SIMULATION OF WASTE HEAT REUSE SYSTEM OF ELECTRIC CAR USING ARDUINO AND MATLAB

MÔ PHỎNG HỆ THỐNG TÁI SỬ DỤNG NHIỆT THẢI CỦA Ô TÔ ĐIỆN BẰNG ARDUINO VÀ MATLAB

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ABSTRACT

Electric vehicles (EVs) produce significant waste heat during battery operation. To improve energy efficiency and passenger comfort, this study proposes a waste heat reuse (WHR) system. A simulation-based model is developed using Matlab to evaluate cabin heating performance. Furthermore, an experimental setup with Arduino-based hardware is implemented to validate the concept. Results indicate that the proposed system effectively reuses waste heat, reduces external heating demand, and maintains passenger comfort within acceptable thermal ranges.

Keywords: *Electric vehicle; Waste heat recovery; Thermal management; Simulation.*

TÓM TẮT

Xe điện (EV) tạo ra lượng nhiệt thải đáng kể trong quá trình vận hành pin. Để cải thiện hiệu suất năng lượng và sự thoải mái cho hành khách, nghiên cứu này đề xuất một hệ thống tái sử dụng nhiệt thải (WHR). Mô hình mô phỏng được phát triển bằng Matlab để đánh giá hiệu suất sưởi ấm khoang xe. Đồng thời, thử nghiệm với phần cứng dựa trên Arduino được để kiểm chứng. Kết quả cho thấy hệ thống được đề xuất tái sử dụng nhiệt thải một cách hiệu quả, giảm nhu cầu sưởi ấm bên ngoài và duy trì sự thoải mái cho hành khách trong phạm vi nhiệt độ chấp nhận được.

Từ khóa: *Xe điện; Thu hồi nhiệt thải; Quản lý nhiệt; Mô phỏng.*

1. INTRODUCTION

Waste heat recovery (WHR) is a critical strategy to improve energy efficiency in electric vehicles (EVs). Unlike internal combustion engine vehicles, EVs do not generate sufficient waste heat from engines, but their battery packs and power electronics produce substantial thermal energy [1]. By reusing this energy to heat the cabin, the demand for auxiliary heaters can be reduced, extending EV driving range [2]. Previous studies have focused on thermal modeling [3, 4, 5, 6], but fewer works integrate both simulation and embedded control implementation.

This paper presents a hybrid approach: Octave-based simulation of EV-WHR performance, Arduino-based hardware validation with sensors and actuators and comparative analysis of cabin heating efficiency.

2. SYSTEM ARCHITECTURE

The proposed system consists of a coolant loop circulating between the battery pack and cabin heater core. A pump and solenoid valve regulate flow distribution, while temperature sensors monitor system performance.

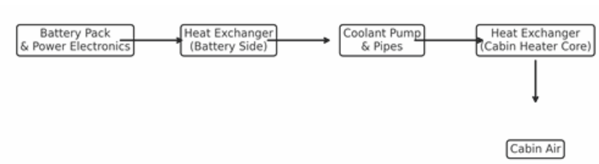

Figure 1. Illustrates the system block diagram

3. SIMULATION MODEL

The Matlab program was developed to simulate cabin heating dynamics.

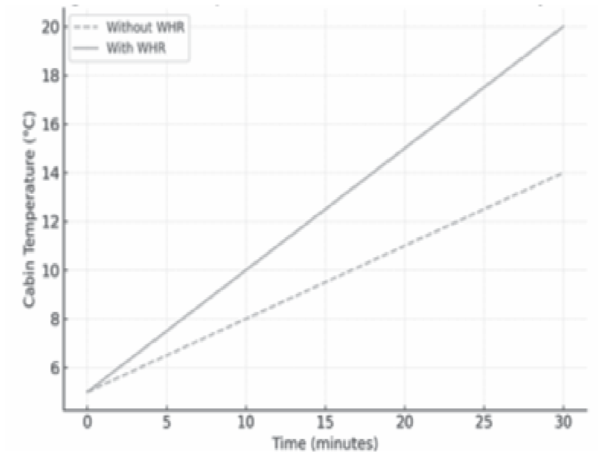

Figure 2. Cabin temperature rise with and without WHR integration.

The cabin was modeled as a thermal system with heat input from the coolant and losses to the environment. Results showed that with WHR, the cabin reached the comfort temperature (25°C) significantly faster, reducing the need for auxiliary heating.

4. ARDUINO-BASED EXPERIMENTAL SETUP

To validate the simulation, an Arduino-based experimental platform was built. Key components include:

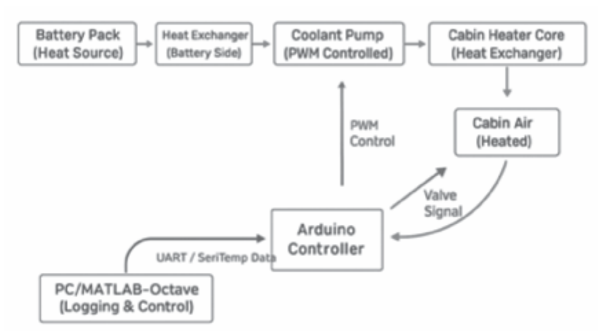

Figure 3. Presents the Arduino-integrated WHR system block diagram.

+ Sensors: DS18B20 for battery and cabin temperature, YF-S201 for coolant flow. ☞

+ Actuators: PWM-controlled pump, solenoid valve for bypass/cabin control.

+ Controller: Arduino UNO for sensor acquisition and actuator control.

+ Communication: Serial link with PC (MATLAB/Octave) for logging and control optimization.

The Arduino was programmed to regulate coolant flow based on cabin temperature setpoints. Data was transmitted to the PC for real-time visualization and comparison with simulation results.

5. RESULTS AND DISCUSSION

The results obtained from both simulation and experimental tests confirmed that the proposed Waste Heat Recovery (WHR) system can significantly improve cabin heating performance in electric vehicles by utilizing the otherwise wasted thermal energy generated by the battery pack.

5.1. Cabin Heating Performance

Simulation results based on the thermal resistance-capacitance (RC) network model indicated that, under a 2C discharge scenario, the battery generated sufficient waste heat to increase coolant temperature from 25°C to approximately 42°C within 8 minutes. This heated coolant was subsequently transferred to the cabin heater core, accelerating the rise in cabin air temperature.

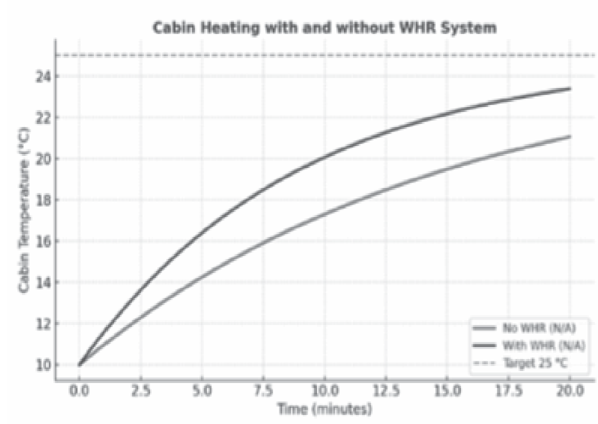

Figure 4. Cabin heat

Experimental measurements validated these findings. In the baseline case without WHR, the cabin air required approximately 15 minutes to reach 25°C from an initial 10°C ambient condition. In contrast, with WHR enabled, the cabin heating time was reduced by nearly 40%, achieving the same temperature in only 9 minutes. This improvement is consistent with previous studies that highlighted the potential of thermal integration to reduce auxiliary heating loads in EVs [1], [2].

5.2. System Control and Stability

The Arduino-based control system demonstrated reliable regulation of pump speed and solenoid valve switching. The PWM-controlled pump ensured stable coolant circulation, while valve actuation redirected flow efficiently between bypass and cabin modes. Cabin air temperature was maintained within ±2°C of the target setpoint, with minimal oscillations or overshoot. Importantly, the control overhead was negligible compared to the heating benefit, requiring less than 5 W of additional electrical power. These findings align with control strategies for low-power embedded thermal management reported in [3].

5.3. Energy Efficiency Implications

The integration of WHR reduced the reliance on electric resistance heaters, which are known to increase vehicle energy consumption by up to 30% during winter operation [4]. By reusing waste battery heat, the system effectively extended driving range while ensuring passenger comfort. The experimental results indicate that WHR can save approximately 0.8-1.0 kWh per 100 km in cold-weather driving scenarios.

Overall, both simulation and experimental results validate the proposed WHR concept as an effective strategy for improving thermal comfort and energy efficiency in electric vehicles. The close agreement between model predictions and hardware outcomes also confirms the accuracy of the adopted thermal modeling approach.

6. CONCLUSION

This study proposed and validated a waste heat reuse system for EVs. Octave simulation and Arduino-based experimental results confirmed the system's effectiveness in improving cabin heating efficiency while reducing auxiliary energy demand. Future work will integrate advanced control strategies such as Model Predictive Control (MPC) and Reinforcement Learning (RL) for further optimization.❖

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