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Computational Investigation on Radiative Heat Transfer Characteristics of an Automotive LED Tail Light

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Nomenclature

ρ is Fluid Density, kg/m^3; E is Energy, J; p is Pressure, Pa; k_{eff} is Effective Conductivity, W/(m·K); T is Temperature, K; h is Sensible Enthalpy, J/kg; $\vec{J}_j$ is Diffusion Flux, mol/(m^{2}s); $\bar{\bar{\tau}}_{eff}$ is Effective Viscous Stress N/m^2; $\vec{V}$ is Velocity Vector, m/s; S_h is Heat Source, J; $q_{out,k}$ is Energy Flux leaving the surface, J; ε_k is Emissivity of the Surfaces, J/m^2; σ is Stefan Boltzmann Constant; T_k is Temperature of the area, K; ρ_k is Density of the area, kg/m^3; $q_{in,k}$ is Energy Flux incident on the surface, J.
Subscripts: *eff* – Effective; *j* – index of coordinate; *h* – heat; *k* – surface.

1. Introduction

In today's modern world, customers demand stylish and sophisticated automobiles for day-to-day transportation [1]. Automotive industry is highly competitive and focuses on cost reduction without compromising the customer-driven requirements and styling characteristics. In terms of style and design, the pattern of lights in a vehicle's front and rear sides is the most intense factor to be considered [2]. The source of lights in vehicle rear lamp systems has undergone various changes over the past few decades. Further materials like durable plastics produced high performance in automobile lighting system. Today's automotive lights aim at improving the lighting and thermal distribution. Some factors like long life span and aerodynamic characteristics can be obtained when utilizing materials like thermoplastic reflectors along with plastic lens [3]. However, such materials are highly sensitive to high temperatures due to which proper and efficient heat transfer analysis has to be conducted to determine the areas susceptible to thermal degradation.

The use of Light Emitting Diode (LED) source in vehicular lighting for illumination and signaling is widely preferred because of its better luminous efficiency and thermal distribution compared with filament source. Tail light malfunctions or failures of filament source are often the cause for 21% rear-end crashes in passenger vehicles reported by National Transportation Highway Traffic Safety Administration (NHTSA) [4]. This resulted in using LED in airfield, runway and taxiway lighting systems [5]. Sokmen et al. [6] studied the effects of fin design, fin material, and free and forced convection on junction temperature in automotive headlamp cooling applications of LED lights using ANSYS CFX 14 software. Furthermore, a new methodology was developed to define the optimum cylindrical fin structure within the given limits. The application of Computational Fluid Dynamics (CFD) methodology in measuring flow over a vehicle platoon further established CFD as an effective design tool in improving the aerodynamic efficiencies of automobiles [7].

Johan and Mikael [8] performed a CFD modeling of headlight condensation. They realized during their research that the methodology was not fully optimized and some areas were found to be quite time consuming. Further, they also stated that the main reason for this deviation remained in the handling of settings and boundary conditions for the radiation model. This in turn created a different temperature distribution on the outer lens when compared to temperature distribution from the physical testing.

Morgado et al. [9] reviewed different radiation models available in ANSYS Fluent from which they selected Surface-to-Surface (S2S) radiation model which allowed accounting for the radiation exchange in an enclosure assuming that there is non-participating media (air and/or water). Ryszard Kantor [10] assumed that there is only negligible contribution from thermal conduction and convection effects to overall heat transfer through vacuum layer. Yilmaz et al. [11] considered only the 'radiation heat transfer' between absorber tube and the glass envelope in evacuated condition of heat collector elements and they adopted Surface to Surface (S2S) radiation modeling. Boulet et al. [12] presumed that radiation is the predominant heat transfer mechanism for industrial tunnel bakery ovens. In their study, the radiation was described using Surface-to-Surface (S2S) model whereas a radiosity method was proposed in this study which did not accounted the contribution of gaseous media. Salah et al. [13] solved the radiative transfer equation by finite-volume method in an axisymmetric two-dimensional geometry with absorbing, emitting, and either isotropically or anisotropically - scattering gray medium.

Since, previous research works on thermal analyses of automotive tail light are limited, the current study focuses on computational study of thermal failure characteristics with respect to different housing materials. Further, the simulation analysis was extended to re-arranging LED arrays so as to achieve better thermal management of tail light assembly without affecting the illumination characteristics.

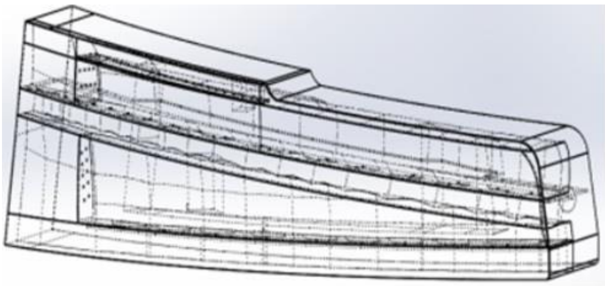
ANSYS Fluent software was used to carry out the numerical simulations. This approach was able to model the thermal process under various materials to provide an overall view of the entire physical phenomenon involved. Heat transfer modes such as convection, conduction and radiation were modelled in ANSYS Fluent in order to predict the wall temperature within automotive tail lights. The study considered some assumptions like 100% electric power from light is converted to thermal energy and a constant heat flux boundary condition on LED. Hot spot determination and airflow analysis were carried out. The S2S thermal radiation model was used to analyses the thermal fluid field in a tail light. The CFD analysis of tail light assembly was validated using the experimental set up.

2. Materials and methods

The numerical simulation methodology includes creating a CAD model of commercial automotive tail light with LED provisions, domain discretization, appropriate radiative heat transfer physics definition and post processing of results. The analysis was carried out in two phases. In first phase of simulation, a conventional automotive LED tail light was considered and modeled with appropriate dimensions. The materials for individual components of the tail light assembly were selected based on literature and the available technical data. Different materials were chosen for housing (back cover) and compared for better heat transfer performance on the basis of maximum temperature limit of individual materials. The analyses brought out the overall thermal performance comparison and optimization based on the thermal properties of the materials. Various arrangements of LED arrays were simulated during the second phase of the simulation. The conventional LED arrangement was considered as the baseline model. The arrangement of LED-s and their positions were altered based on the first cut computational simulation results for better thermal performance.

2.1. CAD modelling

To prepare the exact profiles of the tail light components, the working model of a commercial tail light assembly with LED provision was considered. For the current computational simulation, the tail light assembly of a commercial car was considered. The part was disassembled and all the major dimensions and profiles were marked. The 3D geometry of the conventional tail light assembly of the passenger vehicle was modelled using Solidworks. The profiles and curvatures of the reflectors were drawn analogous to the working model. The PCB boards were modelled with appropriate thickness in order to invoke the conduction mode of heat transfer along with the radiation. Fig. 1 shows the CAD details of the tail light assembly used for the present study's numerical investigation.



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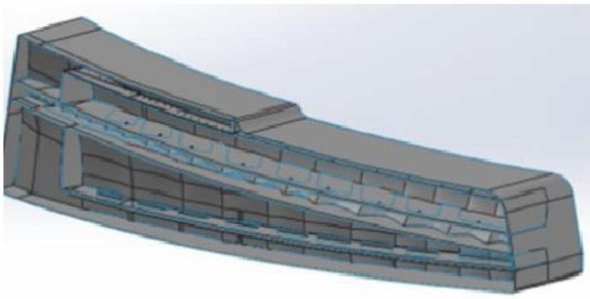

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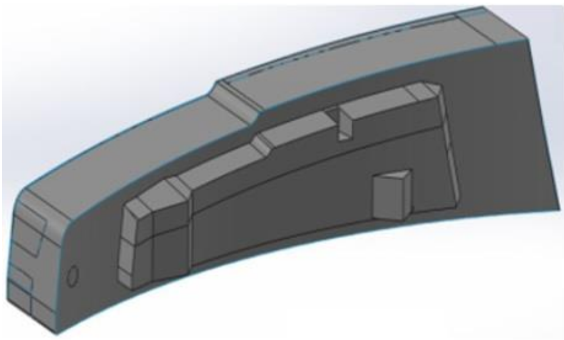

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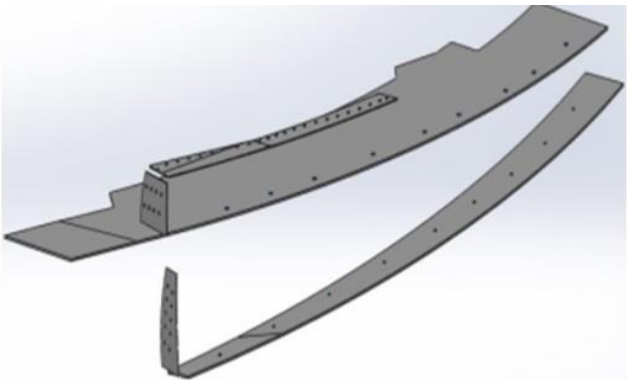

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Fig. 1 CAD details of tail light assembly. a) Wire frame; b) Reflector and inner panel; c) Housing; d) PC boards with LEDs

The overall length of the tail light assembly was 462 mm and the breadth was 98 mm. The total height of the assembly was 105 mm.

2.2. Domain discretization

The geometry cleans up and domain discretization were performed using HYPERMESH software. The surfaces of the tail light assembly, with LED arrangements, were meshed with unstructured triangular elements whereas the computational volume was discretized with standard tetrahedron elements. The complicated curved profiles of reflectors resulted in unstructured meshing, instead of structured elements.

But the mesh refinements were carried out to capture the profiles and a separate mesh independence study was carried out to obtain the optimum element size. Fig. 2 depicts the surface mesh details.

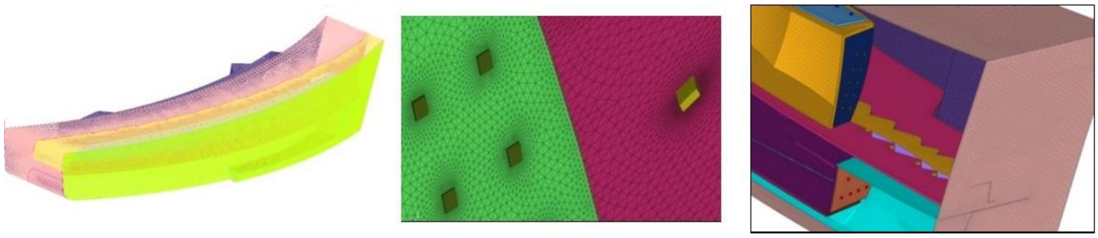

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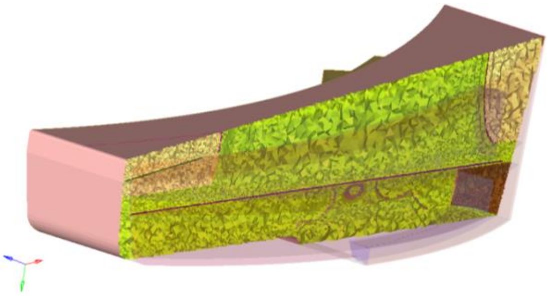
Fig. 2 Mesh details of tail light assembly. a) Mesh wire-frame; b) Surface mesh; c) Mesh refinement near LED

2.2.1. Grid independence study

In order to establish the accuracy and consistency of CFD solution, a separate grid independence study was carried out by varying the surface element size. The volume mesh count inside the flow-thermal domain is completely dependent on surface mesh refinements and growth rate. In this study, five different mesh sizes were chosen for the tail light assembly and the analysis was carried out with fixed thermal boundary conditions. The area-weighted average temperature was calculated over the housing surfaces. The variation in temperature was observed in order to freeze the correct mesh size for the entire analysis.



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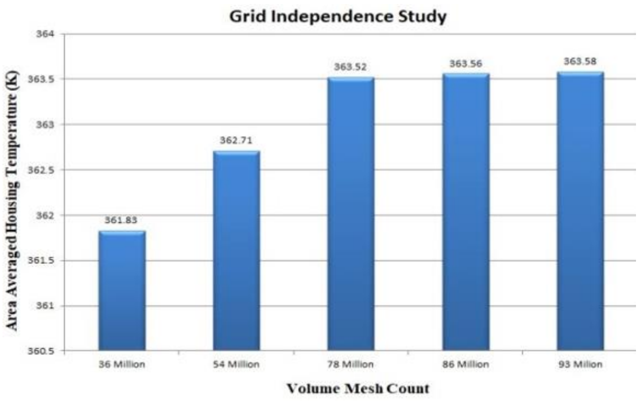

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Fig. 3 Volume mesh cut sectional view (a); Mesh independent study (b)

Fig. 3 shows the volume mesh cut sectional view of the computational domain. Based on the mesh independence study, the total number of volume element considered for the numerical simulation were 78.2 million and the total nodes were around 16.8 million.

2.3. Boundary - physics definition

The discretized domain was applied with appropriate boundary conditions. Standard atmospheric air was the fluid material used for simulation. Gravity model was invoked for gravitational acceleration in flow field. A steady state analysis was carried out with a segregated solver (ANSYS - Fluent). A non-participating medium radiation model (Surface to Surface - S2S) was used to predict the radiative heat transfer since the air is transparent to thermal radiation. Further the medium neither emits nor absorbs the radiant energy from LED-s. Three different materials (Poly Butylene Terephthalate - PBT, Acrylonitrile Butadiene Styrene - ABS and Bulk Molding Compound - BMC) were used to compare the thermal performance of tail light. The material used for cover lens was Poly Methyl Meta Acrylate (PMMA-8N). LED boards were assigned with Poly Carbonate (PC) material. The thermal properties applied for these materials were listed in Table 1. The LED surfaces were heated upto a maximum temperature of 423 K and the LED volumes were patched with the same temperature before starting the solution. The following assumptions were made during the computational simulation:
- the temperature of LED was assumed to be constant.
- the thermal properties were assumed to be isotropic.
- the fluid was assumed to be a non-participating media.

Table 1

Thermal properties of tail light assembly materials

Sl. No	Material	Thermal conductivity, $Wm^{-1} K^{-1}$	Specific heat capacity, $J\ kg^{-1} K^{-1}$	Density, $kg\ m^{-3}$
1	PMMA - 8N	0.18	1470	1190
2	PC	0.29	1250	1850
3	ABS	0.2	2000	1200
4	PBT	0.24	1430	1300
5	BMC	13.4	840	1730

The segregated solver solved the energy equation (Eq. (1)) along with fluid-thermal radiation using Surface to Surface (S2S) model (Eq. (2)) [14].

$$\frac{\partial}{\partial t}(\rho E)+\nabla\cdot\left(\vec{v}\left(\rho E+p\right)\right)=$$
$$=\nabla\cdot\left(k_{eff}\nabla T-\sum_j h_j\vec{J}_j+\left(\bar{\bar{\tau}}_{eff}\cdot\vec{v}\right)\right)+S_k, \quad (1)$$

where: k_{eff} denotes the effective thermal conductivity of the material and $\vec{J}_j$ denotes the diffusion flux. The first three terms of the right hand side of the equation represent the heat transfer due to conduction, diffusion and viscous dissipation. The heat source term is denoted as S_h:

$$q_{out,k}=\varepsilon_k\sigma T_k^4+\rho_k q_{in,k}, \quad (2)$$

where: $q_{out,k}$ is the energy flux leaving the surface, ε_k is the emissivity of the surfaces, σ is the Stefan Boltzmann constant and $q_{in,k}$ is the incident energy flux on surfaces which is a function of Surface to Surface view factor. In the present analysis, the surface view factors were calculated by the solver from mesh faces before initializing the solution.

3. Results and discussions

In the present computational study, simulation was carried out for tail light configuration with different housing materials for LED panel assembly. Further, the thermal performance simulation of tail light was compared by configuring different LED arrangements. The solver solved 'flow and energy' equation with S2S radiation model [15]. The convergence criterion for the energy equation is kept $1*10^{-06}$. Fig. 4 shows the convergence history of energy equation that was solved iteratively.

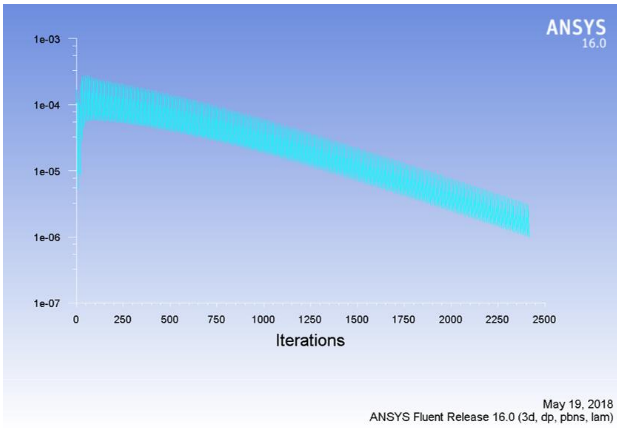
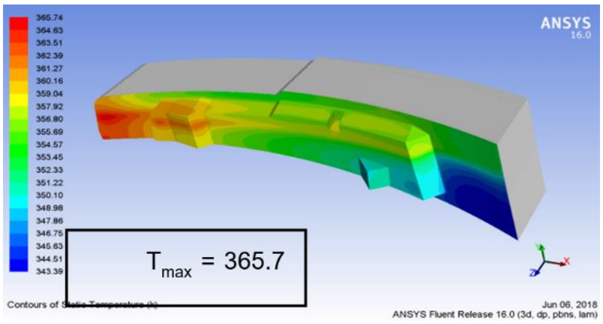


Fig. 4 Convergence history of energy equation

3.1. Effect of housing material

The thermal properties of the materials used for plastic components directly influence maximum temperature obtained in the parts of tail light assembly. The major properties which decide the temperature distribution over LED panels, housing and cover lens are thermal conductivity, specific heat capacity and density. For the present numerical investigation, three different materials were chosen for housing (PBT, ABS and BMC) as mentioned in computational methodology. The computational analysis was carried out for all these three materials individually by changing properties of housing material. The thermal distributions over the housing unit were compared and the temperature results were consolidated for better thermal performance. Temperature contours of various plastic components of LED tail light were plotted and discussed as follows.

The temperature profiles of the tail light housing unit with back cover and side cover surfaces with ABS material are shown in the Fig. 5. It can be understood from the figure that the contour of temperature is not evenly distributed over the back cover. The narrow region of the tail light can be observed with high temperature (365.7 K) whereas the wider region of the tail light can be witnessed via low temperature (343.3 K). The area weighted average temperature of the back cover surface was 354.8 K. The reason for maximum temperature at narrow region of the tail light is that all the PCB-s converge at this region and the maximum number of LED-s get concentrated. Similarly, it can be noticed from Fig. 5 that the numerical results predict high temperature on narrow side for side surfaces of the housing unit (366.4 K) and lower temperature near the wider region (312.33 K). The area averaged temperature of the side surfaces was 349.1 K.



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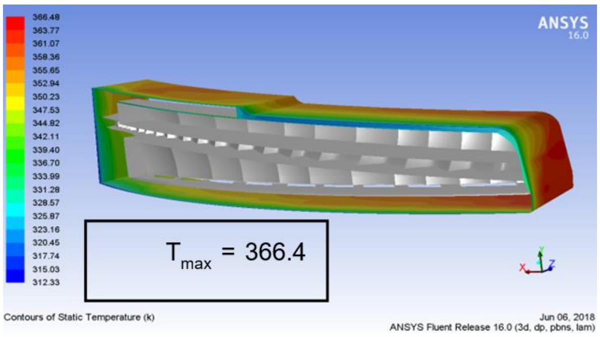

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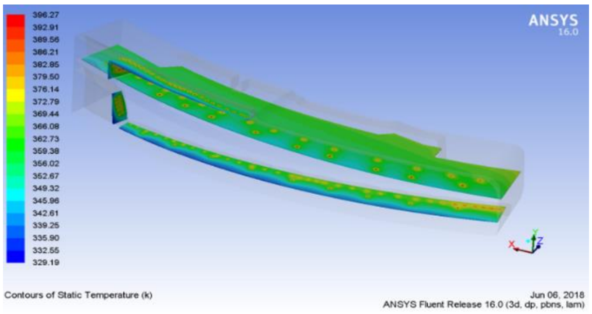
Fig. 5 Temperature distribution over (a) housing back cover and (b) side cover of tail light

The contours of temperature profiles over all PCB inner panels are shown in Fig. 6. The top and bottom PCB-s were fixed with LED on both sides as shown in Fig. 6. The observed average temperature over these PCB panels was 357.8 K. The average junction temperature between PCB and LED was found to be 393.5 K.

The temperature distributions over top-side and bottom-side danger light PCB are shown in the Fig. 7. The temperature profiles follow the exact profile of reflector. The reflector blocks the thermal energy radiated from LED-s and reflects back to the front panel. This is clearly indicated by the low temperature profile over the PC board.

Reflector profiles play an important role in thermal distribution and the performance of LED tail light assembly. The temperature distributions over the brake light reflector and turn-indicator reflector are shown in the Fig. 8. The maximum temperature observed over these reflector surfaces was 368.9 K and their area averaged temperature was 349.44 K.

The thermal performance of LED tail light based on various housing materials was compared and tabulated based on the maximum temperatures observed. Table 2 compares the results obtained from three materials. From the table, it can be understood that the maximum temperature, obtained over the back cover of the housing due to radiation, was more in PBT and BMC materials when compared with ABS material. Further, the temperature difference for attaining the 'limiting value' was more in case of ABS material when compared with other two materials. So from the numerical simulation it can be inferred that using ABS plastic gives a significant thermal performance when compared with other commercial housing materials. Further, from the table, it can be inferred that the area-weighted steady-averaged temperature over the back cover is significantly less in ABS material when compared with other two materials.



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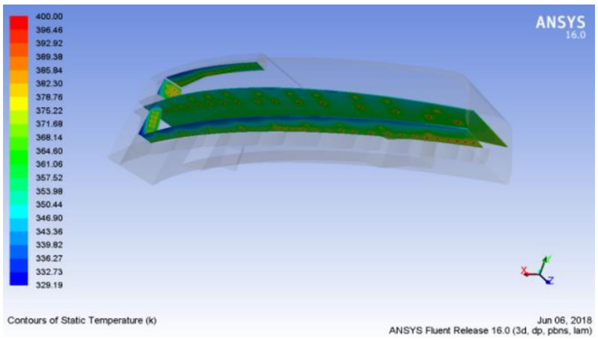

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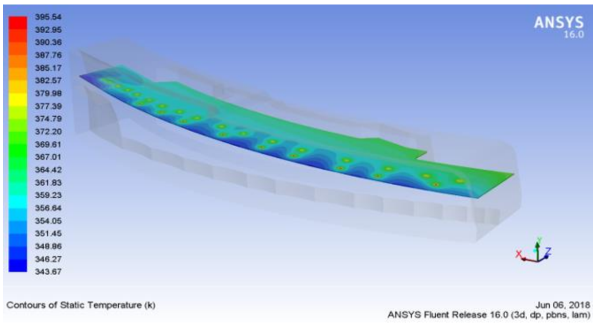
Fig. 6 Temperature distribution over PCB panels of tail light (a) LED-s on Top Side of PCB Boards and (b) LED-s on Bottom Side of PCB Boards



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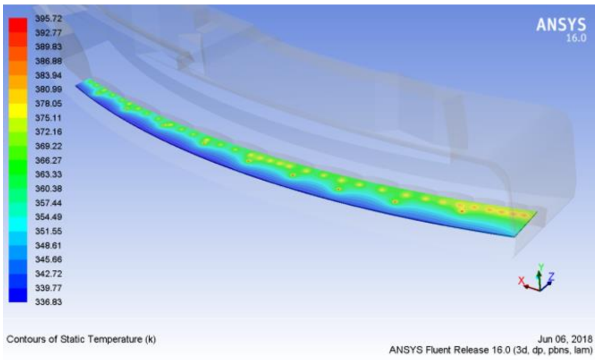

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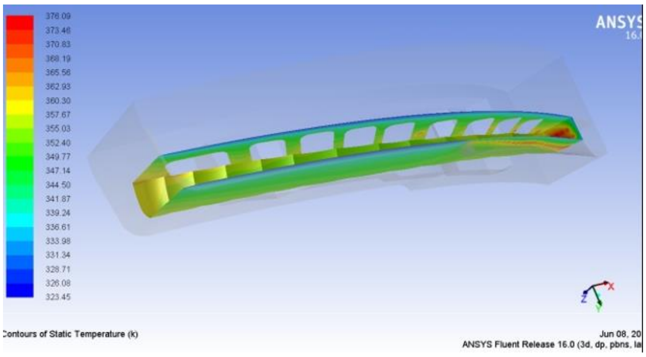
Fig. 7 Temperature contour over (a) top side danger light PCB (b) bottom side danger light PCB



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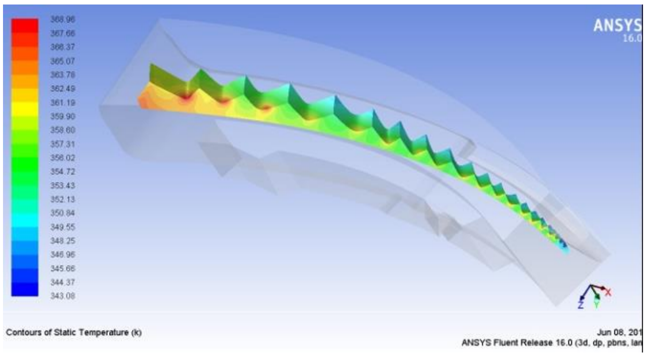

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Fig. 8 Temperature contour over (a) brake light reflector and (b) turn light reflector

Table 2

Comparison of temperatures among different housing materials

Sl. No.	Housing Material	Maximum observed temperature, K	Minimum observed temperature, K	Area weighted average temperature, K	Material limiting temperature, K
1	PBT	375.12	350.90	363.50	393
2	ABS	365.74	343.39	354.80	403
3	BMC	376.66	352.30	365.09	523

The thermal failure analysis for all the components of tail light assembly is consolidated in the Table 3. The maximum temperature limit of various plastic materials and the simulation results were compared for thermal failure analysis. It can be understood from the table that all the plastic components were within the material limit. The housing material used for this thermal failure analysis was ABS plastic which is treated as ‘black material’ while setting up the radiation properties in the solver. The reflectors were considered as fully metalized surfaces whereas the inner lenses were considered as transparent. The maximum temperature was observed over the turn light reflectors and danger light reflectors as indicated in the Table 3.

The numerical simulation also investigated the heat transfer co-efficient of the panel surfaces with three different materials for housing unit. The average surface heat transfer co-efficient of the panel surface is shown in the Fig. 9. The predicted values show a significant variation in the net heat transfer through these panel surfaces. The convective resistance, offered by ABS material, was significantly low when compared with other two materials.

Table 3

Results of thermal analysis for all plastic components

Part	Material	Surface Properties	Material Temperature Limit, K	Simulation Results Temperature, K	Thermal Analysis Status
Housing Unit	ABS	Black	403	365	Passed
Turn Reflectors	PC	Fully Metalized	403	380	Passed
Inner Lenses	PMMA-8N	Transparent	417	334	Passed
Cover Lenses	PMMA-8N	Transparent	417	331	Passed
Danger Reflectors	PC	Fully Metalized	403	378	Passed

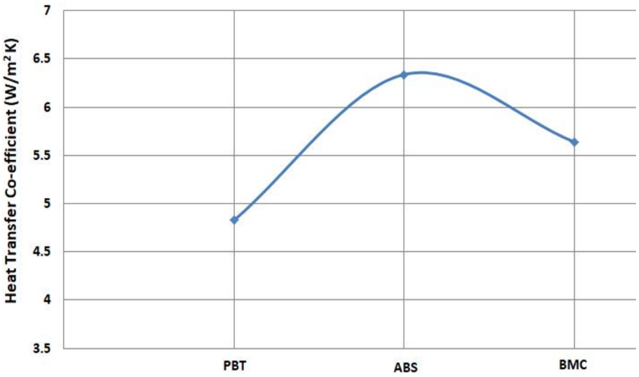
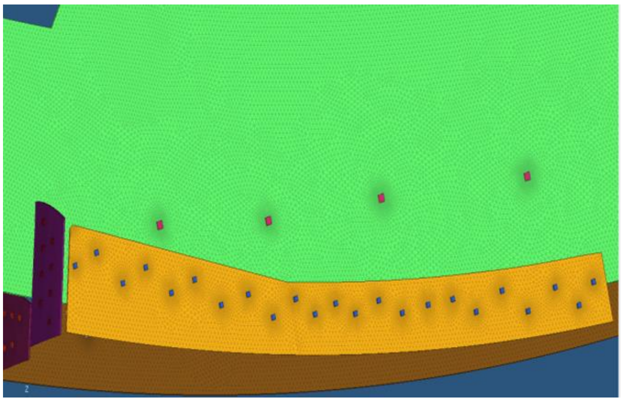


Fig. 9 Effect of material on heat transfer co-efficient of the panel surfaces

3.2. Effect of LED arrangement

The arrangement of LED over PC board was also examined using the computational analysis. Two different configurations of LED arrangements were considered for the investigation. The first arrangement followed the reflector profile in which the LED-s were arranged in series by following the curved pattern whereas in the second arrangement, the LED-s were positioned in rambled (zig-zag) pattern. The computational results for both LED arrangements were compared in order to justify the LED positioning. From the first cut analysis, it can be inferred that ABS material possessed better thermal characteristics and hence it can be used for LED arrangement analysis. Fig. 10 shows the conventional (baseline) LED arrangement and modified (rambled) LED arrangement.

Fig. 11 shows the temperature distribution over various components of LED tail light assembly. The maximum temperature produced over PC boards with conventional LED arrangement was 396.27 K. The temperature induced with new LED arrangement was 394.82 K. So there is a reduction of 1.5 K in the maximum temperature over PCB-s. Likewise, the maximum temperatures induced due to radiative heat transfer over the back cover of the housing with conventional and rambled LED arrangements were 365.74 K and 336.57 K respectively. During analysis, the maximum temperature produced over the reflector surfaces, which were fullymetalized in both conventional and rambled arrangement, were 368.96 K and 366.82 K respectively. So, from the computational results, it can be deduced that the LED arrangement has a significant effect on thermal performance of tail light components. Further, from the computational analysis, a comparison was executed between the convective thermal resistance offered to heat transfer through the panel surfaces of tail light assembly. It can be observed from the numerical results that the heat transfer co-efficient with conventional LED arrangement was 6.34 W/m^2 K whereas the heat transfer co-efficient with rambled LED arrangement was 7.03 W/m^2 K.



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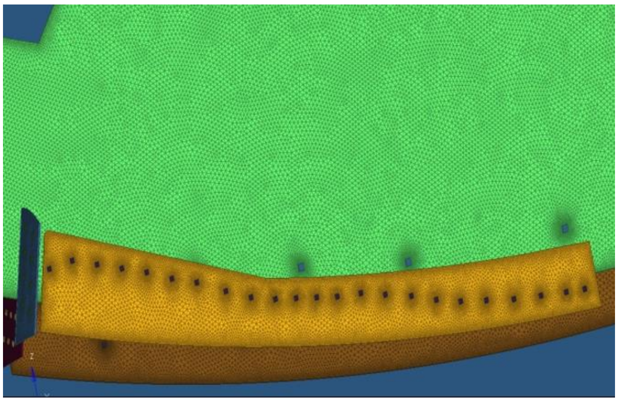

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Fig. 10 LED Arrangements over PC Boards (a) Conventional LED Arrangement and (b) Rambled LED Arrangement

4. Experimental validation

The computational analysis, carried out over the tail lamp, was validated with a working model of the rear light assembly in a passenger car considered for the CFD analysis. The working model was assembled and the thermocouples were attached to critical locations such as near LED, over reflector surfaces, PCB panel and the housing unit. There were nine thermocouples attached to read the steady temperature over these surfaces. The assembly was supplied with a power source of 13.5 V battery and the thermocouple readings were noted down using a digital temperature reader along with a standard power source. Fig. 12 shows the experimental set up used for the validation of tail light analysis. The picture indicates the attachment of thermocouples at various critical locations of tail light assembly.

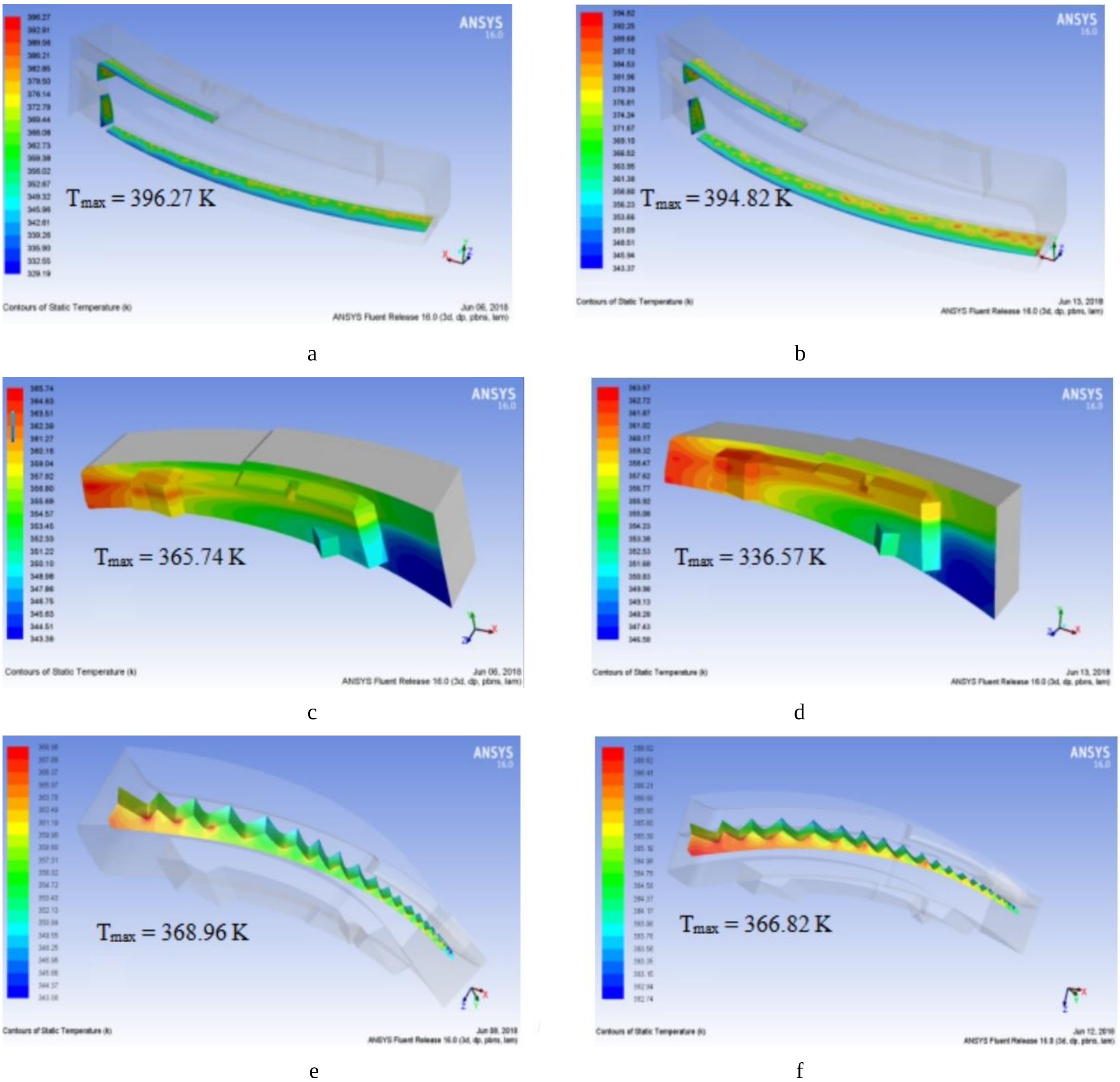

Fig. 11 Comparison of temperature distribution with different LED arrangement (a) PC Board Conventional LED Arrangement, (b) PC Board Rambled LED Arrangement (c) Tail Light Housing Back Cover Conventional LED Arrangement, (d) Tail Light Housing Back Cover Rambled LED Arrangement, (e) Indicator Reflector Conventional LED Arrangement and (f) Indicator Reflector Rambled LED Arrangement

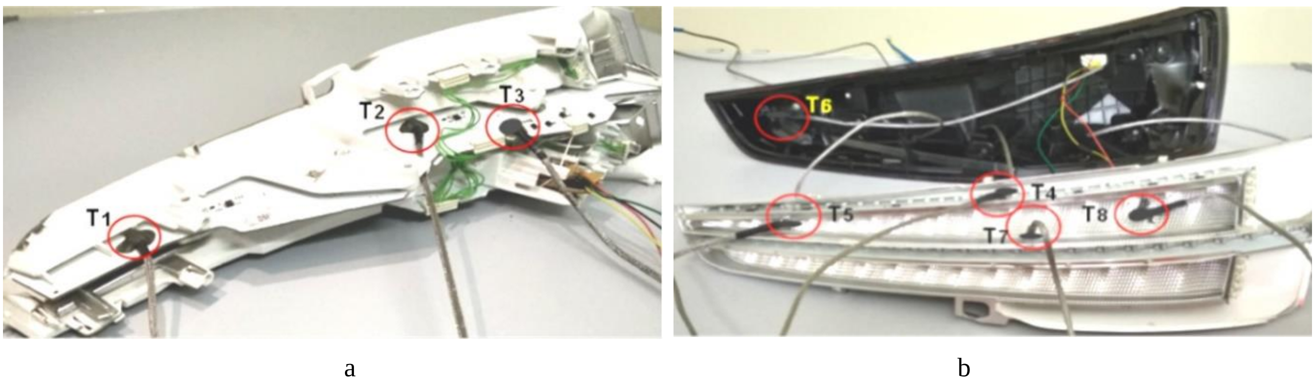

Fig. 12 Attachment of thermocouples at critical locations (a) Back side, (b) Front side and back cover

The experimentation was conducted as per the above setup by making all the LEDs to glow using the power source. The light sources were allowed to illuminate till the temperature of the LEDs attains the steady state. The readings at various thermocouple locations were noted down.

The experimentation was repeated twice again to check for consistency in the readings. Fig. 13 depicts the measurement of temperature at critical location of the tail light assembly during the working condition in the experimentation set up. The temperature indicator shows thermocouple temperatures at various locations.

The experimentation of tail light assembly was carried out with ABS material for back cover housing unit. The CFD values were taken from the points at approximate locations of respective thermocouple as in experiment. From the graph, it can be inferred that both CFD as well as the experiment had the same trend. The maximum deviation from the experimental results was obtained as 9.5 K and the corresponding error percentage was nearly 2.6%. Fig. 14 shows the experimental validation and comparison of results from CFD.

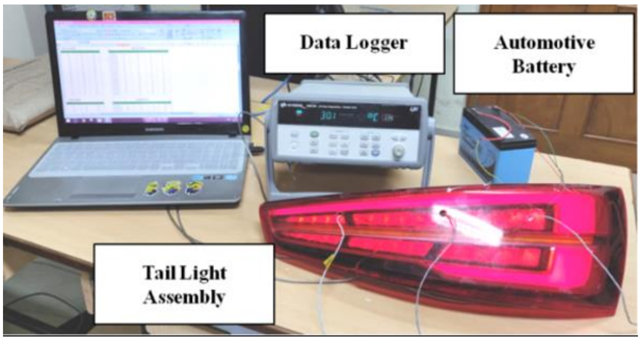

Fig. 13 Experimental set up during working condition

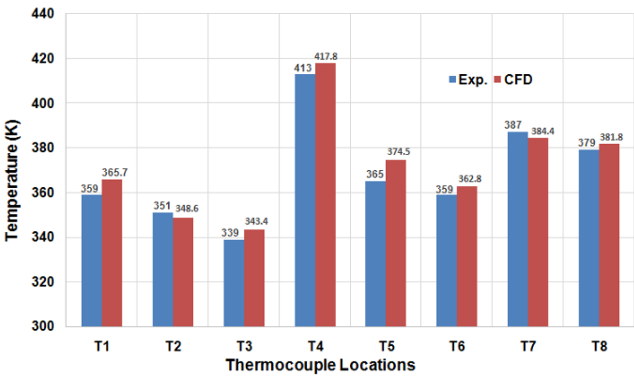

Fig. 14 Comparison of Temperature at Critical locations (Experimental Vs. CFD)

5. Conclusions

The design and optimization of automotive tail light system for improving the road safety was executed in the present study using CFD analysis and was further validated by experimental testing. The thermal performance of tail light was analyzed using three different materials namely (Poly Butylene Terephthalate - PBT, Acrylonitrile Butadiene Styrene - ABS and Bulk Molding Compound - BMC) with cover lens material as Poly Methyl Meta Acrylate (PMMA-8N) and LED board material as Poly Carbonate (PC) respectively. From the present research work, the following observations and inferences have been arrived.

1. It is evident that the computational methodology is an effective means to carry out the thermal management of tail light assembly.
2. Among the three selected housing materials, ABS is found to exhibit a better thermal performance. The predicted maximum temperature (365.74 K) over the housing of tail light assembly was very low when compared with others.
3. The CFD predictions showed that the re-arrangement of LED arrays is more effective by reducing the surface temperatures over the PC boards, reflectors and tail light housing.
4. The re-arrangement of LED-s showed better thermal distribution over the indicator reflectors when compared with the conventional arrangement.
5. The experimental validation conducted during this research work is in alignment with CFD thermal predictions with a maximum percentage deviation of 2.6%.

This leads to a conclusion that the computational approach suggested in this research work can be effectively used to optimize the thermal performance of the tail light assembly of an automobile.

References

1. **Diez-Arroyo, M.** 2018. Metarepresentation and echo in online automobile advertising. Lingua 201: 1-17. https://doi.org/10.1016/j.lingua.2017.08.008.
2. **Peña-García, A.; Peña, P.; Espín, A.; Aznar, F.** 2012. Impact of adaptive front-lighting systems (AFS) on road safety: Evidences and open points, Safety Science 50, 4: 945-949. https://doi.org/10.1016/j.ssci.2011.10.013.
3. **Detlef, D.; Hage, M.; Jerg, F.; Tatartschuk, E.** 2014. Product development process for headlamps and rear lights, Auto Tech Review 3, 5: 28-33. https://doi.org/10.1365/s40112-014-0618-6.
4. National Highway Traffic Safety Administration, Traffic Safety Facts 2005: A Compilation of Motor Vehicle Crash Data from the Fatality Analysis Reporting System and the General Estimates System. Washington, DC 20590. United States Department of Transportation [accessed on 6th January 2017]. Available from internet: https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/810631.
5. **Bullough, J. D.** 2017. Human factors impacts of light-emitting diode airfield lighting. Transportation research record, Journal of the Transportation Research Board 2626, 1: 51-57. https://doi.org/10.3141/2626-07.
6. **Sökmen, K. F.; Yürüklü, E.; Yamankaradeniz, N.** 2016. Computational thermal analysis of cylindrical fin design parameters and a new methodology for defining fin structure in LED automobile headlamp cooling applications. Applied Thermal Engineering 94: 534-542. https://doi.org/10.1016/j.applthermaleng. 2015.10.069.
7. **Tu, J.; Yeoh, G. H.; Liu, C.** 2008. Computational fluid dynamics: a practical approach. Butterworth-Heinemann. https://doi.org/10.1016/ B978- 0-7506-8563-4. X5001-0.

8. **Brunberg, J.; Aspelin, M.** 2011. CFD Modelling of Headlamp Condensation. Master's Thesis in Automotive Engineering, Department of Applied Mechanics, Division of Vehicle Engineering and Autonomous Systems, Chalmers University of Technology, Göteborg, Sweden.
9. **Morgado, T.; Silvestre, N.; Correia, J. R.; Branco, F. A.; Keller, T.** 2018. Numerical modelling of the thermal response of pultruded GFRP tubular profiles subjected to fire, Composites Part B: Engineering 137: 202-216. https://doi.org/10.1016/j.compositesb.2017.11.009.
10. **Kantor, R.** 2016. Modelling of a coupled radiation-conduction heat transfer through a heat shield in vacuum thermal isolation applications, Procedia Engineering 157: 271-278. https://doi.org/10.1016/j.proeng.2016.08.366.
11. **Yılmaz, I. B.; Mwesigye, A.** 2018. Modeling, simulation and performance analysis of parabolic trough solar collectors: A comprehensive review, Applied Energy 225: 135-174. https://doi.org/10.1016/j.apenergy.2018.05.014.
12. **Boulet, M.; Marcos, B.; Moresoli, C.; Dostie, M.** 2018. Sequential inverse method implemented into CFD software for the estimation of a radiation boundary, International Journal of Thermal Sciences 51: 7-15. https://doi.org/10.1016/j.ijthermalsci.2011.08.015.
13. **Salah, M. B.; Askri, F.; Slimi, K.; Nasrallah, S. B.** 2004. Numerical resolution of the radiative transfer equation in a cylindrical enclosure with the finite-volume method, International Journal of Heat and Mass Transfer 47: 2501-2509. https://doi.org/10.1016/j.ijheatmasstransfer.2003.11.023.
14. Ansys Fluent Theory Guide. 2013. The Energy Equation: 134 [accessed on 16 June 2017]. Available from internet: http://www.pmt.usp.br/ACADEMIC/martoran/ NotasModelosGrad/ANSYS%20Fluent%20Theory%20Guide%2015.pdf
15. Ansys Fluent Theory Guide. 2013. The S2S Model Equations: 168 [accessed on 16 June 2017]. Available from internet: http://www.pmt.usp.br/ACADEMIC/martoran/ NotasModelosGrad/ANSYS%20Fluent%20Theory%20Guide%2015.pdf.

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COMPUTATIONAL INVESTIGATION ON RADIATIVE HEAT TRANSFER CHARACTERISTICS OF AN AUTOMOTIVE LED TAIL LIGHT

S u m m a r y

A recent survey by National Transportation Highway Traffic Safety Administration (NHTSA) stated that the rear-end crash of passenger vehicles is the most accounted cause of vehicle crash (more than 21%) compared among all other vehicle crashes. Tail light malfunctions or failure is often the cause for such accidents. There is a pressing need for design and optimization of an automotive tail light system to increase the road safety. The service life for the conventional incandescent light bulb is comparatively lesser than the Light Emitting Diode (LED) tail light. During the physical testing process and its validation in the later development stage, the computational methods can be effectively used for the design optimization of LED tail light system in the development based on the thermal-radiative performance. The results could be incorporated in automotive design industries to produce nearly zero defect and failure-free design with better thermal performances. Therefore, it is highly significant to simulate and study the thermal management through simulation analysis. The present study focuses on a computational analysis of a complex automotive tail light system with a near net shape using Computational Fluid Dynamics (CFD) methodology. The simulation results compared three different materials for housing of tail light assembly along with re-arranging the LED arrays. Among the selected housing materials, Acrylonitrile Butadiene Styrene (ABS) exhibited better thermal performance with the maximum temperature of around 365.74 K compared with other housing materials. The computational results were validated using an experimental set up and the temperature measurements followed the same trend as CFD. The maximum percentage of deviation was not more than 2.6%.

Keywords: Automotive tail light, LED, thermal management, CFD.

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