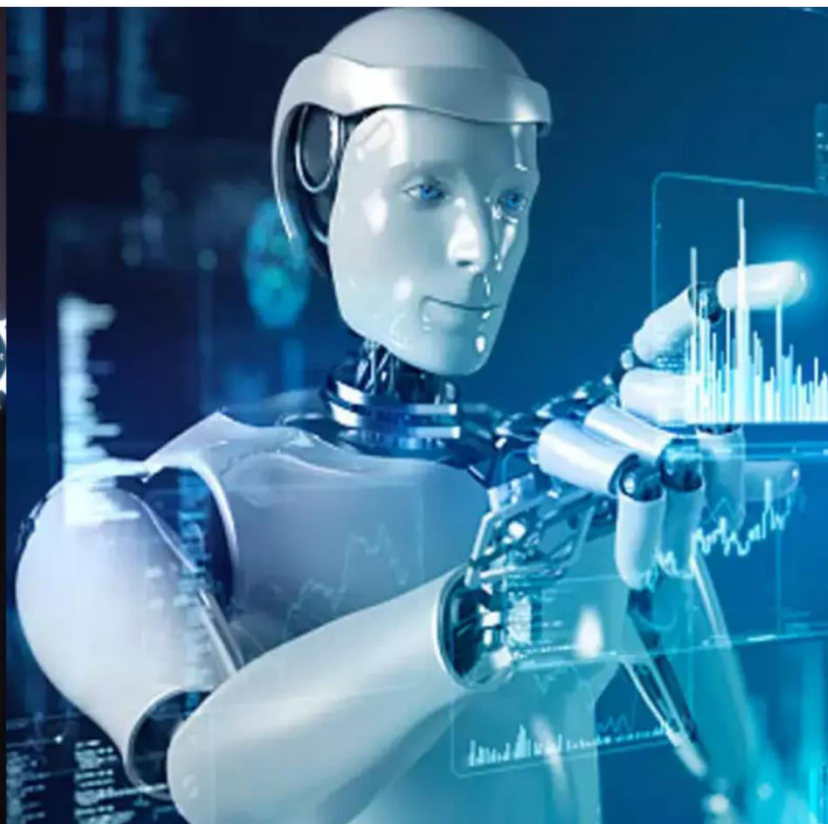




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Topology Optimization and Intelligent Simulation of Microchannel Heat Exchangers for Climate-Responsive HVAC

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ABSTRACT: With the rapid advancement of high-performance electronics, efficient thermal management has become a critical challenge. By leveraging their ultra-compact hydraulic diameters, microchannels offer disruptive heat transfer capabilities, making them ideal for next-gen thermal solutions and sustainable energy systems.

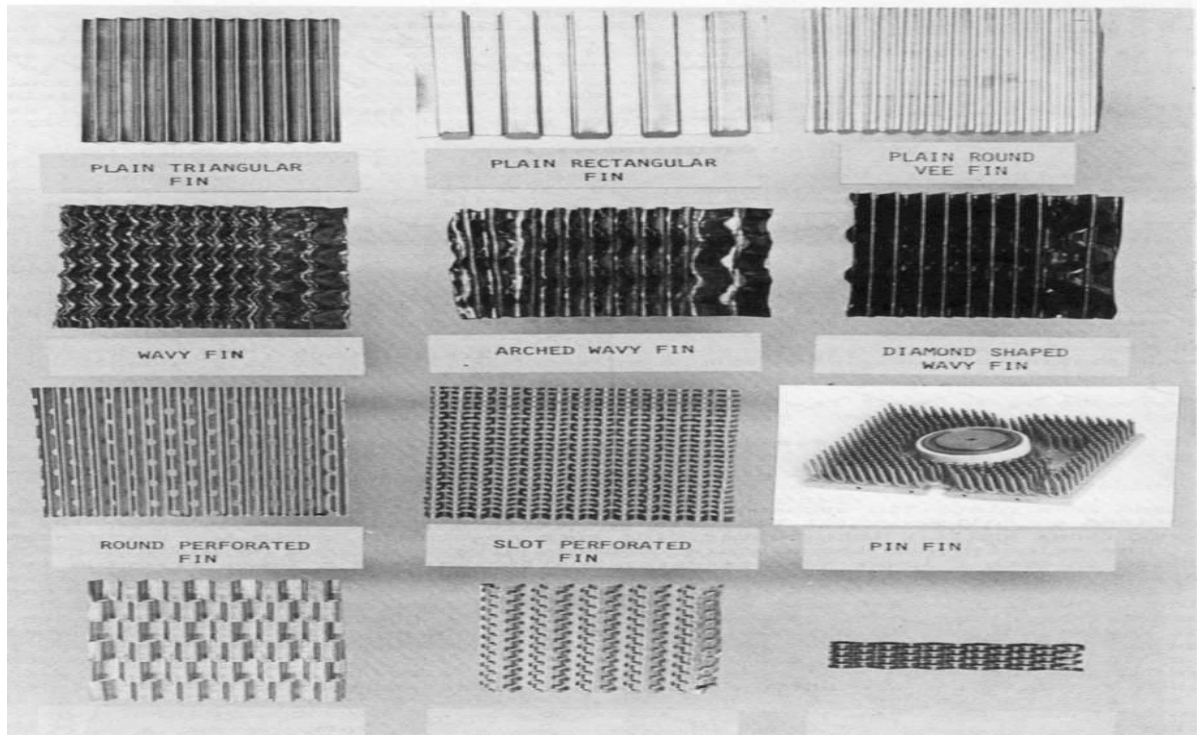
This research explores the design and experimental validation of an advanced microchannel heat exchanger, integrating water and air as working fluids. The system is meticulously optimized with six rows of water microchannels (4 mm height) and seven rows of air microchannels (10 mm height), all precision-brazed for enhanced durability. A high-efficiency military-grade fan enables active forced convection cooling, while a precision-engineered constant heat source ensures controlled testing conditions.

Experimental results showcase the heat exchanger's ability to deliver an impressive 681 W of cooling within a space-efficient 677.6 cm³ volume, significantly outperforming conventional commercial heat exchangers in thermal density. Additionally, AI-driven data analytics are employed to evaluate the air-side Colburn modulus concerning the Reynolds number, offering deeper insights into aerothermal dynamics and performance optimization.

KEYWORDS: Microchannel, Heat Exchanger, Thermal Management, Next-Gen Cooling, AI-Driven Analytics, Sustainable Energy Systems, High-Efficiency Design

I. INTRODUCTION

This introductory chapter explores the critical role of heat exchangers with microchannel flow and heat transfer in advanced electronics cooling. It contextualizes their significance within emerging global cooling technologies and the evolving demands of the national-level HVAC industry, emphasizing efficiency, miniaturization, and thermal management innovation.



1.1 Heat Exchanger

A heat exchanger is an essential thermal management device engineered to efficiently transfer heat between two or more fluids, a solid surface and a fluid, or even between solid particles and a fluid while maintaining thermal equilibrium. These systems play a crucial role in a wide range of industrial and commercial applications, facilitating processes such as fluid stream heating or cooling, as well as phase transitions like evaporation and condensation in both single and multi-component fluid mixtures. Heat exchangers are widely utilized in power generation, HVAC systems, chemical processing, refrigeration, and automotive industries, ensuring optimal energy utilization and improved system efficiency.

1.2 Miniaturization and Microchannel Concepts

The principle of miniaturization serves as the foundation for a relatively nascent technological domain known as Micro Electro Mechanical Systems (MEMS). The visionary physicist Richard P. Feynman foreshadowed this shift toward miniaturization in his ground breaking lecture, "There's Plenty of Room at the Bottom," presented at the annual meeting of the American Physical Society in 1959. In his address, he made a profound observation: "In the year 2000, when they look back at this age, they will wonder why it was not until the year 1960 that anybody began to seriously move in this direction." His insights laid the groundwork for advancements in nanotechnology and microfabrication, shaping the trajectory of modern engineering and innovation.

it is essential to establish a clear definition of the term microchannel. The classification of microchannels remains a topic of ongoing discussion among researchers, with varying perspectives based on manufacturing techniques, fluid dynamics, and rarefaction effects.

Manufacturing-Based Classification by Mehendale et al. [8] proposed a classification system based on the precision and techniques required for fabricating different channel sizes, defining the smallest channel dimension (CD) as follows:

- **Microchannels:** $1\ \mu\text{m} < \text{CD} < 100\ \mu\text{m}$
- **Minichannels:** $100\ \mu\text{m} < \text{CD} < 1\ \text{mm}$
- **Compact Passages:** $1\ \text{mm} < \text{CD} < 6\ \text{mm}$
- **Conventional Passages:** $\text{CD} > 6\ \text{mm}$

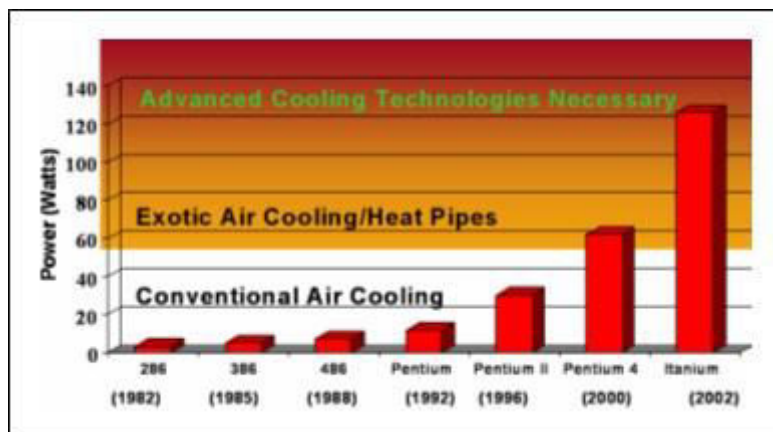
Rarefaction-Based Classification Kandlikar and Grande [9] introduced an alternative classification that considers the rarefaction effects of gases, particularly at smaller scales, with the following categorization:

- **Transitional Microchannels:** $1\ \mu\text{m} < \text{CD} < 10\ \mu\text{m}$
- **Microchannels:** $10\ \mu\text{m} < \text{CD} < 200\ \mu\text{m}$
- **Minichannels:** $200\ \mu\text{m} < \text{CD} < 3\ \text{mm}$
- **Conventional Passages:** $\text{CD} > 3\ \text{mm}$

As microfluidic and microscale heat transfer technologies evolve, these classifications help guide research and development in high-performance thermal management, electronics cooling, and biomedical applications.

1.3 Electronics Cooling Technologies

Since the advent of microchips, electronic cooling techniques have advanced rapidly, paralleling the evolution of the electronics industry. Effective thermal management is essential, as high temperatures accelerate material degradation and failure at interconnects, reducing component lifespan and system reliability. Integrated circuits are becoming smaller while heat dissipation increases, necessitating a shift from passive cooling to advanced thermal management systems. The power dissipation trend in INTEL processor chips, shown in Fig. 1.5, exemplifies this progression in the semiconductor industry.



Trends in increasing power density and categorization of cooling methods employed by INTEL

1.4 Motivation

Industry electronics demand stringent thermal management due to higher heat dissipation and extreme operating conditions. Typical operating ranges extend from $-40\ ^\circ\text{C}$ to $+60\ ^\circ\text{C}$, with upper limits posing significant challenges. While some components withstand up to $+150\ ^\circ\text{C}$, maintaining surfaces below $+85\ ^\circ\text{C}$ is preferred for reliability. High-performance chips can experience temperature rises exceeding $20\ ^\circ\text{C}$.

Depending on heat flux, cooling methods range from air cooling to microchannel liquid cooling. Liquid cooling is used for fluxes in the tens of W/cm^2 , while fluxes above $100\ \text{W}/\text{cm}^2$ require microchannel cooling, which is common in phased array radar modules. Efficient heat dissipation relies on liquid-to-air heat exchangers, where smaller channels enhance heat transfer but increase pressure drop. Brazed microchannel heat exchangers are optimal for military applications requiring high thermal performance.

1.5 Present Study

This study experimentally investigates a microchannel heat exchanger for liquid cooling in HVAC applications, assessing its heat removal limits. It also aims to develop a domestically manufactured exchanger, reducing import dependence and enhancing design flexibility. Optimizing fin dimensions improves cooling efficiency while minimizing size and weight for HVAC applications.

Adaptive thermal management is achieved by modifying fin parameters to meet rising heat flux demands. Domestic production streamlines procurement reduces costs, and improves responsiveness in HVAC projects.

II. LITERATURE SURVEY

This review examines recent research on microchannel heat exchangers (μ HEX), focusing on studies relevant to this thesis.

Al-Nmir et al. [19] numerically analyzed parallel plate μ HEX, incorporating slip boundary conditions. Their findings indicate that increasing Knudsen number (Kn) enhances velocity slip, reducing frictional resistance and increasing wall temperature. Mathew and Hegab [20] developed a thermal model for parallel flow μ HEX, showing that heat exchanger effectiveness depends on the fluid with the lowest heat capacity.

Chevron plate heat exchangers were studied experimentally by [21], providing correlations for heat transfer and pressure drop. Tsuzuki et al. [23] introduced an S-shaped fin configuration, reducing pressure drop while maintaining heat transfer rates. A recent study [24] investigated the impact of channel shape on μ HEX performance, finding circular channels most effective.

Experimental work by [25] validated classical heat transfer theory in μ HEX, highlighting plate conduction resistance as a key limitation. Schgulla et al. [8] examined plastic μ HEX with high heat flux capacity. Kang and Tseng [27] modeled cross-flow μ HEX, analyzing the interplay between effectiveness, heat transfer, and pressure drop. Their results confirmed that increasing heat exchanger size boosts heat transfer but also increases pressure drop.

Vamadevan and Kraft [28] studied aluminium brazing effects on μ HEX durability, while Wen et al. [29] used CFD and PIV to analyze turbulent flow in plate-fin heat exchangers. Foli et al. [30] applied multi-objective genetic algorithms to optimize μ HEX design. Nika et al. [31] explored thermoacoustic phenomena, and Kanlayasairi and Paul [32] developed a microlamination method for NiAl microchannel arrays.

Jiang et al. [33] compared μ HEX with porous media, demonstrating superior heat transfer but higher pressure drops. Alpsan [7] investigated μ HEX for phased array radar cooling, showing copper's superior performance over aluminum. Philips [34] experimentally and numerically analyzed fluid flow and heat transfer in μ HEX, confirming theoretical predictions.

Despite extensive μ HEX research, studies on two-fluid cross-flow μ HEX performance and channel shape effects remain limited, though interest in this area has grown.

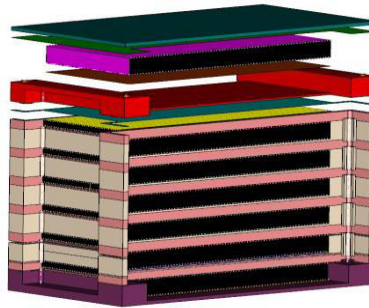
III. EXPERIMENTAL PROCEDURES AND RESULTS

This chapter presents the design, manufacturing, and experimental setup of the microchannel heat exchanger, highlighting key procedures, challenges, and preliminary stages.

Design of the Microchannel Heat Exchanger

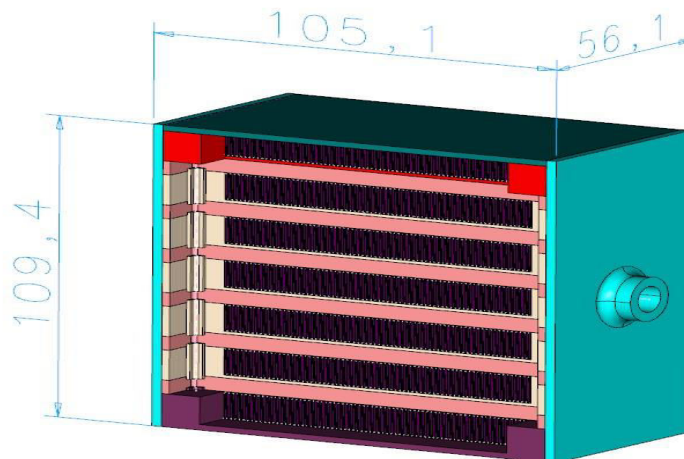
The manufacturing method for the microchannel heat exchanger was selected based on accuracy, material compatibility, and availability in India. Laser machining, EDM, chemical etching, and micro sawing were dismissed due to depth limitations, material constraints, or unavailability. Brazing was chosen for its durability in military applications, despite requiring precise execution to avoid defects that could reduce performance by 15-20%.

ASELSAN's available 4 mm and 10 mm plain fins were used due to time constraints. Water was selected as the coolant for simplicity. A crossflow, sandwich-type design was implemented, with 4 mm fins for water, 10 mm fins for air, and six water layers for efficient cooling. A fan mounting detail was included for optimized airflow.



A view of the sandwich construction design of the microchannel heat exchanger

A finger protection part was designed for the fan. Aluminum 6061 was chosen for the heat exchanger due to its brazing compatibility, manufacturability, and availability. The preliminary design is shown in Fig.



The preliminary design of the microchannel heat exchanger

Manufacturing of the Microchannel Heat Exchanger

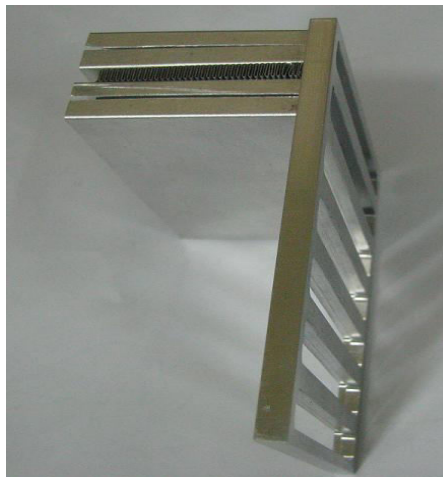
After completing the heat exchanger design, the next step was selecting a suitable brazing method. The available options were dip brazing and vacuum brazing. Although ASELSAN had vacuum brazing capability, the staff had limited experience, and brazing vertical joints posed difficulties. Since the heat exchanger required vertical joints, dip brazing at ASELSAN's subcontractor, EMD Inc., was identified as the most feasible option.

The Preliminary Heat Exchangers

Before dip brazing the preliminary heat exchanger, test specimens were prepared using aluminium 3003 O fins, a material known for its brazing compatibility. The fins were brazed between two flat plates, and after successful testing, the preliminary heat exchanger was produced. Figures illustrate the production steps. However, leakage tests revealed issues at certain points. Further examination showed that the thin plates failed to withstand the brazing temperature of approximately 600°C, causing their edges to bend and preventing proper contact between adjacent plates.



A view of the sandwich construction of the air side plain fins for the preliminary heat exchanger before dip brazing



A view of the assembly step of the preliminary heat exchanger before dip brazing

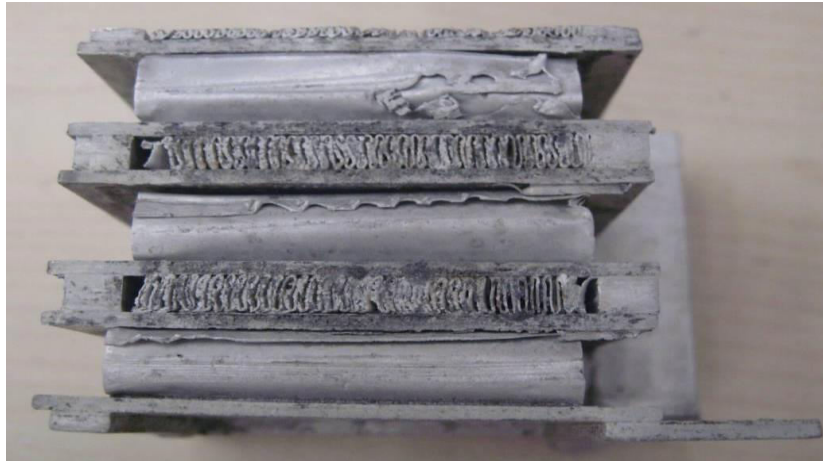
To address this issue, a rectangular box profile was considered. However, due to production constraints, its thickness was limited to 1-1.5 mm. Increasing the thickness would have raised wall resistance and weight, contradicting the goal of a lightweight heat exchanger. The initial test box profile was unsuitable for dip brazing, requiring a redesign, which delayed production by two months. Delays were further compounded by subcontractor dependencies in Turkey.

Despite issues with flatness and uniform thickness, the secondary heat exchanger was brazed due to time constraints. Figure X illustrates the dip-brazed secondary heat exchanger with the box profile.

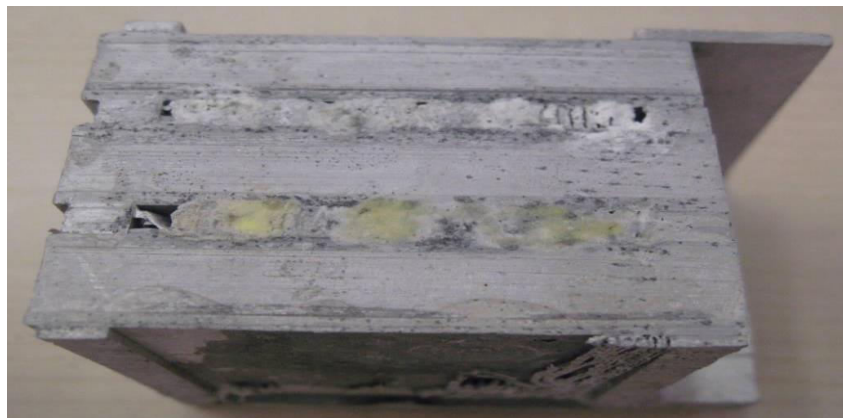


Secondary heat exchanger in dip brazing

Leakage tests showed a reduction in leaks, but the heat exchanger was not fully sealed. Additionally, salt deposits were found in the microchannels. To investigate, the preliminary heat exchanger was sliced into four sections. Figures show the sliced sections, revealing salt accumulation in the water channels. Over time, salt particles continued to emerge from the exchanger, confirming significant contamination.



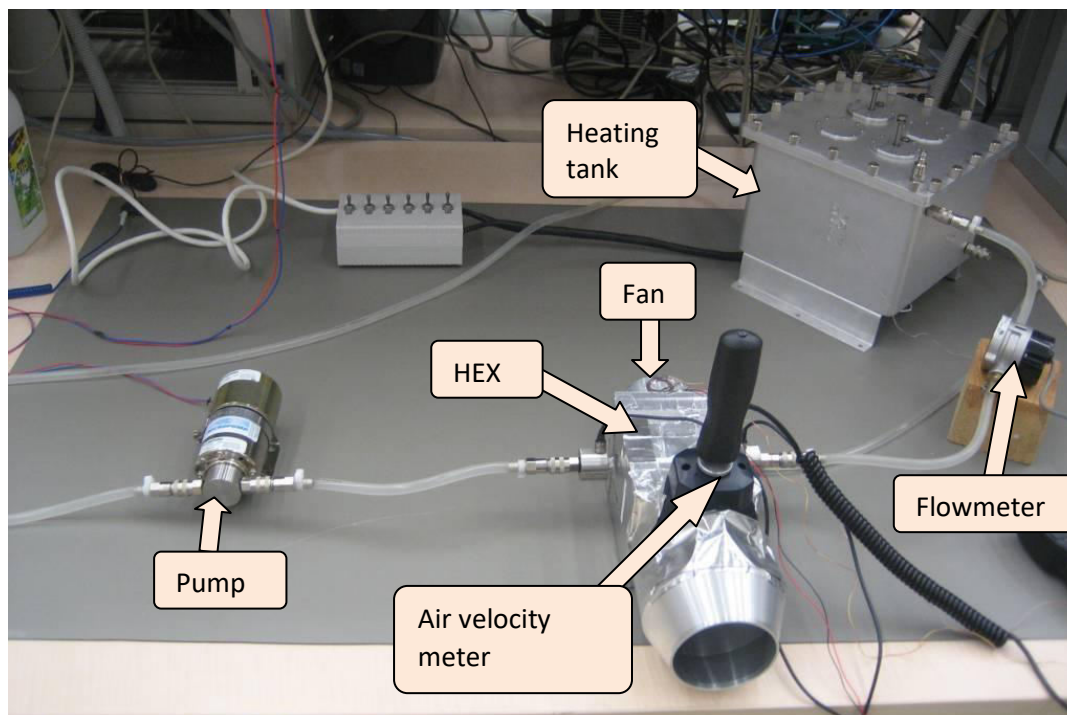
A view of the first quarter specimen of the preliminary microchannel heat exchanger produced in dip brazing, after being sliced into four specimens



A view of the second quarter specimen of the preliminary microchannel heat exchanger produced in dip brazing, after being sliced into four specimens

Test Setup

A new experimental setup was built to test the microchannel heat exchanger, simulating a typical liquid cooling system. It included a closed-loop coolant flow and a precise measurement system for pressure, temperature, and flow rate. The setup comprised a heating tank with heaters, a pump, a flow meter, a fan, transducers, a data logger, and the heat exchanger. A view of the test setup is shown in Fig., and the instrument details are listed in Table.



A view of the experimental setup

Experiments

The test setup allowed control over water and air flow rates. Water flow was adjusted by varying the pump input voltage, with selected rates of 0.009 kg/s, 0.013 kg/s, 0.019 kg/s, and 0.024 kg/s. Airflow was regulated by changing the fan current, ranging from 0.4 A to 1.2 A. All input parameters are summarized in Table. The heat load varied between 200 W and 1200 W, with 800 W used for most tests and 1200 W in the final experiments to assess system response.

Temperature, pressure, and flow rate data were recorded every 10 seconds and transferred to a PC via Agilent Benchlink software. Fig illustrates the data logger and power supply.

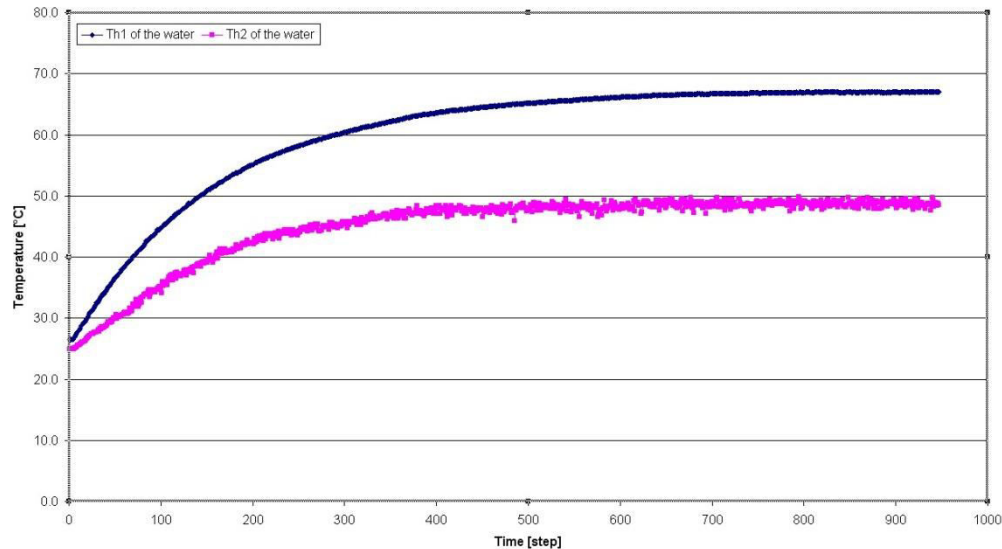


Data logger and the power supply used in experiments

Table: Input variables of the experiments

| Experiment Number | Input Heat to water in heating tank [W] | Pump Input Voltage [V] / Current [A] | Fan Input Voltage [V] / Current [A] |
|-------------------|---|--------------------------------------|-------------------------------------|
| 1 | 800 | 10 / 0.088 | 26 / 1.090 |
| 2 | 800 | 15 / 0.130 | 26 / 1.090 |
| 3 | 800 | 20 / 0.180 | 26 / 1.073 |
| 4 | 800 | 28 / 0.286 | 26 / 1.064 |
| 5 | 800 | 10 / 0.081 | 22.858 / 0.9 |
| 6 | 800 | 15 / 0.124 | 22.858 / 0.9 |
| 7 | 800 | 20 / 0.174 | 23.040 / 0.9 |
| 8 | 800 | 28 / 0.284 | 22.898 / 0.9 |
| 9 | 800 | 10 / 0.077 | 20.994 / 0.8 |
| 10 | 800 | 15 / 0.110 | 21.102 / 0.8 |
| 11 | 800 | 20 / 0.161 | 20.998 / 0.8 |
| 12 | 800 | 28 / 0.262 | 21.066 / 0.8 |
| 13 | 800 | 10 / 0.077 | 19.214 / 0.7 |
| 14 | 800 | 15 / 0.114 | 19.205 / 0.7 |
| 15 | 800 | 20 / 0.163 | 19.196 / 0.7 |
| 16 | 800 | 28 / 0.263 | 19.050 / 0.7 |
| 17 | 800 | 10 / 0.076 | 17.170 / 0.6 |
| 18 | 800 | 15 / 0.112 | 17.232 / 0.6 |
| 19 | 800 | 20 / 0.163 | 17.285 / 0.6 |
| 20 | 800 | 28 / 0.248 | 17.270 / 0.6 |
| 21 | 800 | 10 / 0.077 | 15.191 / 0.5 |
| 22 | 800 | 15 / 0.117 | 15.201 / 0.5 |
| 23 | 800 | 20 / 0.165 | 15.201 / 0.5 |
| 24 | 800 | 28 / 0.273 | 15.156 / 0.5 |
| 25 | 800 | 10 / 0.081 | 13.025 / 0.4 |
| 26 | 800 | 15 / 0.120 | 13.075 / 0.4 |
| 27 | 800 | 20 / 0.173 | 13.070 / 0.4 |
| 28 | 800 | 28 / 0.278 | 13.086 / 0.4 |
| 29 | 1200 | 10 / 0.078 | 26 / 1.054 |
| 30 | 1200 | 15 / 0.126 | 26 / 1.060 |
| 31 | 1200 | 20 / 0.168 | 26 / 1.054 |
| 32 | 1200 | 28 / 0.285 | 26 / 1.057 |

Measurements were continuously monitored to determine when the system reached a thermal steady-state at each flow rate and heat load. Inlet and outlet water temperature graphs over time were plotted for all experiments to confirm steady-state conditions. Fig. illustrates the temperature vs. time graph for Experiment 5, generated in Excel. Due to Excel's row limit, the time scale represents interval counts rather than real-time values.



Inlet and outlet temperatures of the water & time step for experiment 5

Once thermal equilibrium was reached, the next step was to systematically adjust either the flow rate or the heat load to analyze the microchannel heat exchanger's performance under varying conditions. Flow rate modifications were implemented in controlled increments, ensuring that each new condition remained stable long enough to achieve steady-state operation before proceeding further. Likewise, heat load variations were introduced gradually to accurately assess the heat exchanger's response. This method ensured consistent and reliable data collection, enabling a thorough evaluation of the system's thermal efficiency.

Experimental Results

During the experiments, the recorded water parameters corresponding to the given input conditions were systematically compiled into tables. Similarly, the measured air parameters for all test scenarios were documented in separate tables, ensuring a structured and comprehensive presentation of the experimental data.

Table: Measured parameters of water for all experiments

| Experiment Number | Flow rate of water [kg/s] | Inlet Temperature of water [°C] | Outlet Temperature of water [°C] | Temperature Difference of water [°C] |
|-------------------|---------------------------|---------------------------------|----------------------------------|--------------------------------------|
| 1 | 0.009 | 63.8 | 44.9 | 18.9 |
| 2 | 0.013 | 61.3 | 48.2 | 13.1 |
| 3 | 0.019 | 59.1 | 49.9 | 9.2 |
| 4 | 0.024 | 57.8 | 51.3 | 6.5 |
| 5 | 0.009 | 67.0 | 48.6 | 18.4 |
| 6 | 0.013 | 65.0 | 53.2 | 11.8 |
| 7 | 0.019 | 64.4 | 56.5 | 7,9 |
| 8 | 0.024 | 64.6 | 59.5 | 5,1 |
| 9 | 0.009 | 70.7 | 52.9 | 17,8 |
| 10 | 0.013 | 67.6 | 55.9 | 11,7 |
| 11 | 0.019 | 66.4 | 58.1 | 8,3 |

| | | | | |
|----|-------|------|------|------|
| 12 | 0.024 | 64.5 | 58.4 | 6,1 |
| 13 | 0.009 | 71.8 | 54.4 | 17,4 |
| 14 | 0.013 | 70.6 | 58.0 | 12,6 |
| 15 | 0.019 | 69.0 | 61.0 | 8.0 |
| 16 | 0.024 | 67.5 | 61.8 | 5.7 |
| 17 | 0.009 | 75.4 | 60.7 | 14.7 |
| 18 | 0.013 | 73.3 | 62.1 | 11.2 |
| 19 | 0.019 | 73.2 | 66.2 | 7.0 |
| 20 | 0.024 | 72.2 | 67.5 | 4.7 |
| 21 | 0.009 | 80.7 | 64.4 | 16.3 |
| 22 | 0.013 | 79.0 | 68.1 | 10.9 |
| 23 | 0.019 | 78.5 | 72.8 | 5.7 |
| 24 | 0.024 | 77.8 | 73.9 | 3.9 |
| 25 | 0.009 | 88.0 | 72.2 | 15.8 |
| 26 | 0.013 | 86.9 | 77.1 | 9.8 |
| 27 | 0.019 | 86.7 | 80.5 | 6.2 |
| 28 | 0.024 | 86.8 | 83.3 | 3.5 |
| 29 | 0.009 | 86.6 | 60.8 | 25.8 |
| 30 | 0.013 | 79.5 | 63.8 | 15.7 |
| 31 | 0.019 | 79.2 | 66.8 | 12.4 |
| 32 | 0.024 | 78.5 | 70.9 | 7.6 |

Table: Pressure drop of water for all experiments

| Experiment Number | Inlet Pressure of water [bar] | Outlet Pressure of water [bar] | Pressure drop of water [bar] |
|-------------------|-------------------------------|--------------------------------|------------------------------|
| 1 | 1.334 | 1.302 | 0.032 |
| 2 | 1.316 | 1.276 | 0.040 |
| 3 | 1.344 | 1.297 | 0.047 |
| 4 | 1.468 | 1.409 | 0.059 |
| 5 | 1.339 | 1.306 | 0.033 |
| 6 | 1.323 | 1.286 | 0.037 |
| 7 | 1.370 | 1.327 | 0.043 |
| 8 | 1.505 | 1.453 | 0.052 |
| 9 | 0.866 | 0.833 | 0.033 |
| 10 | 1.433 | 1.393 | 0.040 |
| 11 | 1.428 | 1.382 | 0.046 |
| 12 | 1.490 | 1.437 | 0.053 |
| 13 | 1.546 | 1.511 | 0.035 |
| 14 | 1.169 | 1.113 | 0.056 |
| 15 | 1.145 | 1.102 | 0.043 |
| 16 | 1.217 | 1.168 | 0.049 |
| 17 | 1.298 | 1.266 | 0.032 |
| 18 | 1.211 | 1.172 | 0.039 |

| | | | |
|----|-------|-------|-------|
| 19 | 1.220 | 1.178 | 0.042 |
| 20 | 1.300 | 1.256 | 0.044 |
| 21 | 1.444 | 1.412 | 0.032 |
| 22 | 1.335 | 1.298 | 0.037 |
| 23 | 1.328 | 1.291 | 0.037 |
| 24 | 1.411 | 1.366 | 0.045 |
| 25 | 1.675 | 1.645 | 0.030 |
| 26 | 1.543 | 1.506 | 0.037 |
| 27 | 1.530 | 1.490 | 0.040 |
| 28 | 1.611 | 1.572 | 0.039 |
| 29 | 1.825 | 1.792 | 0.033 |
| 30 | 1.386 | 1.349 | 0.037 |
| 31 | 1.483 | 1.441 | 0.042 |
| 32 | 1.538 | 1.495 | 0.043 |

Table: Measured parameters of air for all experiments

| Experiment Number | Flow rate of air [m ³ /s] | Velocity of air [m/s] | Inlet Temperature of air [°C] | Outlet Temperature of air [°C] | Temperature Difference of air [°C] |
|-------------------|--------------------------------------|-----------------------|-------------------------------|--------------------------------|------------------------------------|
| 1 | 0.02118 | 3.25 | 23.4 | 45.0 | 21.6 |
| 2 | 0.02118 | 3.25 | 23.5 | 47.7 | 24.2 |
| 3 | 0.02118 | 3.25 | 23.6 | 48.6 | 25.0 |
| 4 | 0.02118 | 3.25 | 23.7 | 49.6 | 25.9 |
| 5 | 0.01950 | 3.10 | 23.4 | 49.8 | 26.4 |
| 6 | 0.01950 | 3.10 | 24.3 | 53.0 | 28.7 |
| 7 | 0.01950 | 3.10 | 25.4 | 54.2 | 28.8 |
| 8 | 0.01950 | 3.10 | 26.0 | 56.0 | 30.0 |
| 9 | 0.01868 | 2.80 | 24.4 | 56.0 | 31.6 |
| 10 | 0.01868 | 2.80 | 23.4 | 56.8 | 33.4 |
| 11 | 0.01868 | 2.80 | 23.1 | 57.4 | 34.3 |
| 12 | 0.01868 | 2.80 | 23.3 | 57.4 | 34.1 |
| 13 | 0.01595 | 2.45 | 23.8 | 57.3 | 33.5 |
| 14 | 0.01595 | 2.45 | 23.4 | 59.6 | 36.2 |
| 15 | 0.01595 | 2.45 | 23.4 | 60.1 | 36.7 |
| 16 | 0.01595 | 2.45 | 23.4 | 60.6 | 37.2 |
| 17 | 0.01372 | 2.10 | 24.0 | 60.9 | 36.9 |
| 18 | 0.01372 | 2.10 | 23.6 | 63.1 | 39.5 |
| 19 | 0.01372 | 2.10 | 24.7 | 64.8 | 40.1 |
| 20 | 0.01372 | 2.10 | 23.9 | 65.4 | 41.5 |
| 21 | 0.01141 | 1.75 | 23.9 | 66.6 | 42.7 |
| 22 | 0.01141 | 1.75 | 24.1 | 69.0 | 44.9 |
| 23 | 0.01141 | 1.75 | 23.9 | 70.3 | 46.4 |

| | | | | | |
|----|---------|------|------|------|------|
| 24 | 0.01141 | 1.75 | 24.0 | 71.0 | 47.0 |
| 25 | 0.00886 | 1.35 | 24.3 | 74.7 | 50.4 |
| 26 | 0.00886 | 1.35 | 24.2 | 77.1 | 52.9 |
| 27 | 0.00886 | 1.35 | 24.3 | 78.3 | 54.0 |
| 28 | 0.00886 | 1.35 | 24.4 | 79.6 | 55.2 |
| 29 | 0.02118 | 3.25 | 25.0 | 62.3 | 37.3 |
| 30 | 0.02118 | 3.25 | 23.5 | 62.9 | 39.4 |
| 31 | 0.02118 | 3.25 | 24.6 | 66.0 | 41.4 |
| 32 | 0.02118 | 3.25 | 25.4 | 67.7 | 42.3 |

Discussion and comparison of results

This chapter focuses on analyzing and comparing the experimental results to identify trends, correlations, and variations among different test conditions. A detailed discussion is provided to interpret the observed data, highlighting key performance indicators of the microchannel heat exchanger. Possible factors influencing the results, such as variations in flow rates, heat loads, and system stability, are explored. Additionally, any deviations from expected outcomes are examined, considering potential sources of error, limitations of the experimental setup, and the influence of material properties or manufacturing techniques. Through this comparative evaluation, valuable insights into the thermal performance and efficiency of the heat exchanger are drawn.

Outlet Temperatures of water

Figure presents the outlet water temperatures recorded across all experiments, during which the air mass flow rate varied between 0.01296 kg/s and 0.00537 kg/s.

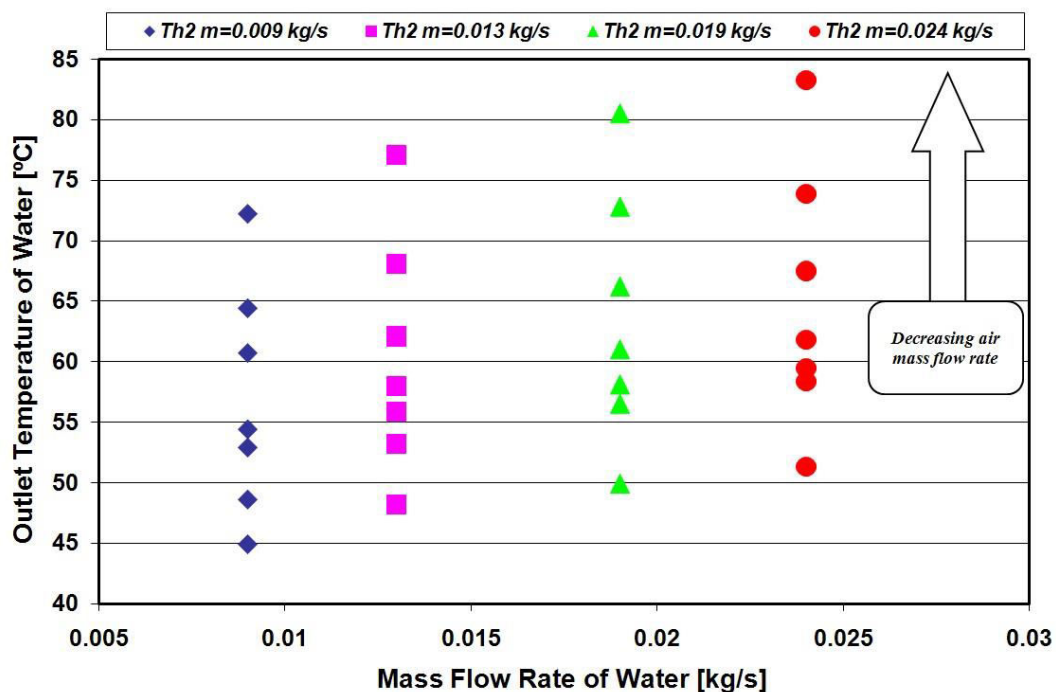


Figure: Outlet temperatures of water

As depicted in Fig., an increase in the water mass flow rate leads to a slight rise in its outlet temperature. This is because higher flow rates shorten the time water spends in the microchannel heat exchanger, reducing the heat transfer opportunity.

In Fig., lowering the fan speed decreases the air mass flow rate from 0.01296 kg/s to 0.00537 kg/s, which reduces the heat transfer between water and air. As a result, a 2.5-fold reduction in air mass flow rate causes the water outlet temperature to rise by approximately 1.5 times. Although heat transfer is generally dependent on air mass flow rate, some heat dissipates into the surrounding environment, which remained at room temperature during the tests.

Pressure Drop of Water

Figure illustrates the water pressure drop across all experiments, with air mass flow rates varying from 0.01296 kg/s to 0.00537 kg/s. A detailed summary of water pressure drop values is provided in Table.

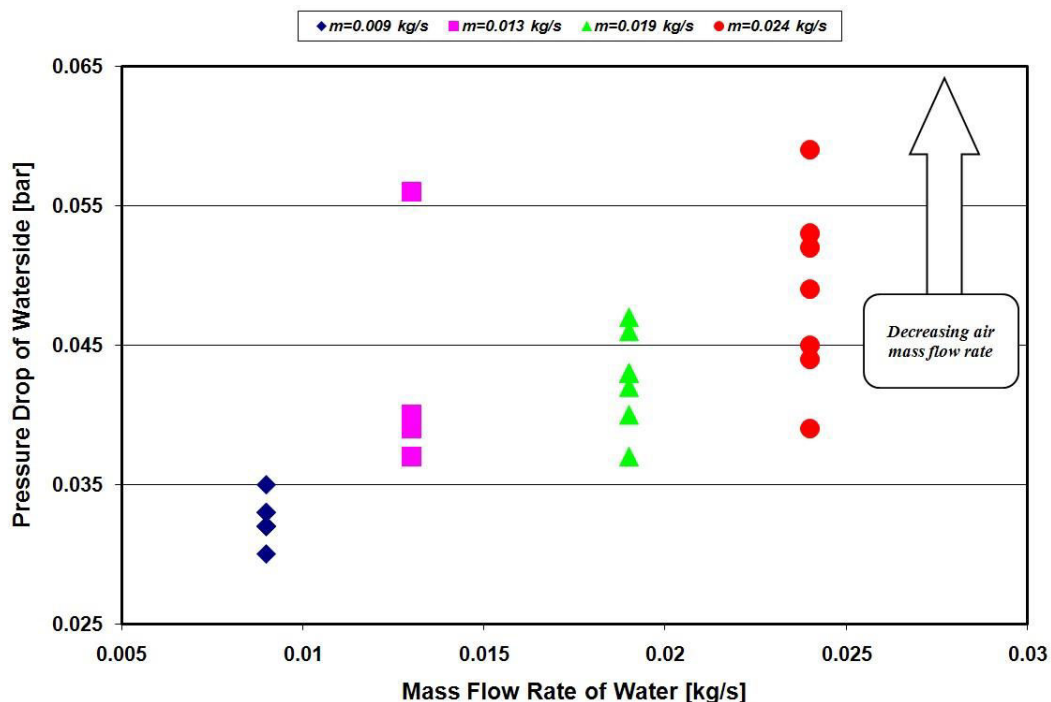


Figure: Pressure drop of water

The figure illustrates a slight rise in pressure drop as the water flow rate increases from 0.009 kg/s to 0.024 kg/s. As the air flow rate decreases, the difference in pressure between the water inlet and outlet becomes more pronounced. Additionally, the pressure drop at higher water flow rates and lower airflow rates is nearly twice that of lower water flow rates and higher airflow rates. Given that the system operates at around 4–5 bars, minor pressure drops of 30–50 mbar are negligible and do not significantly impact system performance.

Effectiveness

The efficiency of the microchannel heat exchanger under varying air mass flow rates, ranging from 0.01296 kg/s to 0.00537 kg/s, is illustrated in Figure. A comprehensive breakdown of the effectiveness of each experiment is documented in Appendix B, specifically in Tables.

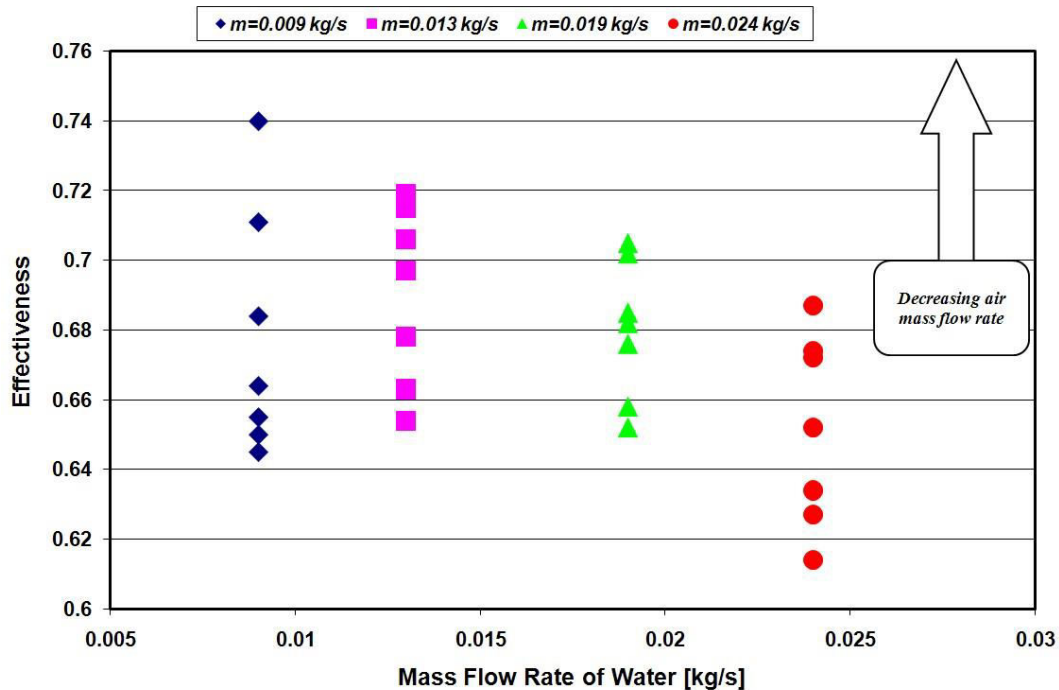


Figure: Effectiveness of the microchannel heat exchanger

At a water flow rate of 0.009 kg/s, the heat exchanger's effectiveness increases by approximately 10% as the air flow rate decreases. A similar pattern is noted at 0.013 kg/s, though the increase is about 6%. When the water flow rate reaches 0.019 kg/s, the effectiveness is 0.71 at maximum airflow and slightly reduces to 0.70 at minimum airflow. Overall, as the airflow rate changes from 0.01296 kg/s to 0.00537 kg/s, effectiveness remains fairly consistent. However, at the highest water flow rate, effectiveness declines from 0.69 to 0.63.

Evaluation of the Experimental Setup

The experimental setup was designed to replicate a real liquid cooling system using six heaters and a pump to simulate heat loads and flow conditions.

Measuring airflow rate accurately was challenging, as the air velocity meter, placed 10 cm from the heat exchanger, may have led to inaccuracies. Similarly, water flow rate measurements relied on a flowmeter requiring frequency-to-flow conversions, introducing potential errors.

Despite using high-accuracy thermocouples and transducers, their placement 10 cm from the air inlet and 1-2 cm from the water inlet/outlet—caused minor deviations. Additional errors stemmed from instrument precision, rounding, and general measurement uncertainties.

IV. CONCLUSION

Efficient heat dissipation is crucial in HVAC systems, making microchannel heat exchangers ideal due to their high heat transfer efficiency. Plain fins (4 mm and 10 mm) formed the microchannel structure. Manufacturing methods were evaluated, considering channel geometry, material, and feasibility in Turkey. Dip brazing led to leakage and salt blockages, prompting a shift to vacuum brazing, requiring design modifications.

An experimental setup was built to heat and circulate coolant using water and air. A heating tank provided consistent heat, while a military fan enabled forced convection cooling.

Testing confirmed the new heat exchanger matched commercial performance, achieving a 73% volume reduction and 40% weight savings. The air-side Colburn modulus was also determined based on the Reynolds number.

REFERENCES

1. R. K. Shah and D. P. Sekulic, Fundamentals of Heat Exchanger Design, John Wiley & Sons, 2003
2. S. Kakaç and H. Liu, Heat Exchangers Selection, Rating and Thermal Design, 2nd Edition, CRC Press LLC, 2002
3. S. Kakaç, A.E. Bergles, F. Mayinger, Heat Exchangers Thermal-Hydraulic Fundamentals and Design, Hemisphere Publishing Corporation, 1981
4. Geoffrey F. Hewitt, HEDH : Heat Exchanger Design Handbook, New York: Begell House, 2002
5. R.P. Feynman, "There's Plenty of Room at the Bottom", Miniaturization, H.D. Gilbert, ed., 282-296, Reinhold Publishing, New York, 1961.
6. D.B. Tuckerman, R.F.W. Pease, "High-Performance Heat Sinking for VLSI", IEEE Electron Device Letters, Vol. EDL-2, No.5, 1981.
7. Alpsan Emrah, Experimental Investigation and Numerical Analysis of Microchannel Heat sinks for Phased Array Radar Cooling Applications, Msc Thesis, Mechanical Engineering Department, METU, Ankara, 2008
8. S.S. Mehendale, A.M. Jacobi, R.K. Shah, "Fluid Flow and Heat Transfer at Micro- and Meso-scales with Application to Heat Exchanger Design," Applied Mechanics Reviews, Vol.53, pp.175-193, 2000.
9. S.G. Kandlikar, W.J. Grande, "Evolution of Microchannel Flow Passages – Thermohydraulic Performance and Fabrication Technology", Heat Transfer Engineering, Vol.24, pp.3-17, 2003.
10. N.T. Obot, "Toward a Better Understanding of Friction and Heat/Mass Transfer in Microchannels – A Literature Review", Microscale Thermophysical Engineering, Vol.6, pp.155-173, 2003.
11. M. Bahrani, M.M. Jovanovich, "Pressure Drop of Fully Developed Laminar Flow in Microchannels of Arbitrary Cross-Section", Journal of Fluids Engineering, Vol.128, pp.1036-1044, 2006.
12. M. Bahrani, M.M. Jovanovich, J.R. Culham, "Pressure Drop of Fully Developed, Laminar Flow in Rough Microtubes", Journal of Fluids Engineering, Vol.128, pp.632-637, 2006.
13. T. Bayraktar, S.B. Pidugu, "Characterization of Liquid Flows in Microfluidic Systems", International Journal of Heat and Mass Transfer, Vol.49, pp.815-824, 2006.
14. S. G. Kandlikar, S. Garimella, D. Li, S. Colin and M. R. King, Heat Transfer and Fluid Flow In Minichannels and Microchannels, Elsevier, 2006
15. M. Gad-el-Hak, "The Fluid Mechanics of Microdevices – The Freeman Scholar Lecture", Journal of Fluids Engineering, Vol.121, pp.5-33, 1999.
16. D. Bharathan, K. Gawlik, B. Kramer, S. Rogers, T.J. Hendricks, "Advanced Power Electronics - Thermal Management", National Renewable Energy Laboratory (NREL) Publications, 2003 http://www.nrel.gov/vehiclesandfuels/powerelectronics/pdfs/advanced_power_electronics_thermal_mgmt.pdf, last accessed on April 10th, 2010
17. R.S. Prasher, J. Chang, I. Sauciu, S. Narasimhan, D. Chau, D. G. Chrysler, A. Myers, S. Prstic, C. Hu, C., "Nano and Micro Technology-Based NextGeneration Package-Level Cooling Solutions", INTEL Technology Journal Vol.9, pp.285-296, 2005.
18. Melcor™ Product Catalogue, www.melcor.com, 2007, last accessed on April 10th, 2010
19. M.A. Al-Nimr, M. Maqableh, A.F. Khadrawi, S.A. Ammourah, Fully developed thermal behaviors for parallel flow microchannel heat exchanger, International Communications in Heat and Mass Transfer, Vol. 36, pp. 385-390, 2009
20. B. Mathew, H. Hegab, Application of effectiveness-NTU relationship to parallel flow microchannel heat exchangers subjected to external heat transfer, International Journal of Thermal Sciences Vol. 30, pp.1-10, 2009
21. D. Dovic, B. Palm, S. Svaic, Generalized correlations for predicting heat transfer and pressure drop in plate heat exchanger channels of arbitrary geometry, International Journal of Heat and Mass Transfer, Vol. 52, pp. 4553-4563, 2009
22. Dović, The analysis of single-phase flow in chevron channels of plate heat exchangers, Int. MSc Thesis, Energy Department, Royal Institute of Technology, Stockholm, 2000
23. Nobuyoshi Tsuzuki, Motoaki Utamura, Tri Lam Ngo, Nusselt number correlations for a microchannel heat exchanger hot water supplier with S-shaped fins, Applied Thermal Engineering, Vol. 29, pp. 3299-3308, 2009

24. Mushtaq I. Hasan, A.A. Rageb, M. Yaghoubi, Homayon Homayoni, Influence of channel geometry on the performance of a counter flow microchannel heat exchanger, International Journal of Thermal Sciences, Vol. 48, pp. 1607-1618, 2009
25. N. Garcia-Hernando, A. Acosta-Iborra, U. Ruiz-Rivas, M. Izquierdo, Experimental investigation of fluid flow and heat transfer in a single-phase liquid flow micro-heat exchanger, International Journal of Heat and Mass Transfer, Vol. 52, pp. 5433-5446, 2009
26. Ulrich Schygulla, Jürgen J. Brandner, Eugen Anurjew, Edgar Hansjosten, Klaus Schubert, Micro heat changers and surface-micro-coolers for high heat flux, Proceedings of the Sixth International ASME Conference on Nanochannels, Microchannels and Minichannels ICNMM2008, Darmstadt, Germany, 2008
27. Shung-Wen Kang, Shin-Chau Tseng, Analysis of effectiveness and pressure drop in micro cross-flow heat exchanger, Applied Thermal Engineering, Vol. 27, pp. 877-885, 2007
28. Gowreesan Vamadevan, Fank F. Kraft, Processing effects in aluminum micro-channel tube for brazed R744 heat exchangers, Journal of Materials Processing Technology, Vol. 191, pp. 30-33, 2007
29. Jian Wen, Yanzhong Li, Aimin Zhou, Ke Zhang, An experimental and numerical investigation of flow patterns in the entrance of plate-fin heat exchanger, International Journal of Heat and Mass Transfer, Vol. 49, pp. 1667-1678, 2006
30. Kwasi Foli, Tatsuya Okabe, Markus Olhofer, Yaochu Jin, Bernhard Sendhoff, Optimization of micro heat exchanger-CFD, analytical approach and multi-objective evolutionary algorithms, International Journal of Heat and Mass Transfer, Vol. 49, pp. 1090-1099, 2006
31. Philippe Nika, Yannick Bailly, François Guermeur, Thermoacoustics and related oscillatory heat and fluid flows in micro heat exchangers, Vol. 48, pp. 3773-3792, 2005
32. K. Kanlayasiri, B.K. Paul, A nickel aluminide microchannel array heat exchanger for high-temperature applications, Journal of Manufacturing Processes, Vol. 6, No.1, 2004
33. Pei-Xue Jiang, Ming-Hong Fan, Guang-Shu Si, Ze-Pei Ren, Thermal– hydraulic performance of small scale micro-channel and porous-media heatexchangers, International Journal of Heat and Mass Transfer, Vol. 44, pp. 1039-1051, 2001
34. Philips Wyne Allen, Experimental and Numerical Investigation of Fluid Flow and Heat Transfer in Microchannels, Msc Thesis, Mechanical Engineering Department, Louisiana State University, 2007
35. S. Kakaç, R. K. Shah, A. E. Bergles, Low Reynolds Number Flow Heat Exchangers, Hemisphere Publishing Corporation, 1983
36. R. K. Shah and A. L. London, Laminar Flow Forced Convection In Ducts, Academic Press, 1978
37. B. Sunden and M. Faghri, Computer Simulations in Compact Heat Exchangers, Vol. 1, Computational Mechanical Publications, 1998
38. F. P. Incropera and D. P. DeWitt, Fundamentals of Heat and Mass Transfer, 4th Edition, John Wiley & Sons, 1996
39. R. K. Shah, A. D. Krams and D. Metzger, Compact Heat Exchangers, Hemisphere Publishing Corporation, 1990
40. P. Roberts, Industrial Brazing Practice, CRC Press LLC, 2004
41. N. Lashko and S. Lashko, Brazing and Soldering of Metals, Mir Publishers, 1979
42. R. Fabian, Vacuum Technology, Practical Heat Treating and Brazing, ASM International, 1993
43. M. M. Schwartz, Brazing, ASM International, 1987
44. Material Property Data, www.matweb.com, last accessed on April 15th, 2010
45. B. Sunden and R.H. Shah, Compact heat exchangers, R.T. Edwards Inc., 2007
46. W. M. Kays and A. London, Compact Heat Exchangers – A summary of basic heat transfer and flow friction design data, McGraw-Hill Book Company Inc., 1958
47. Ehsan Sadeghi, Majid Bahrami, Ned Djilali, Estimation of Nusselt number in microchannels of arbitrary cross-section with constant axial heat flux, Heat Transfer Engineering, Vol. 31, pp. 666-674, 2010
48. Yu-Tang Chen, Shung-Wen Kang, Wen-Chian Tuh and Tsung-Hsin Hsiao, Experimental investigation of fluid flow and heat transfer in microchannels, Tamkang Journal of Science and Engineering, Vol.7, No.1, pp. 11-16, 2004
49. W. M. Kays and A.L. London, Compact heat exchangers, 2nd Edition, McGraw-Hill Series in Mechanical Engineering, 1964
50. Ralph L. Webb, Nae-Hyun Kim, Principles of Enhanced Heat Transfer, Taylor & Francis Group, 2005
51. Ramesh K. Shah, Compact Heat Exchangers and Enhancement Technology for the Process Industries, Begell House, 1999
52. W. Roetzel, P.J. Heggs and D. Butterworth, Design and Operation of Heat Exchangers, Springer-Verlag, 1991

53. C. J. Thwaites, Capillary Joining – Brazing and Soft-Soldering, Research Studies Press, 1982
54. J. J. Ginoux, Heat Exchangers, North Atlantic Treaty Organization Advisory Group For Aerospace Research And Development, 1972
55. Lytron™ Application Note and Product Catalogue, www.lytron.com, 2007, last accessed on, April 10th, 2010
56. Siyuan Wu ^a, Rijing Zhao ^a, Xinghua Wei ^a“Air-side thermal-hydraulic analysis and parameter optimization for vertical-fin microchannel heat exchanger” Volume 226, 25May2023, 120297, <https://doi.org/10.1016/j.applthermaleng.2023.120297>
57. S.A. Abdollahi ^a, P. Jalili ^b, B. Jalili ^b“Computer simulation of Cu: AlOOH/water in a microchannel heat sink Using a porous media technique and solved by numerical analysis AGM and FEM” Available online 3 February 2023, 100432, <https://doi.org/10.1016/j.taml.2023.100432>.
58. Qun Han, Zhaoxuan Liu, Wenming Li“Enhanced thermal performance by spatial chaotic mixing in a saw-like micro channel” Volume 186, April 2023, 108148, <https://doi.org/10.1016/j.ijthermalsci.2023.108148>.
59. P. Pontes ^a, I. Gonçalves ^a, M. Andreadaki ^b, A. Georgoulas ^b, A.L.N. Moreira ^a“ Fluid flow and heat transfer in micro channel devices for cooling applications: Experimental and numerical approaches” Volume 218, 5 January 2023, 119358, <https://doi.org/10.1016/j.applthermaleng.2022.119358>.
60. Jianhong Zhou, Qiang Li, Xuemei Chen “ Micro pin fins with topologically optimized configurations enhance Flow boiling heat transfer in manifold microchannel heatsinks”Volume206, 1June2023,123956, <https://doi.org/10.1016/j.ijheatmasstransfer.2023.123956>
61. Tingbo Hou “ Pressure drop and heat transfer performance of microchannel heat exchangers with elliptical concave cavities” Volume 218, 5 January 2023, 119351, <https://doi.org/10.1016/j.applthermaleng.2022.119351>
62. Zhiwei Chen, Peng Qian, Zizhen Huang, Wenjing Zhang, Minghou Liu“ Study on flow and heat transfer of liquid metal in the microchannel heat sink” Volume 183, January 2023, 107840, <https://doi.org/10.1016/j.ijthermalsci.2022.107840>
63. Majid Khan ^a, S.Z. Shuja ^{a b}, B.S. Yilbas “ A case study on innovative design and assessment of a microchannel heat sink with various turbulators arrangements” Volume 31, March 2022, 101816, <https://doi.org/10.1016/j.csite.2022.101816>



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