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Research Article

A Sustainable, Hands-On Approach to Teaching Heat Transfer in Automotive Engineering

Krisztián Horváth*[1], Antal Bakonyi[2], Daniel Feszty[3]
[1,2,3]*Department of Whole Vehicle Engineering, Széchenyi István Universit, Hungary*

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ABSTRACT

This study introduces a low-cost, custom-built apparatus designed to enhance engineering education by demonstrating heat transfer principles. The device, repurposed from a liquid cooling system, integrates key components such as a copper CPU block, aluminum radiator, and power meter. Students conducted experiments measuring temperature, energy consumption, and system efficiency, validating the apparatus's performance through theoretical alignment. The project-based learning approach fostered critical thinking and practical skills, while the use of sustainable materials emphasized environmental responsibility. This scalable, accessible tool provides an innovative solution for bridging the gap between theoretical knowledge and hands-on applications in thermodynamics. The demonstration equipment helps engineering students to better understand and remember what they have learned.

Keywords: Heat transfer; Engineering Education; Experimental Apparatus; Project-Based Learning; Liquid Cooling System.

INTRODUCTION

Technical higher education has long been focused on modernizing educational programs to bridge the gap between theoretical knowledge and practical application. In vehicle engineering, understanding thermodynamic principles is essential for designing efficient and safe systems. Understanding heat transfer processes can be challenging for students if they rely only on theoretical lectures. Heat transfer, a core topic within this domain, plays a pivotal role in the development of engines, cooling systems, and other key vehicle components. However, traditional teaching methods, such as lectures and seminars, often fall short in effectively conveying these complex engineering concepts, leading to limited student engagement and comprehension.

To address this challenge, innovative approaches that prioritize hands-on, project-based learning have gained prominence. Previous research has concluded that active, experiential project-based learning can significantly increase understanding of complex topics [1,2]. Physical demonstration tools have been shown to be most effective in making abstract concepts more understandable [4,5].

Agarwala and Chin (2019) have increased the effectiveness of fluid dynamics education by using 3D printers in wind tunnel measurements [5]. Physics teaching demonstration tools in heat transfer-related topics also play a significant role in improving understanding [6].

Unfortunately, high-quality demonstration systems are often prohibitively expensive, limiting their availability in educational environments.

This study introduces a custom-built, low-cost experimental apparatus for demonstrating heat transfer principles, leveraging a repurposed Thermaltake Bigwater SE liquid cooling system. The setup includes the following components: a laboratory power supply copper CPU block, an aluminium radiator, a water pump and a power meter.

The laboratory power supply provides the electrical power. An electric stove serves as the heat source, with the power meter logging the system's energy consumption and temperature measurements taken at various points. This innovative design provides students with an affordable platform to explore thermodynamic processes while fostering critical thinking and problem-solving skills. Throughout the measurement series, it was observed that engineering students are more engaged when they take their own measurements and have to evaluate their own data.

The apparatus offers a sustainable solution by repurposing existing materials, aligning with modern educational goals of resource efficiency and reduced environ-mental impact. Sustainable engineering education is becoming an increasingly important part of universities and training courses. It enables students to conduct detailed measurements and calculations, including heat transfer coefficients, energy flow analysis, and system efficiency evaluations, promoting a deeper understanding of heat transfer phenomena. As students actively engage in assembling, measuring, and analyzing data, this hands-on approach enhances their practical skills and theoretical knowledge.

The aim of this article is to show how this sustainable, low-cost demonstration tool can help education and contribute to the practical knowledge of engineering students. Furthermore, it details the design, operation and pedagogical value of the experimental device. It contributes to the advancement of engineering education by integrating sustainable practices with innovative teaching methods.

THEORETICAL BACKGROUND

Heat transfer is a physical process in which thermal energy flows from one material to another due to a temperature difference. The three main modes of heat transfer are [7-9].

1. **Conduction:** Heat conduction is the process of heat transfer through a solid material, where energy is transferred by collisions between adjacent particles. This type of heat transfer is typical in solids.
2. **Convection:** Heat convection occurs in fluids (liquids or gases) where heat is transferred by the movement of fluid particles. Convection can be natural (e.g., warm air rising) or forced (e.g., air moved by a fan).
3. **Radiation:** Heat radiation is the transfer of heat in the form of electromagnetic waves, which can occur without a medium, such as the transfer of heat from the Sun to the Earth.

Basics of Heat Transfer

The heat transfer coefficient (U) is a quantity that characterizes the intensity of heat transfer, indicating the amount of heat that passes through a unit area per unit of time for a given temperature difference [8]. Fourier's law is the fundamental equation for heat conduction:

$$q = -k \cdot \mathrm{A} \cdot \frac{\Delta \mathrm{T}}{\Delta \mathrm{x}}, \tag{1}$$

q is the heat flux (W),

k is the thermal conductivity of the material (W/m·K),

A is the area through which heat is transferred (m^2),

ΔT is the temperature difference (K),

Δx is the distance over which the heat is transferred (m).

METHODOLOGY

The methodology employed in this study was centered on the design, construction, and educational application of a custom-built heat transfer demonstration apparatus. The process can be categorized into the following phases:

Apparatus Design and Development

The experimental setup was designed to be cost-effective and user-friendly, incorporating the following components:

• Copper CPU Block: Dimensions of 60 x 78 x 23.5 mm, chosen for its high thermal conductivity.

• Aluminum Radiator and Fan: Ensuring efficient dissipation of heat from the circulating coolant.

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• Water Pump: Operating at 12 V DC to maintain a steady flow of coolant.

• Electric Stove: Providing controlled heat input to the system.

• Power Meter: Monitoring the energy consumption of the system.

• Metal Pot and Coolant: Serving as the medium for heat transfer, with a capacity of 0.8 liters of water.

The arrangement of these components is illustrated in Figure 1, which shows the complete demonstration setup of the liquid cooling system.

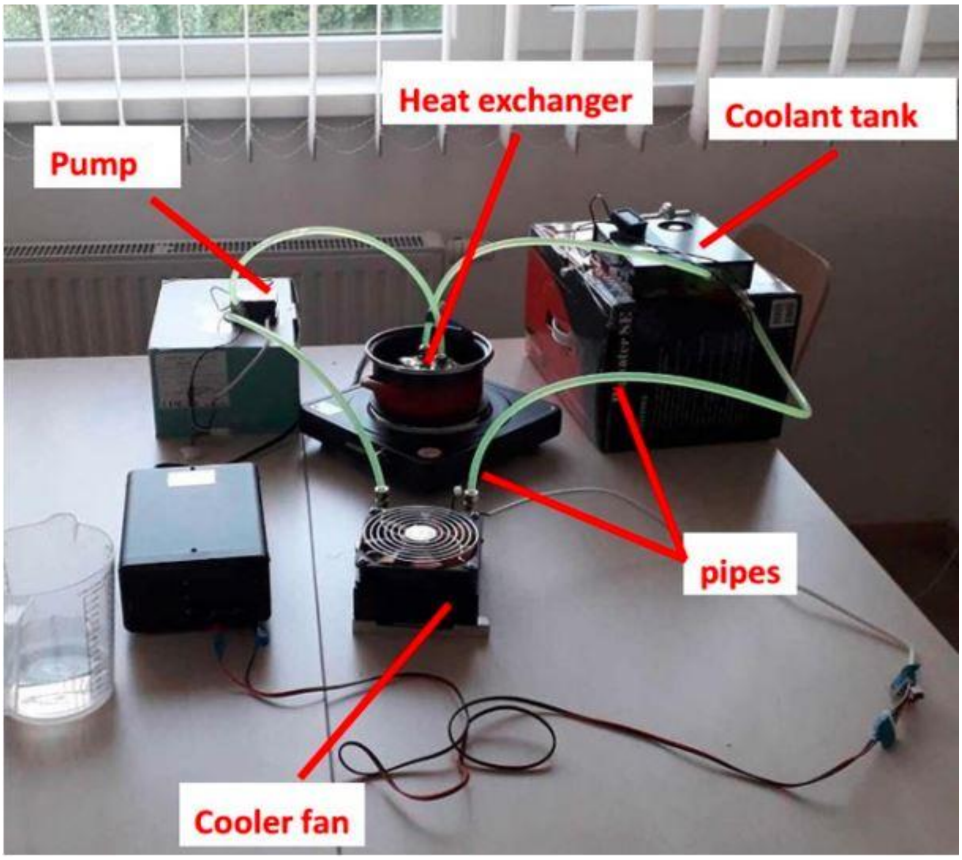

Figure 1. Demonstration setup of the liquid cooling system.

Experimental Protocol

System Preparation

• The CPU block was placed in the metal pot filled with 0.8 liters of tap water.

• The pot was mounted on an electric stove set to low heat to prevent boiling.

• The cooling loop, including the pump as shown in Figure 2, the radiator as shown in Figure 3, and the expansion tank, was assembled and filled with coolant.

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Figure 2. Liquid cooling system pump with quick connectors.

Measurements

- Temperature measurements were taken at various points, including the water in the pot, the CPU block, and the radiator surface.
- Energy consumption was continuously logged using the power meter.
- Data collection was carried out by students in teams, ensuring collaborative learning.

Figure 3. Aluminum radiator with fan.

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Figure 4. Laboratory power supply and power meter.

RESULTS

A physical demonstration experiment successfully assembled from an old computer CPU cooler showed reliable and stable operation. It provided an efficient platform for demonstrating thermodynamic principles. Enabling students to carry out detailed experiments. The custom-built demonstration device allowed students to observe key parameters such as heat transfer coefficients and calculate system efficiency. Time-based analyses showed changes in temperature and heat loss, and efficiency measurements demonstrated minimal energy loss. The students also identified possible improvements, such as optimizing and controlling the flow rate of the coolant or even measuring the flow of the coolant. They also identified the causes of measurement uncertainties and inaccuracies. The system provided an excellent platform for understanding the most important thermodynamic principles, as it was able to demonstrate them in a reproducible way in a real-life environment.

Students conducted the following measurements and calculations:

1. **Temperature Measurement:**

- Recorded temperature variations at multiple points:
- Water temperature at different points in the pot and the expansion tank.
- Surface temperatures at different points on the CPU block and radiator.
- Recorded time-based temperature changes at one-minute intervals to observe the thermal behavior of the system.

2. **Energy Consumption:**

- Logged the system's electrical energy consumption using an electrical power meter.
- Calculated the total energy input and its correlation with temperature rise over time.

3. **Heat Transfer Coefficients:**

- Derived the heat transfer coefficient (U) to quantify the system's heat dissipation efficiency.
- Used the temperature difference between the system and its environment as a key parameter.

4. **Heating Efficiency:**

- Evaluated the system's efficiency by comparing the energy input with the energy absorbed by the water.
- Identified significant heat loss to the environment, impacting overall efficiency.

5. Heat Loss Analysis:

- Determined the heat loss coefficient and modeled heat dissipation behavior over time.
- Assessed the effects of system temperature on the rate of heat transfer to the surroundings.

6. Thermodynamic Modeling:

- Developed a model of the heat transfer process to estimate energy flows and evaluate performance.
- Analyzed thermal equilibrium conditions, balancing heat input and loss.

Educational Outcomes:

It has provided students with hands-on experience to link theoretical thermodynamics with real-world applications to better understand what follows:

- Heat transfer principles, including conduction, convection, and radiation.
- The role of energy consumption and heat dissipation in system performance.
- Practical challenges in optimizing thermal systems for efficiency.

The combination of experimental data and theoretical analysis provided students with valuable skills in measurement, data processing, and system evaluation, reinforcing the pedagogical value of the apparatus.

For the students, the experimental data obtained during the measurement and its analysis provided valuable insights into data processing and system evaluation. This all confirmed the pedagogical value of the device. The energy consumption observed during the heating phase closely followed the linear temperature increase with a small lag, reflecting the steady state of the heat input rate. The heat loss coefficient estimated near the heat equilibrium was in line with theoretical expectations, which also confirmed the ability of the device to accurately model real thermodynamic processes.

The results provided by the device provide excellent evidence that it is not only a useful educational tool but also a reliable instrument for demonstrating theoretical principles in practice. The close agreement between experimental and theoretical data confirms the relevance of the system in both scientific and applied engineering contexts.

DISCUSSION

The results of the Experiment perfectly highlight the potential of recycled custom-made educational equipment as a sustainable educational tool. It offers an effective tool for understanding heat transfer processes and principles, which helps to bridge the gap between theoretical and practical applications.

The modular and cost-effective structure of the demonstration device offers the possibility of scalability, reparability and further development, so it can be easily and cost-effectively provided and reproduced for a wide range of educational institutions.

Among the main advantages of the equipment is sustainability. The reuse of materials that exist but are no longer really used in the computer world is consistent with the current goals of resource efficiency and environmental responsibility. This not only reduces the expected costs of educational institutions but also raises awareness of sustainability for students. This is becoming increasingly critical in modern engineering practice.

The project-based learning methodology used in this study supports effective teaching with the demonstration tool. The students actively participated in teams in recording and analyzing the measurement data obtained during the operation of the demonstration device. This all helped to develop problem-solving, teamwork, and critical thinking skills.

It can be said that the use of the demonstration tool is in line with current trends in engineering education, which primarily emphasize experiential and collaborative learning as a possible alternative to traditional frontal education.

The device offers several additional development potentials, which can further enhance its role in education. For example, adding more sensors can improve accuracy and extend the range of experiments. Modifications to the cooling system, such as variable flow rates, can provide deeper insight into system performance under different conditions. All these development options can further increase the versatility of the device.

It is possible to further expand the range of experiments by using materials with different thermal conductivity, heat exchangers and insulating materials. Cooling system adjustments, such as the introduction of variable speed fans and pumps, can provide deeper insight into the performance of dynamic thermal systems under different operating conditions. Their application would expand the capabilities of the device and make it even more versatile device.

CONCLUSION

This paper presents a custom-built, low-cost heat transfer demonstration device recycled from a CPU cooler used in computing. The application of the demonstration device successfully bridges the gap between theoretical concepts and practical applications in engineering education. The device has proven to be a sustainable tool for demonstrating thermodynamic principles, due to the recycled materials and the modular design.

The results obtained from the measurement and data evaluation demonstrate the efficiency and reliability of the device. All this proved that the demonstration device is able to show real heat transfer processes. Using the physical demonstration device, students have gained valuable hands-on experience while developing critical problem-solving and teamwork skills. The project-based learning approach has further enhanced these results, ensuring a deeper understanding. As a scalable and cost-effective solution, the tool has significant potential for wider application in engineering education.

Future developments could include the addition of advanced sensors and adjustable parameters to expand the scope of experiments and further enhance the apparatus's educational value. By building on its current strengths, the device can continue to serve as a versatile and impactful resource in engineering education.

The findings from this study not only validate the apparatus as a reliable tool for teaching heat transfer principles but also highlight its potential applicability in broader engineering contexts. The system's modular design and ability to replicate theoretical thermodynamic concepts in a controlled, practical environment make it an ideal platform for research and development in areas such as industrial thermal management, HVAC (Heating, Ventilation, and Air Conditioning) system optimization, and renewable energy systems, including solar thermal applications.

Moreover, the apparatus's cost-effective and sustainable design aligns with the increasing demand for resource-efficient solutions in engineering education and industry. Its adaptability to simulate various thermal conditions and configurations underscores its potential for cross-disciplinary use, offering value not only in automotive engineering but also in aerospace, energy, and manufacturing fields.

By bridging the gap between theoretical knowledge and practical application, this apparatus provides a scalable and impactful solution for advancing engineering education and applied research, reinforcing its relevance across multiple domains.

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