Thermal Performance Analysis of Hybrid Air and Liquid Cooling Systems for Pc Processors

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***Abstract*—This study examines a hybrid air and liquid cooling system designed to improve heat dissipation in high-performance PC processors. The system integrates aluminum fins and a copper liquid cooling pipe, supported by a single fan, to enhance thermal efficiency through combined convection and conduction. Evaluation was carried out using CFD simulations (ANSYS) and Data Acquisition (DAQ) testing. Thermocouples, temperature probes, and flow sensors were placed at key locations such as the processor surface and coolant outlet to measure real-time thermal performance.DAQ data validated the simulation results, confirming the system's accuracy and efficiency. Future improvements will focus on optimizing fin design, pipe configuration, and using advanced materials to boost performance further.**

***Index Terms*—Hybrid cooling, Air-liquid cooling system, Thermal performance, Heat dissipation, Aluminum fins, Copper cooling pipe, Processor cooling, CFD simulation (ANSYS), Data Acquisition (DAQ),Temperature reduction, Heat flux.**

I. INTRODUCTION

The fundamentals of CPU cooling systems, emphasizing the importance of effective thermal management in preventing overheating, throttling, and hardware failure. It introduces three main cooling types: air cooling, using heat sinks and fans; liquid cooling, utilizing coolant loops and radiators; and hybrid cooling, which combines both for superior performance. The chapter also discusses heat sink design, highlighting the role of fins, airflow, and material selection (copper and aluminum) to maximize heat dissipation. Three key heat transfer mechanisms—conduction, convection, and radiation—are explained, with conduction and convection being dominant in CPU cooling. Finally, the role of Data Acquisition (DAQ) testing is detailed as essential for evaluating cooling effectiveness through real-time measurements of temperature, flow rate, and fan speed, aiding in validating and improving hybrid cooling system designs.

II. MATERIAL SELECTION

2.Material Selection for CPU Cooling System

The selection of materials for the cooling system components is based on their physical, thermal, and mechanical properties, ensuring maximum heat dissipation, structural stability, and system longevity. Below is a detailed analysis of each material used in the cooling system

2.1 Aluminum- Fin:

Aluminum fins are widely used in CPU heat sinks due to their lightweight nature, excellent thermal conductivity, and corrosion resistance. The fins increase the surface area for heat dissipation, allowing effective cooling through convection.

Fig 1 Aluminium- Fin

2.2 COPPER-PIPE:

Copper pipes are widely used in liquid cooling systems due to their excellent heat transfer capabilities, corrosion resistance, and mechanical strength. Their role in CPU cooling systems is to transport heated coolant from the processor to the radiator, ensuring efficient heat dissipation.

2.3 FAN AND FAN BODY-PLASTIC

Plastic materials like Polycarbonate (PC), Acrylonitrile Butadiene Styrene (ABS), and Polypropylene (PP) are commonly used for CPU cooling fans and fan bodies due to their lightweight, durability, and cost-effectiveness. These materials offer good strength, thermal stability, and resistance to wear.

Fig 2 Fan

2.4 PROCESSOR CAP- COPPER

Processor Cap (Integrated Heat Spreader - IHS) Made of Copper.The Processor Cap, commonly referred to as the Integrated Heat Spreader (IHS), is a metal cover placed on the CPU’s surface. Its primary role is to distribute heat evenly from the processor’s cores to the cooling system. Copper is frequently used due to its superior thermal conductivity and mechanical stability.

Fig 3 Processor Cap-Copper

2.5 PUMP

A copper pump is commonly used in CPU liquid cooling systems due to its excellent thermal conductivity and durability. The internal components of the pump, such as the water block and heat-exchange surfaces, are made from copper, while the outer housing is typically plastic.

Fig 4 Pump

2.6 RADIATOR

Radiators in computers are primarily used in liquid cooling systems to dissipate heat absorbed from components like CPUs and GPUs. They function by transferring heat from the liquid coolant to the air via metal fins, typically aluminum or copper. Fans mounted on the radiator increase airflow to enhance cooling performance. Radiators come in various sizes (120mm, 240mm, 360mm) depending on the cooling demand and chassis space. They enable more efficient and quieter cooling compared to traditional air cooling.

Fig 5 Radiator

2.7 THERMAL GREASE

Thermal grease, also known as thermal paste, thermal compound, or heat sink compound, is a thermally conductive substance used in computers to enhance heat transfer between the processor (CPU or GPU) and the heatsink. It's a critical component in maintaining optimal thermal performance.

Fig 6 Thermal Grease

III. FORMULA:

1.Cross-Sectional Area (A):

$A=W\times H$

2. Mass Flow Rate ($\dot{m}$):

$\dot{m} = \rho.A.v$

3.Heat Transfer Rate (Q):

$Q = m.\ Cp.\Delta T$

Where:

$\Delta T = T2 - T1$

4.Convective Heat Transfer Coefficient (h):

$h = Nu.kDh/h.$

V. MODELLING

3D modeling is an indispensable initial step in the design and analysis of our hybrid CPU cooling system, transforming conceptual ideas into precise digital blueprints. Utilizing Computer-Aided Design (CAD) software like SolidWorks or Fusion 360, we meticulously create three-dimensional representations of every component: the intricate aluminum fins, the winding copper pipe with its internal liquid channels, the water block, and the fan housing. This detailed digital construction allows for immediate visual inspection, enabling us to identify and rectify potential design flaws or interferences long before physical prototyping begins

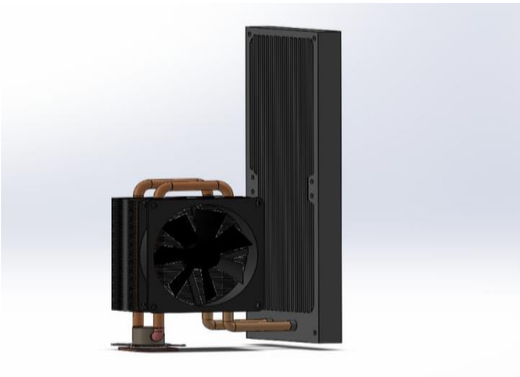


Fig 6 Desinging

VI. CFD ANALYSIS

Computational Fluid Dynamics (CFD) testing and analysis is an essential step in evaluating the performance of the hybrid (air + water) cooling system. CFD simulations allow engineers to model and analyse the flow of air and liquid coolant through the system, By simulating real-world conditions, CFD can predict potential issues related to airflow, coolant flow, heat transfer, and other fluid dynamics.

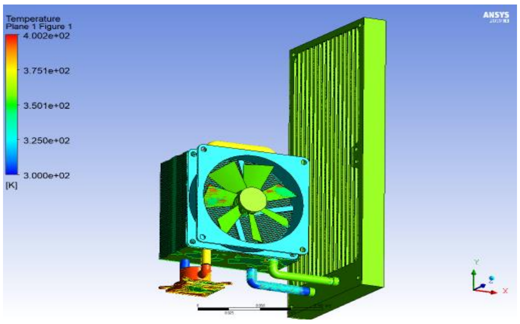


Fig 7 CFD Analysis

VII. EXPERIMENTAL APPARATUS AND DATA REDUCTION

Data Acquisition (DAQ) testing for PC processor cooling involves precisely measuring and recording thermal performance using specialized hardware and software. This process typically utilizes sensors like thermocouples and thermistors placed on the CPU, heatsink, and coolant lines, along with flow and pressure sensors for liquid systems, to gather real-time data. A DAQ device then converts these analog sensor signals into digital data, which DAQ software collects, logs, and visualizes as the PC processor undergoes various workloads, from idle to stress tests.

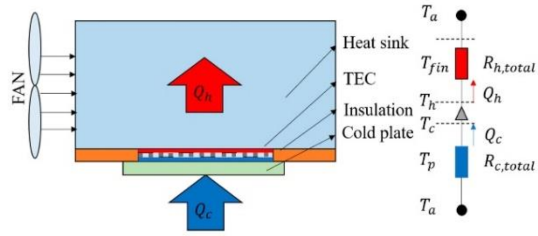


Fig 8 Thermal resistance of pc processor

This comprehensive data collection enables engineers to accurately analyze heat transfer rates, temperature stability, and overall cooling efficiency, crucial for validating models, optimizing designs, and ensuring the longevity and performance of the CPU.

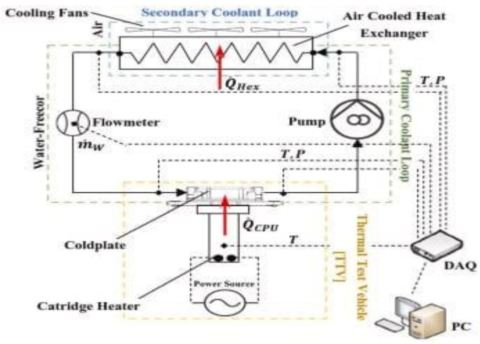
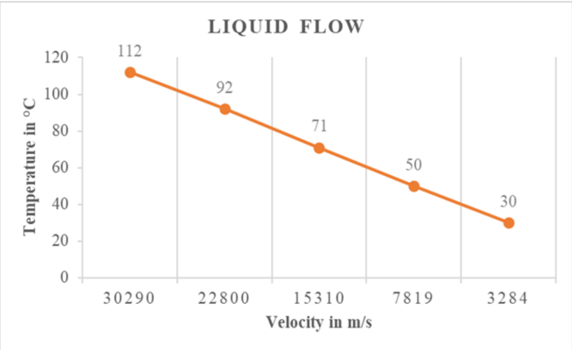


Fig.9 Wireframe diagram of the liquid cooling system using air cooled heat exchanger system.

VIII. CONCLUSION

This project's comprehensive investigation into hybrid CPU cooling, supported critically by Data Acquisition (DAQ) testing, is set to significantly advance thermal management strategies. By meticulously evaluating the performance of combined air and liquid cooling, assessing fan placement, and developing a predictive thermal model, the project aims to uncover optimal configurations. Thermal analysis was conducted using both Computational Fluid Dynamics simulations and Data Acquisition testing. The CFD model predicted temperature and fluid flow behaviour, while the DAQ system recorded real-time data from thermocouples and flow sensors. Experimental results showed a coolant temperature drop from 42 °C at the inlet to 30.3 °C at the outlet, with a flow velocity of 0.3 m/s, validating the system's effectiveness. The hybrid system achieved better thermal performance than air-only cooling by maintaining lower CPU temperatures and reducing thermal resistance.



Temperature Vs Velocity

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