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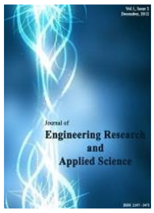

# Effect of Using R-1234ze Refrigerant Instead of Water-Methanol Fluid in Laptop Heat Pipes on CPU Temperature

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**Abstract**
Excessive temperatures generated by the CPU in laptop computers across various operating environments can lead to significant damage to electronic components. To mitigate this, heat pipes are employed. Within these heat pipes, refrigerants are used to effectively transfer heat from the laptop's CPU to the surroundings, thereby reducing system temperatures to safe operating levels and ensuring the continuous functionality of electronic systems and components. Traditionally, a water-methanol mixture has been utilized as the working fluid in heat pipes. This study experimentally compares the usability of the next-generation R-1234ze refrigerant as a replacement for the water-methanol mixture fluid in the heat pipe of an Intel Core processor-equipped laptop, based on temperature measurement results. Experiments were conducted under three distinct operating conditions: idle, normal load (during video playback), and maximum load. Internal CPU temperature measurements were taken every 5 seconds for 20 minutes in each environment using the Core Temp software. The internal CPU temperature variations were evaluated for both the water-methanol mixture fluid and the new generation R-1234ze refrigerant. The experimental results indicate that the R-1234ze refrigerant can indeed be utilized in laptop heat pipes and exhibits promising thermal performance.

**Keywords:** *Laptop, Heat pipe, CPU processor temperature, Water-methanol, R-1234ze*

## 1. Introduction

Heat pipes are widely used across numerous sectors, including manufacturing, industry, communication, and defense, for the thermal control of electronic circuits and computers. Thanks to their compact size and lightweight construction, heat pipes facilitate effective heat transfer, playing a crucial role in cooling the CPU processor unit of computers. Particularly in laptop computers, the CPU processor and other electronic circuit components can reach high temperatures by continuously generating heat within a confined space, especially during intensive operation. These excessive temperatures can cause severe damage to the computer's electronic components. Therefore, it is essential to effectively transfer thermal energy to the surroundings and reduce system temperatures to safe operating levels to ensure the continuous optimal performance of the CPU. For this purpose, CPU processor cooling is critical in computer systems.

Due to the thinness, lightness, and small dimensions of laptop computers, the reduction in size and increase in component density have led to enormous heat flux values for modern electronic and photonic devices [1]. The formation of local hot spots with large temperature gradients on the CPU processor chip represents the biggest bottleneck for the proper functioning of devices, making cooling at the laptop processor chip level extremely challenging [2]. To ensure the continuous operability of the CPU, the generated heat energy must be effectively transferred to the environment, and the CPU's temperature must be reduced to appropriate levels. Performance measurements of computer CPU processors have shown that a 10 °C temperature drop increases the operating speed of the circuit by an average of 2% [3, 4]. The working fluid for a heat pipe is selected based on its operating temperature range. The selection of the working fluid is also critical for the proper functioning of the heat pipe and for establishing the capillary mechanism; the liquid phase of the working fluid must wet the body material [5].

The performance of heat pipes is related to various physical parameters, including heat pipe

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configuration, geometric characteristics, operating parameters, physical dimensions, fin additions, tube material, and number of turns. It is emphasized that proper material selection is crucial for compatibility with the working fluids, which is extremely important for the system's efficiency and reliability [6]. Laptop cooling technologies are continuously evolving, with next-generation devices aiming to offer more efficient and quieter cooling solutions [7]. Recently, the results of heat pipe studies with different working fluids found in the literature are presented below in Table 1.

Table 1. Recent loop heat pipe studies with different working fluids in literature

| **Evaporator Shape/Material** | **Working Fluid** | **Max. Heat Load** | **Max. Temperature** | **Source** |
|---|---|---|---|---|
| Disk / Brass | Water | 120 W | 85 °C | [8] |
| Disk / Brass | Methanol | 160 W | 85 °C | [9] |
| Disk / Copper | Methanol | 160 W | 90 °C | [10] |
| Disk / Copper | Water | 140 W | 90 °C | [11] |
| Rectangular / Stainless Steel | Acetone | 280 W | 100 °C | [12] |
| Rectangular / Copper | Water / Methanol / Ethanol | 900-380-320 W | 95 °C | [13] |
| Rectangular / Copper | Water–Copper nanofluid | 100 W | 66.1 °C | [14] |
| Rectangular / Copper | Water | 75 W | 110 °C | [15] |
| Rectangular / Copper | Water | 150 W | 85 °C | [14] |

## 2 CPU processor temperature measurement process

The CPU processor temperature measurement process utilizes an Intel Core laptop with specifications detailed in Table 2.

Table 2. Specifications of the Intel Core laptop

| **Feature** | **Specification** |
|---|---|
| Processor Brand | Intel |
| Processor Model | 2410M |
| Processor Speed | 2.30 GHz |
| Graphics Card Chipset | AMD®, HD6370 |
| Graphics Card Memory | 1024 MB |
| RAM Type | DDR3 |
| Disk Capacity | 500 GB |
| Screen Size | 15.6 inches |
| System Memory (RAM) | 4 GB |

The Core Temp software was utilized to measure the CPU temperature, as depicted in Figure 1. This program is a compact, user-friendly, and powerful tool that allows for the individual monitoring of each core's temperature within the system's CPU.

The FurMark2 stress test program (v2.4.3) was used to generate maximum load conditions on the laptop's CPU. Traditionally, a water-methanol mixture is employed in laptop heat pipes. In this study, a homogeneous mixture of methanol and water with a methanol volume ratio of 73% was charged into the laptop heat pipe at a pressure of 50 kPa.

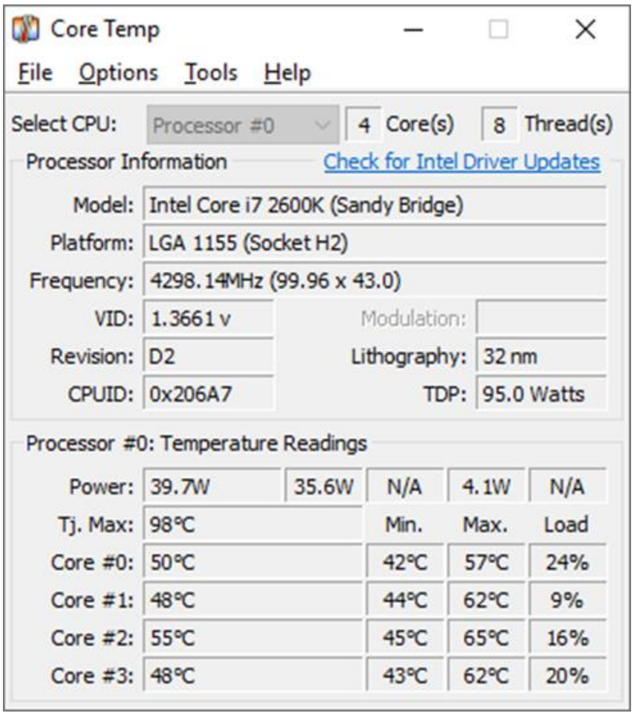


Figure 1. A screenshot of the Core Temp program.

R-1234ze is regarded as the best medium-pressure, low Global Warming Potential (GWP) refrigerant on the market when all its characteristics are balanced. Many equipment manufacturers have chosen it for applications with capacities ranging from a few kilowatts to 20 MW and charges ranging from 300 grams to 13 megatons because it is an energy-efficient substitute for traditional refrigerants in a variety of medium-temperature applications. Among its many uses are air-cooled and water-cooled chillers, heat pumps, refrigerators, vending machines, beverage dispensers, district heating and cooling, and air dryers. R-1234ze satisfies important user requirements, such as performance, cost-effectiveness, environmental impact, and safety, and has won multiple industry awards. ASHRAE Standard 34 (ISO 817) states that R-1234ze is non-flammable. When combined with compressed air and exposed to powerful ignition sources, it can, nevertheless, catch fire.

CPU processor temperatures were measured every 5 seconds for 20 minutes for each test condition, utilizing the Core Temp software. The photograph of the connection of the heat pipe on the laptop is given in Figure 2.

Temperature measurements were taken under three distinct operating conditions: a) When the laptop was operating at idle, b) During video playback (representing normal usage), and c) Under maximum load using the FurMark stress test program as shown in Figure 3.

Figure 2. The photograph of the connection of the heat pipe on the laptop.

## 3. Results

Results present experimental results concerning the cooling efficacy on a laptop of two different working fluids, the factory-original water-methanol mixture and the refrigerant R-1234ze, within an unmodified heat pipe structure. All experimental studies were conducted in a climate-controlled room, with the ambient temperature maintained at 20 °C throughout all tests.

### 3.1. Temperature analysis for CPU processors on the heat pipe in an idle environment

The CPU temperatures of the laptop, operating in an idle environment, were measured every 5 seconds for 20 minutes using the Core Temp software.

The results of these internal CPU temperature measurements are presented as time-temperature graphs. Figure 4 displays the data for the water-methanol mixture, while Figure 5 shows the data for the R1234ze refrigerant.

In the idle working environment, the maximum temperature of the water-methanol fluid was measured to be around 76 °C, the minimum temperature was 40 °C, and the average temperature was 47 °C. For the R-1234ze refrigerant operating under idle conditions, the maximum observed temperature was approximately 58.3 °C, the minimum was 38.2 °C, and the average temperature was 41.5 °C. Based on these average temperature values, it's evident that R-1234ze provides better performance compared to the water-methanol fluid. Furthermore, while the water-methanol fluid exhibited significant temperature fluctuations, the R-1234ze fluid demonstrated considerably more stable temperature behavior.

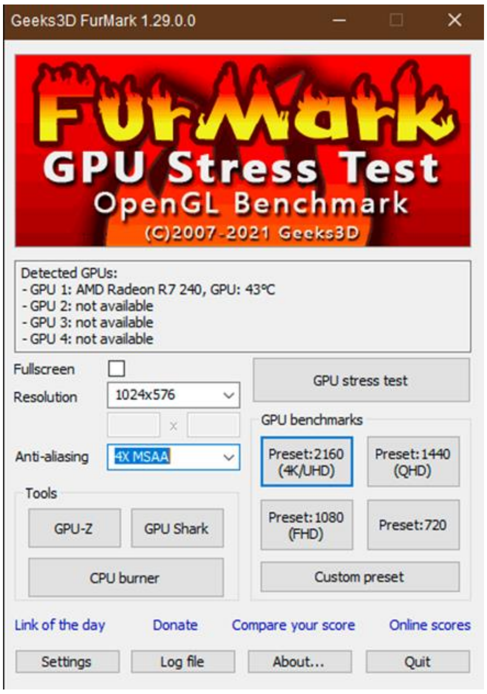


Figure 3. A screenshot of the FurMark stress test program

### 3.2. Temperature analysis for CPU processors on heat pipe in a playback (representing normal usage) environment

The CPU temperatures of the laptop, operating in a video playback environment (representing normal usage), were measured every 5 seconds for 20 minutes using the Core Temp software.

The results of these internal CPU temperature measurements are presented as time-temperature graphs. Figure 6 displays the data for, while Figure 7 shows the data for the R1234ze refrigerant. In the video playback (representing normal usage) environment, the maximum temperature of the water-methanol fluid was measured to be around 77 °C, the minimum temperature was 52 °C, and the average temperature was 65 °C. For the R-1234ze refrigerant operating under a video playback environment (representing normal usage) condition, the maximum observed temperature was approximately 98.3 °C, the minimum was 90 °C, and the average temperature was 94.75 °C. Based on these average temperature values, it's evident that the water-methanol mixture fluid provides better performance compared to R-1234ze refrigerant.

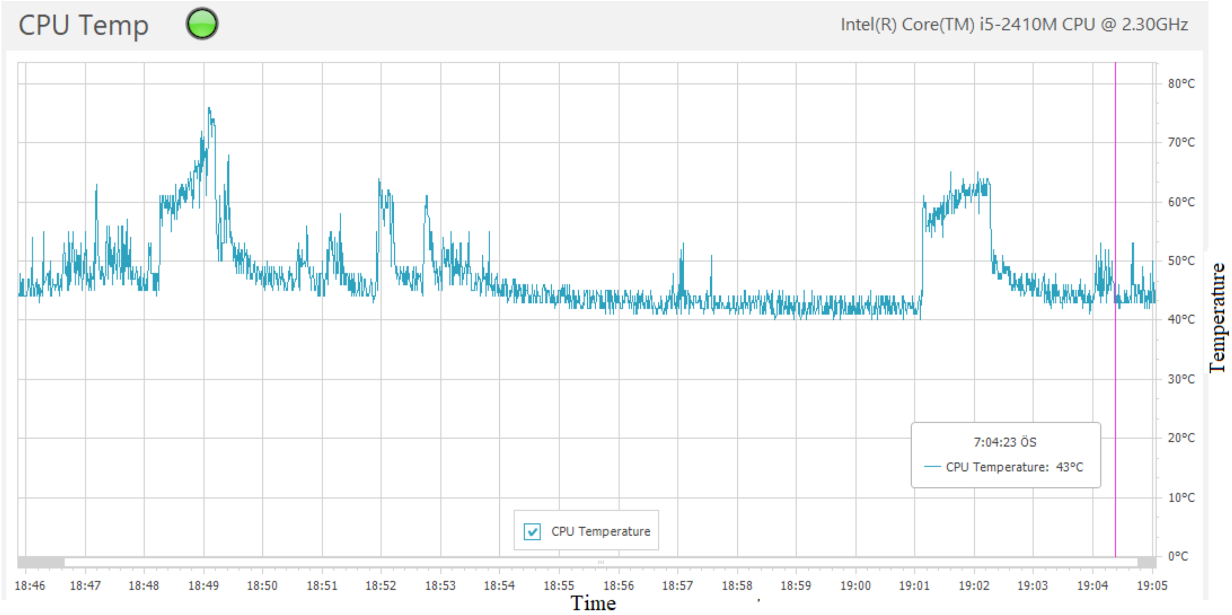


Figure 4. Time-temperature graph of the CPU processor in an idle operating environment in a heat pipe with water-methanol fluid.

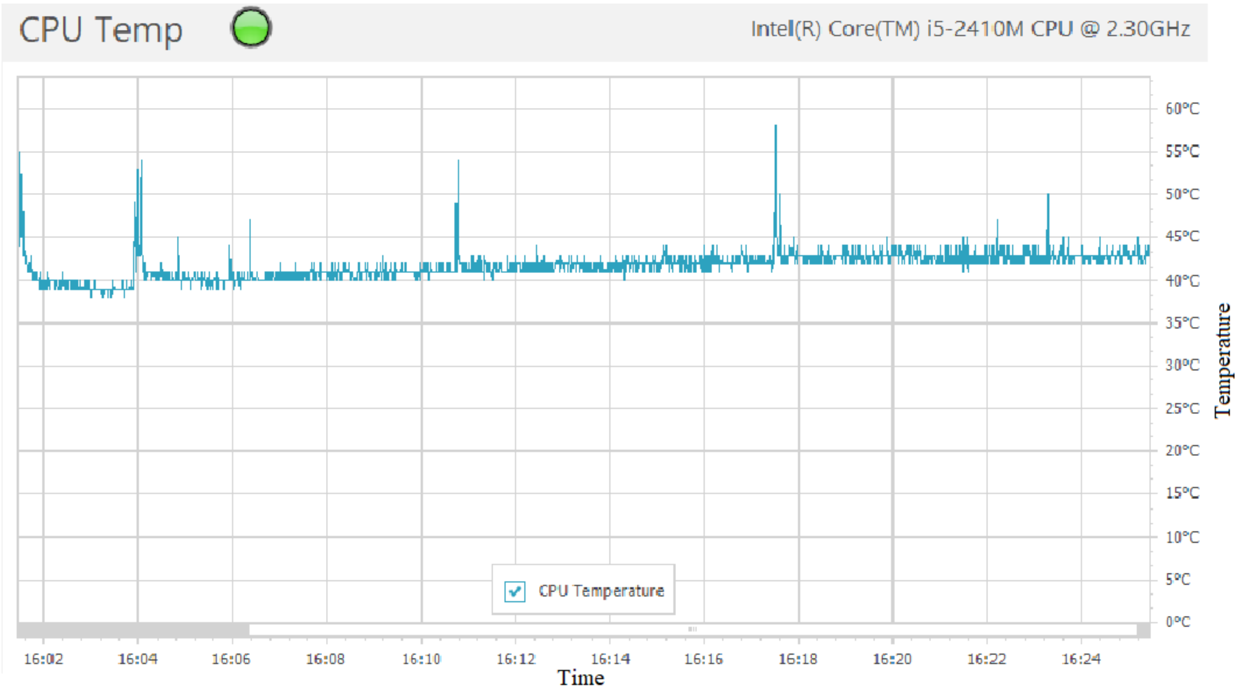


Figure 5. Time-temperature graph of the CPU processor in an idle operating environment in a heat pipe with the refrigerant R-1234ze.

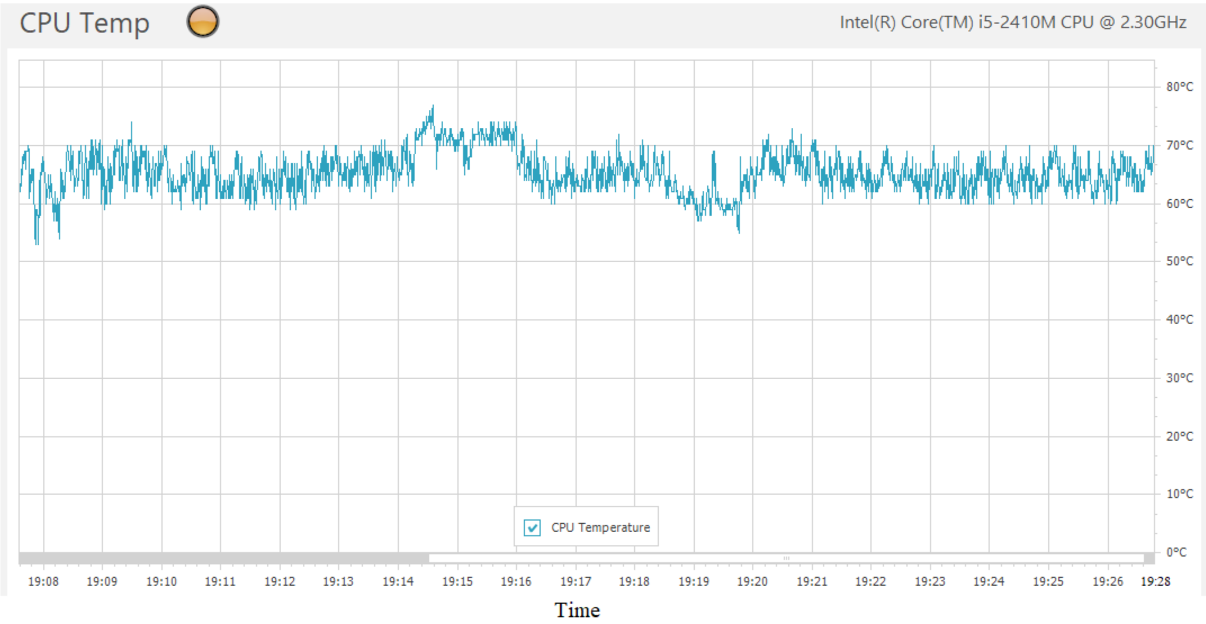


Figure 6. Time-temperature graph of CPU processor in video playback (representing normal usage), operating environment in heat pipe with water-methanol fluid.

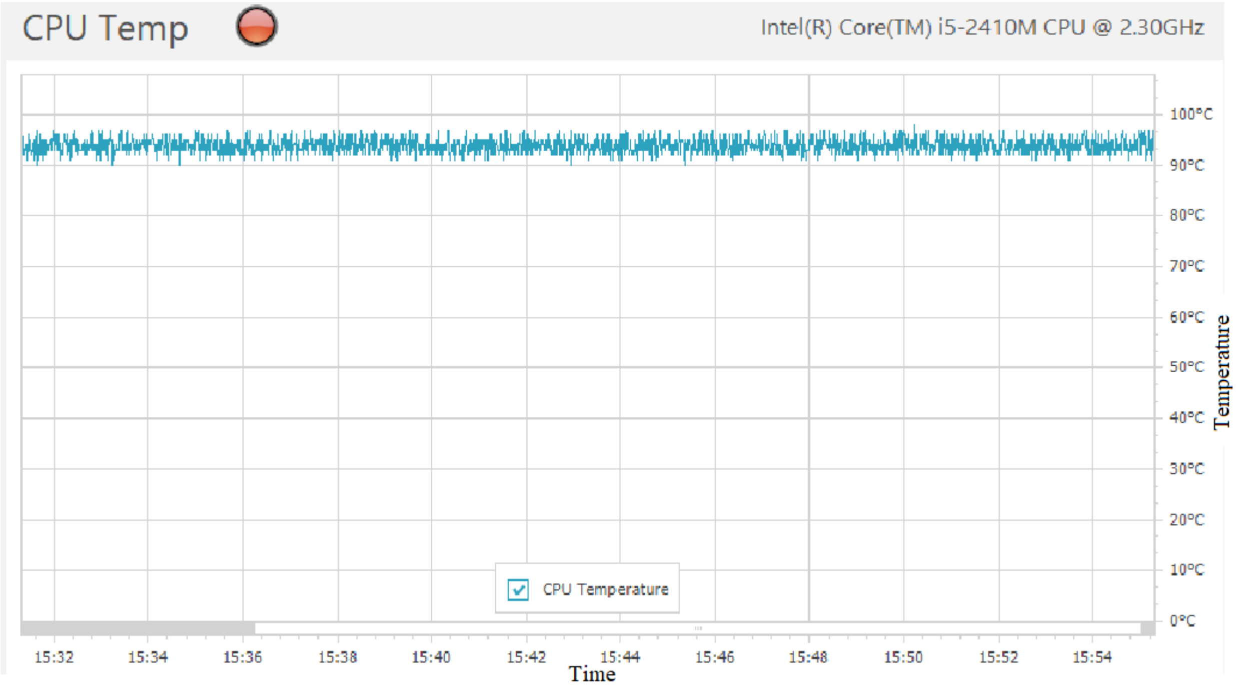


Figure 7. Time-temperature graph of CPU processor in video playback (representing normal usage), operating environment in heat pipe with the refrigerant R-1234ze.

**3.3. Temperature analysis for CPU processors on the heat pipe in the maximum load environment.**

The CPU temperatures of the laptop, operating in a maximum load environment, were measured every 5 seconds for 20 minutes using the Core Temp software. The results of these internal CPU temperature measurements are presented as time-temperature graphs. Figure 8 displays the data for the water-methanol mixture, while Figure 9 shows the data for the R1234ze refrigerant.

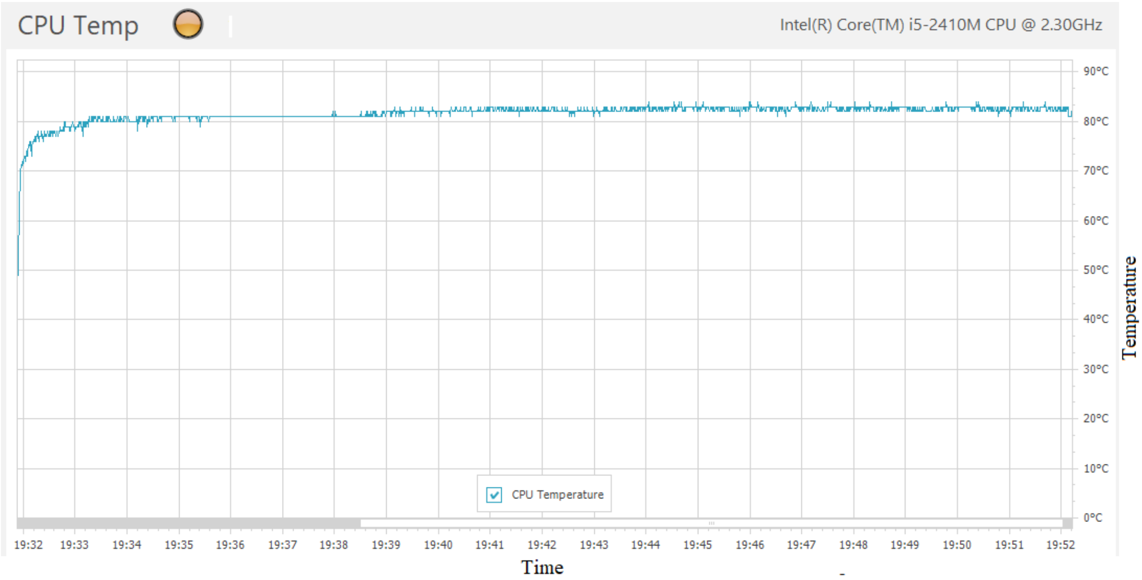


Figure 8. Time-temperature graph of the CPU processor in a maximum load environment operating environment in a heat pipe with water-methanol fluid.

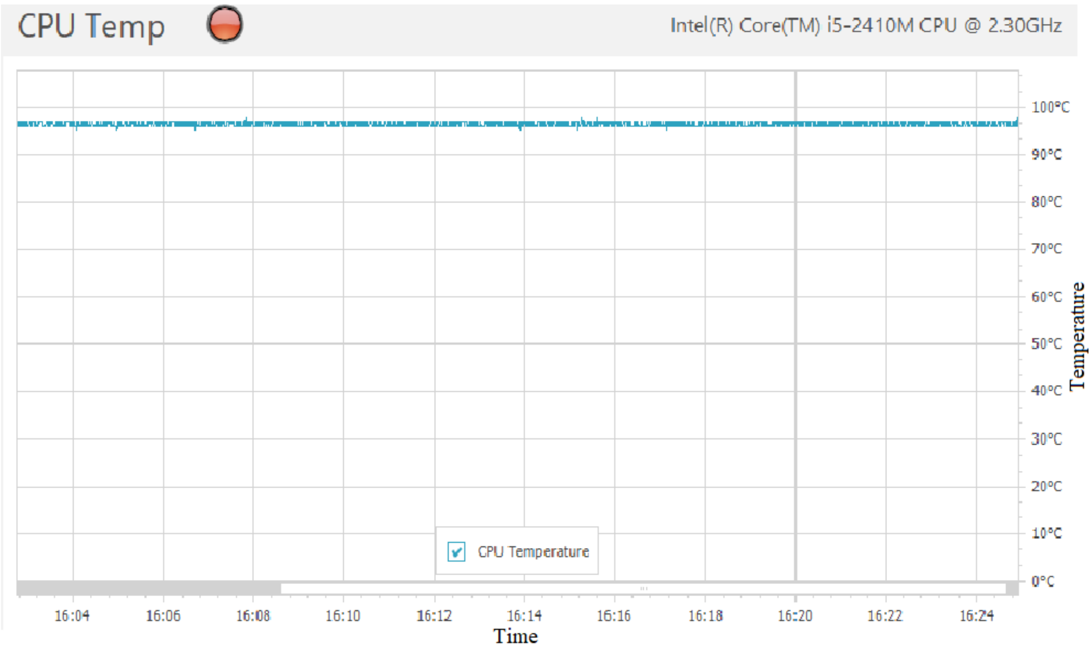


Figure 9. Time-temperature graph of CPU processor in v maximum load environment operating environment in a heat pipe with the refrigerant R-1234ze.

Upon examining the graph, it has been determined that the CPU reaches a maximum temperature of approximately 84°C when operating under 100% load. When maximum load commences from a minimum temperature, the CPU temperature rises from 50°C to approximately 80°C within one minute. Concurrently with the initiation of this load, the fan was observed to operate at maximum capacity, successfully maintaining the CPU temperature below critical levels. Over the subsequent 19-minute interval, the average temperature remained stable at approximately 82°C under maximum load.

CPU temperature measurements were recorded every 5 seconds for 20 minutes using Core Temp software while the laptop's CPU operated at 100% capacity under maximum load, generated with the aid of the FurMark benchmark program. Analysis of the graph reveals that under maximum CPU load (100% capacity), the CPU processor reached a maximum temperature of approximately 97.7°C, a minimum of 94.9°C, and an average of 96.6°C.

As seen in graphs 8 and 9, during maximum load on the laptop, the internal software actively manages the CPU temperature by running the heat pipe-connected fan at maximum revolutions to keep it below critical thresholds. It is a known safeguard that if the critical temperature level is exceeded and reaches a higher point, the internal software will shut down the computer to protect the motherboard and CPU processor.

## 4. Conclusions

This study investigates the variation of internal CPU temperatures in a laptop with different working fluids within its heat pipe, across three distinct computer operating environments. The research demonstrates that R-1234ze, a next-generation refrigerant, can be utilized in heat pipes without modifying the existing heat pipe structure, serving as an alternative to the conventionally used water-methanol mixture.

It has been established that when the wick structure of the laptop's heat pipe is optimized for compatibility with alternative refrigerants, complete capillarity can be achieved. This finding suggests that these alternative refrigerants could replace the widely used water-methanol fluid mixture, offering improved performance.

In conclusion, the chosen R-1234ze refrigerant exhibited excellent compatibility and performance within the laptop heat pipe. Notably, the computer did not shut down at any point during experiments involving extreme temperature loads, highlighting the effectiveness of R-1234ze in maintaining thermal stability.

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