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# LIQUID COOLING OF LED CAR HEADLAMPS USING POLYMERIC HOLLOW FIBERS

**Mráz K.[*], Kroulíková T.[**], Resl O.[***]**

**Abstract:** *Thermal management of high-power Light Emitting Diodes (LED) car headlamp is important because high temperatures decrease life span of LEDs significantly. Polymeric hollow fibers of a small diameter (approx. 1 mm) were used to create a compact liquid cooling systems of LED car headlights. The cooling performance of liquid cooling system installed on the headlight Printed Circuit Board (PCB) of Skoda Octavia and Skoda Enyaq was tested. Results of the testing show that the proposed plastic radiators ensure efficient and uniform cooling of the PCBs and keep the LEDs operation temperature much below the recommended 110°C. As the heat generation is relatively small for liquid cooling (tens of watts), there is only 3-10 l/hour flow rate of coolant needed, allowing to operate the plastic radiator with low velocity and pressure drops (below 1kPa).*

**Keywords: Polymeric heat exchanger, Automotive headlights, LED cooling, Hollow fibers, Liquid cooling system**

## 1. Introduction

The lifetime of a LED headlight is considered even longer than the lifetime of a modern vehicle. However, this lifetime can be ensured only if LEDs are operated at reasonable conditions and with proper thermal management (generally not more than 110°C). In the available literature, there is a lot of research on the thermal management of PCBs with LED components. High-brightness multi-LED packages were investigated in terms of thermal performance in the study of Yung et al. (2010). Different cooling methods, such as heat sink, heat pipe, and liquid micro-jet were also investigated for high power LED applications and active radar systems (Liu et al., 2006.). In the study of Ramos et al. (2011) dielectric coolant was used directly and the cooling performance of LEDs was investigated in terms of flow behavior and coolant type. Cooling of LED car headlights by heat pipes was investigated in a comprehensive study by Singh (2020).

Heat exchangers and heat sinks are commonly made of metals such as various steel grades, aluminum alloys, and copper. Recently, composites and plastics have entered the scene, offering several outstanding features such as being lightweight, chemically stable, generally cheaper and their fabrication process causes smaller ecological footprint (Kominek et al., 2021). Polymeric hollow fibers are a promising alternative to finned-tube heat exchangers, as the tiny fibers (ø1 mm) have high surface-to-volume ratios. Despite of a low thermal conductivity of polymers, the thermal resistance of the fiber wall is very small thanks to its thinness (approx. 0.1 mm). A hollow fiber of a small diameter has very high internal heat transfer coefficient (1000-5000 W/m2K). Heat exchangers with hollow fibers were recently tested in various automotive industry (Bohacek et al. 2019, Kroulikova et al., 2021) as well as in HVAC applications (Bohacek et al., 2021) and showed a promising potential.

In the present study, experiments were performed to evaluate the proposed liquid cooling of high beam light units SK38 (Skoda Octavia) and SK316 (Skoda Enyaq). For both light units, the passive aluminum heat sink was replaced by the relevant plastic cooler (see Fig. 1 and Fig. 2.). This conference paper is based on the journal paper (Mraz et al., 2021), published recently in Q1 journal *Case Studies in Thermal*

[*] Ing. Kryštof Mráz: Heat Transfer and Fluid Flow Laboratory, Faculty of Mechnanical Engineering, Brno University of Technology, Technická 2896/2; 616 69, Brno; Krystof.Mraz@vut.cz

[**] Ing. Tereza Kroulíková: Heat Transfer and Fluid Flow Laboratory, Faculty of Mechnanical Engineering, Brno University of Technology, Technická 2896/2; 616 69, Brno; Tereza.Kroulikova@vut.cz

[***] Ing. Ondřej Resl: Heat Transfer and Fluid Flow Laboratory, Faculty of Mechnanical Engineering, Brno University of Technology, Technická 2896/2; 616 69, Brno; Ondrej.Resl@vut.cz

*Engineering*. We refer readers interested in this topic to this original paper, which covers the performed research in full detail.

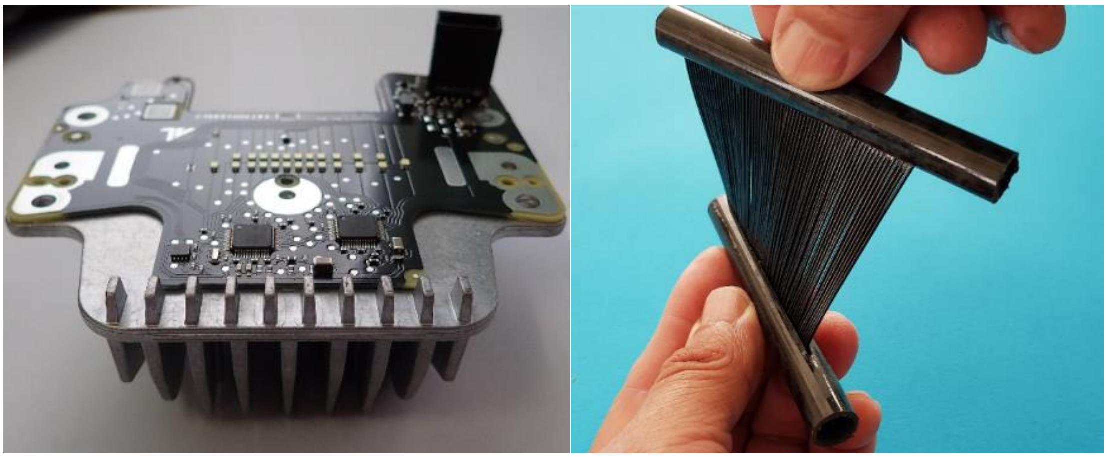

*Fig. 1: Left: High beam light unit SK38 from Skoda Octavia with conventional aluminum passive cooler; Right: Example of heat exchanger made of polymeric hollow fibers*

## 2. Experimental methods

LEDs are placed on a printed circuit board (PCB) together with the controlling electronics in a modern automotive headlight. An example of the LED headlight PCB is shown in Fig. 1, left. Even if the LED is an efficient source of light, the generated heat is typically 20 – 30W and the tendency is to use even higher number of LEDs producing over 50W of heat. Heat generated by a LED increases its temperature rapidly: LED temperature of 140°C was measured after only 10 seconds after turning on the SK38 headlight without any cooling. In the present study, hollow fibers made of polyamide 612 with outer diameter 1 mm and wall thickness 0.1 mm (10% of diameter) were used. Tested heat exchangers were made of fibers connected on both sides into small manifolds made of carbon epoxy composite (see Fig. 1, right). From both light units, the aluminum coolers were removed and replaced by heat exchangers made of polymeric hollow fibers. The adhesive with the copper microparticles (thermal conductivity 1.5 W/mK) was used to bond the heat exchanger to the PCB plate. Four thermocouples type K were attached to both units, (see Fig. 2). Both light units were built into the optical system of the head lamps and electrically connected to the vehicle control system. The tests were carried out with the maximum light performance, but the heat power was not identical as the headlamp electronics has its own built-in control of the LEDs temperature.

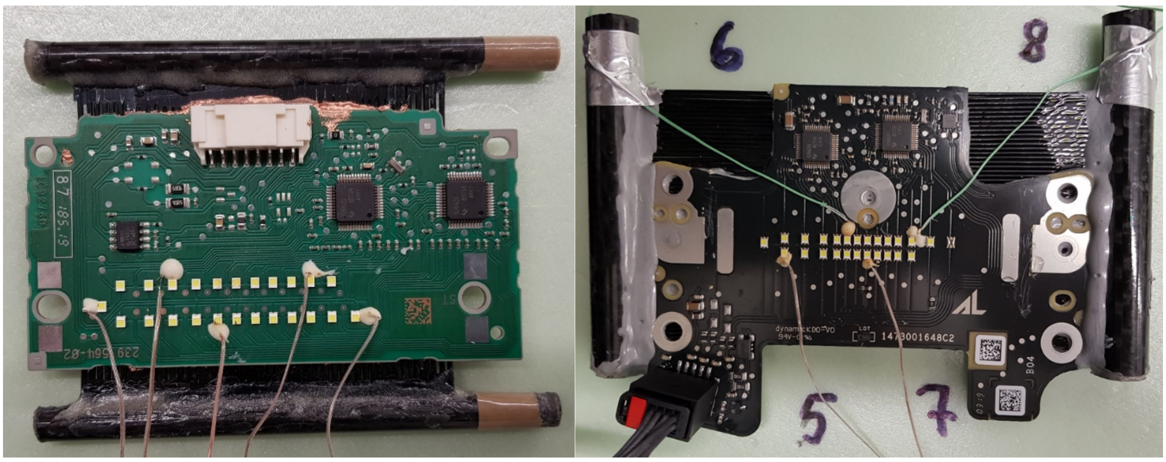


*Fig. 2: SK316 (left) and SK38 (right) units with polymeric heat exchangers attached to the rear sides and with thermocouples attached to LEDs*

The heat exchanger was connected to the water cooling system, where the input and the output temperatures and flow rate of the coolant were measured. The proof-of-concept tests were done with an input coolant temperature of 17°C and 40°C. Temperature 40°C was chosen as the second test temperature because it is a typical temperature available in a car from a low temperature car radiator. Experiments were done with the defined temperature difference ΔT between the input and output cooling water temperatures and the flow rate was adjusted to obtain the defined ΔT. The data were recorded for stationary regime when stable temperatures and flow rate were set. The tested unit was electrically connected to the car headlamp, and the light control functions were managed by the computer simulator, which replaces the car control system. The electric power was measured by the digital multimeter, and micro-thermocouples monitored the temperature of LEDs. The temperature reading from micro-thermocouples was averaged for the central part of the LEDs line (values T LED center) and for side thermocouples (values T LED side).

## 3. Results and Discussion

The results of the experiments for the light unit SK316 are summarized in Tab. 1. Similar sets of results were obtained also for the light unit SK38, but it is not presented here due to the page limit. We refer interested readers to the related journal paper (Mraz et al., 2021). The value $T_{IN}$ is the water input temperature, ΔT is the water temperature difference and P is the electric power of the light unit.

*Tab. 1: Results of experiment with light unit SK316*

| Experiment | $T_{IN}$ (°C) | ΔT (°C) | T LED side (°C) | T LED center (°C) | Flow rate (l/h) | P (W) |
|---|---|---|---|---|---|---|
| 1 | 17.0 | 3 | 30.8 | 41.2 | 10.1 | 35.1 |
| 2 | | 5 | 41.7 | 50.6 | 6.0 | 34.8 |
| 3 | | 7 | 46.2 | 58.8 | 3.4 | 27.3 |
| 4 | | 10 | 61.2 | 72.5 | 2.2 | 25.8 |
| 5 | 40.0 | 3 | 54.5 | 67.1 | 9.7 | 33.9 |
| 6 | | 5 | 56.1 | 67.8 | 4.8 | 27.8 |
| 7 | | 7 | 63.0 | 73.0 | 3.1 | 25.4 |
| 8 | | 10 | 64.2 | 74.6 | 2.4 | 27.9 |

The flow inside of the small-diameter hollow fibers is laminar with Reynolds number ranging 20 – 136. Due to the laminar flow, the inside Nusselt number and the heat transfer coefficient are constant and velocity-independent. The calculated heat transfer coefficient is 2387 W/m2K for water at 17°C and 2522 W/m2K for water at 40°C. Measurements of temperature field on the PCB plate with LEDs showed that a low thermal conductivity of the PCB plate prevents heat distribution from the overheated hot spot in the center to the sides of the LEDs row. Cooling of the headlight unit is substantial even with low coolant flow rates. However, even the maximum observed flow rate of 10 l/h is negligible compared to the flow rates in automotive radiators (hundreds and thousands of liters per hour).

Figure 3 shows the influence of flow rate and temperature of the cooling water on the temperature of LEDs. For higher flow rates, a large temperature difference can be observed between the central hot spot and the sides of the LED row. However, even an elevated coolant temperature of 40°C provides sufficient cooling, as 110°C is considered as operation temperature limit of LEDs. Laboratory tests were done with setting the light unit to maximum intensity. Table 1 shows that the measured power is not constant. This is due to a built-in system which reduces the power of the light unit with increasing temperature. Pressure losses in the heat exchanger grow linearly with increasing flow rate. Due to different viscosity, the pressure losses when using 17°C water were approximately two times higher as when using 40°C water. Pressure losses were generally low: in the range of 50–800 Pa. Details about pressure losses calculation are in the related original journal paper.

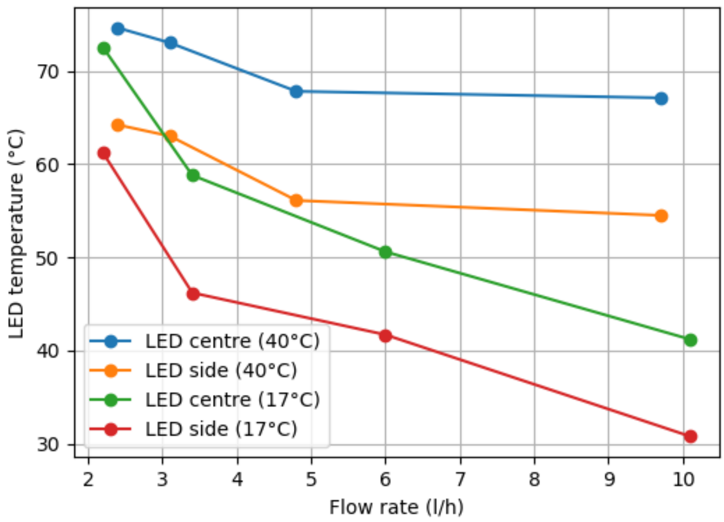


*Fig. 3: Average temperature of LED components with various flow rates for the lighting unit SK316*

## 4. Conclusions

Overheating of LEDs reduces the lifetime and durability of light unit. A liquid cooling system using hollow polymeric fibers as a heat transfer surface is used in this case study. The tested polymeric heat exchangers are about ten times lighter than the aluminum ones. Moreover, the carbon footprint of polymers is generally much lower than aluminum. It is possible to implement this heat exchanger into an existing vehicle thermal management system, such as low temperature car radiator. The present study showed that a LED headlight cooling system based on polymer hollow fibers has a significant potential, especially regarding the trend of further increasing power of LED headlights. The tested heat exchangers used uniform spacing of the hollow fibers on the cooled surface. Further improvement can be obtained if the fiber spacing is denser in the center of the LED line, where the main part of heat is generated. The side parts of a PCB plate can be cooled with fibers placed less densely.

## Acknowledgement

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