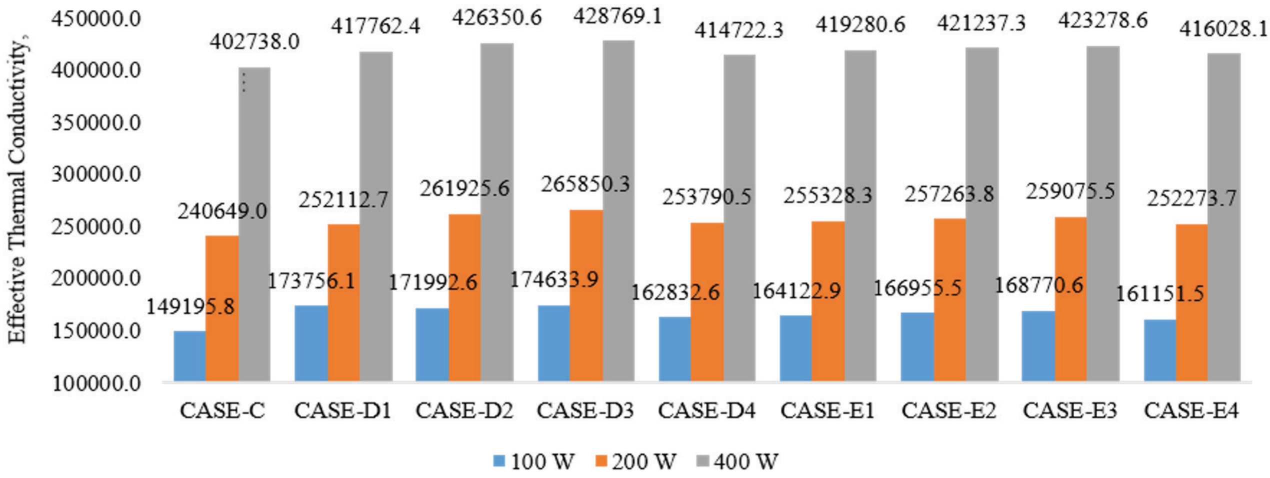

Figure 11. Effect of working mediums on effective thermal conductivity.

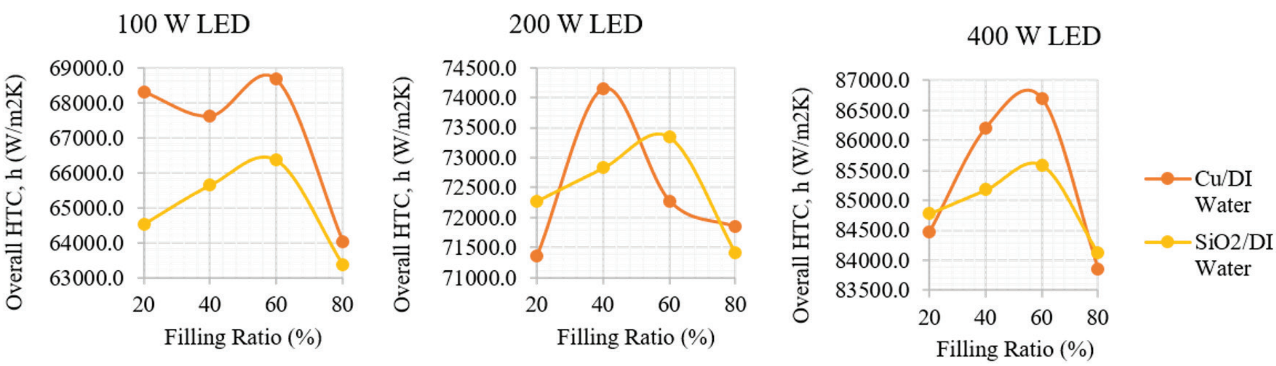

Figure 12. Effect of filling ratio on overall heat transfer coefficient.

Effect of working mediums on effective thermal conductivity

Figure 11 demonstrates the comparative results of effective thermal conductivity by varying the working medium for all three types of LEDs with a heat pipe under experimentation, i.e., 100W, 200W, and 400W. The highest effective thermal conductivity has been found in case D3 (Cooling with Cu/DI water-filled heat pipe at 60% filling ratio) again for all types of LEDs. Cu/DI water with 60% filling ratio has 17.1% and 3.5% higher effective thermal conductivity in comparison with DI water and SiO2/DI water for 100 W LED. Cu/DI water with 60% filling ratio has 10.5% and 2.6% higher effective thermal conductivity in comparison with DI water and SiO_2/DI water for 200 W LED. Cu/DI water with 60% filling ratio has 6.5% and 1.3% higher effective thermal conductivity in comparison with DI water and SiO_2/DI water for 400 W LED. The effective thermal conductivity is higher in 400 W LED, whereas lower has been observed in 100 W LED.

Overall Heat Transfer Coefficient (HTC)

Effect of filling ratio on overall heat transfer coefficient

Figure 12 illustrates the comparative results of the overall heat transfer coefficient by varying the filling ratio for 20%, 40%, 60%, and 80% for all three types of LEDs with a heat pipe under experimentation, i.e., 100W, 200W, and 400W. The highest overall HTC has been found with a 60% filling ratio in Cu/DI water and SiO_2/DI water-filled heat pipe again for all types of LED. Cu/DI water with 60% filling ratio has 0.51%, 1.54% and 7.25% higher overall HTC as compared to 20%, 40% and 80% filling ratio for 100 W LED. Cu/DI water with 40% filling ratio has 3.89%, 2.58% and 3.21% higher overall HTC as compared to 20%, 60% and 80% filling ratio for 200 W LED. Cu/DI water with 60% filling ratio has 2.6%, 0.6% and 3.4% higher overall HTC as compared to 20%, 40% and 80% filling ratio for 400 W LED.

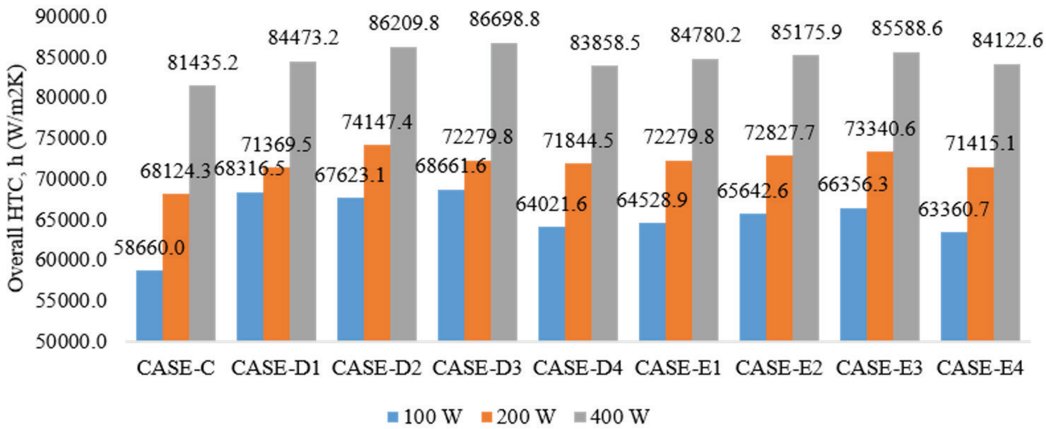

Figure 13. Effect of working mediums on overall heat transfer coefficient.

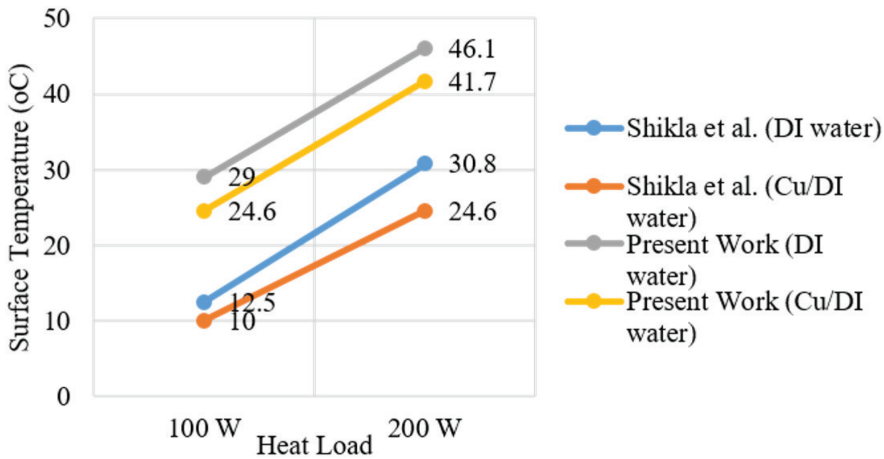

Figure 14. Comparison of present work in the form of surface temperature with heat load (DI water and Cu/DI water as working medium, horizontal position, 60% filling ratio).

Effect of working mediums on the overall heat transfer coefficient

Figure 13 demonstrates the comparative results of the overall heat transfer coefficient by varying the working medium for all three types of LEDs with the heat pipe under experimentation, i.e., 100W, 200W, and 400W. The highest overall HTC has been found in case D3 (Cooling with Cu/DI water-filled heat pipe at 60% filling ratio) again for all types of LED. Cu/DI water with 60% filling ratio has 17.1% and 3.5% higher overall HTC in comparison with DI water and SiO_2/DI water for 100 W LED. Cu/DI water with 60% filling ratio has 6.1% and 1.4% higher effective overall HTC in comparison with DI water and SiO_2/DI water for 200 W LED. Cu/DI water with 60% filling ratio has 6.5% and 1.3% higher overall HTC in comparison with DI water and SiO_2/DI water for 400 W LED. The overall HTC is higher in 400 W LED, whereas a lower value has been observed in 100 W LED.

Comparison and Validation

Figure 14 compares the present work with Shukla et al. [32] in the form of surface temperature with heat load by filling DI water and Cu/DI water as the working fluid. The horizontal orientation, 60% filling ratio, and two-layered screen mesh inserted cylindrical heat pipe type remained constant. Similarly, the DI water and Cu/DI water-filled heat pipes were investigated in both studies.

Results conclude that in all studies, the surface temperature was lower in Cu/DI water as a working medium than in DI water. Furthermore, the surface temperatures have been enhanced with the heat load in the present work and in Shukla et al. [32]

CONCLUSION

This work establishes how to thermally manage high-wattage LEDs using a heat pipe with a screen mesh wick and distilled water-based Cu and SiO_2 mono nanofluids. Researchers analyze the results obtained after experimentation to improve outcomes. Researchers have observed the following conclusions.:

1. Performance improvement has been found with nanofluid-filled heat pipes instead of DI water-filled heat pipes for all types of LEDs. Cu/DI water with a 60% filling ratio has a 15.2% lower temperature difference than DI water for 100 W LEDs. The dispersion of nano-additives in DI water enhances the thermo-physical properties of the working medium.
2. CuO/DI water-filled heat pipes are more effective than DI water-filled heat pipes and SiO_2/DI water-filled heat pipes for all types of LEDs. Cu/DI water with a 60% filling ratio has a 3.5% lower temperature difference than SiO_2/DI water for a 100 W LED. The thermal conductivity of Cu is far better than that of SiO_2, which enhances the heat transport mechanism.
3. A 60% filling ratio is optimum for nanofluid-filled heat pipes and all types of LEDs. Cu/DI water with a 60% filling ratio has 0.81%, 1.60%, and 7.16% lower temperature differences than 20%, 40%, and 80% filling ratios for 100 W LEDs. A less than 60% filling ratio leads to a scarce working medium, whereas a more than 60% filling ratio leads to overflow.
4. Higher power leads to reduced thermal resistance compared with lower power (e.g., a 400W LED has lower thermal resistance than 100 W and 200 W LEDs). Thermal resistance is inversely proportional to heat load.

Furthermore, thermal analysis of LED cooling using nanofluid-filled heat pipes can be analyzed using different heat pipes such as flat, oscillating, pulsating, revolving, and rotating. Also, the hybridization of nanoparticles, proportion, variation in concentration, particle size, and shape can be investigated further. The mathematical model or simulated analysis may predict the performance trends of LEDs in the future.

NOMENCLATURE

Abbreviations

CCT	Correlated Color Temperature
CHP	Closed Loop Heat Pipe
Cu	Copper
DI	Distilled
GaN	Gallium Nitride
LED	Light Emitting Diode
NABL	National Accreditation Board for Testing and Calibration Laboratories
OHP	Oscillating Heat Pipe
SiO_2	Silicon Oxide

Symbol

HTC	Heat Transfer Coefficient (W/mK)
T	Temperature (°C)
Wt	Weight Fraction (%)

Subscripts

e	Evaporator section
c	Condenser section

AUTHORSHIP CONTRIBUTIONS

Authors equally contributed to this work.

DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

STATEMENT ON THE USE OF ARTIFICIAL INTELLIGENCE

Artificial intelligence was not used in the preparation of the article

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