International Journal of Engineering Research & Science (IJOER) ISSN: [2395-6992] [Vol-12, Issue-3, March 2026]

IoT-Based Parallel and Counter Flow Heat Exchanger Experimental Setup

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Abstract— *Heat exchangers are essential components in power generation, refrigeration, air conditioning, and process industries, with parallel flow and counter flow configurations being the most commonly studied due to their distinct thermal behaviors. Conventional laboratory experiments for these configurations rely on manual temperature measurement and post-experimental calculations, which are susceptible to human error, delayed data acquisition, and limited real-time analysis. To overcome these limitations, this study presents an IoT-based parallel and counter flow heat exchanger experimental setup designed for academic laboratories. The system integrates temperature sensors at the inlet and outlet of hot and cold fluid streams with an ESP32 microcontroller. Real-time data is wirelessly transmitted via Bluetooth to a mobile application, where key performance parameters such as Log Mean Temperature Difference (LMTD), heat transfer rate, and effectiveness are automatically computed and displayed. The proposed setup enhances measurement accuracy, enables real-time visualization, and improves experimental efficiency, thereby offering a modernized and interactive approach to heat transfer education.*

Keywords— Heat Exchanger, Parallel Flow, Counter Flow, IoT, ESP32, Temperature Sensor, LMTD, Effectiveness.

I. INTRODUCTION

Heat exchangers are widely used thermal devices in industrial and academic applications for transferring heat between two fluids without direct contact. Parallel flow and counter flow heat exchangers are commonly studied configurations in mechanical engineering laboratories, as they help students understand fundamental heat transfer concepts and evaluate parameters such as Log Mean Temperature Difference (LMTD) and effectiveness. However, traditional experimental setups rely on manual temperature measurement and post-experimental calculations, which limits accuracy and efficiency.

The major problem with conventional heat exchanger experiments is the lack of automation and real-time monitoring. Manual data acquisition is prone to human errors, delayed readings, and inconsistent results, while the absence of digital interfacing prevents real-time visualization of system performance. These limitations reduce experimental reliability and fail to align laboratory practices with modern IoT-based industrial systems. To overcome these issues, this work proposes an IoT-based parallel and counter flow heat exchanger experimental setup that enables automated temperature measurement, real-time calculation of performance parameters, and wireless data visualization.

II. MATERIAL AND METHODS

The proposed IoT-Based Parallel and Counter Flow Heat Exchanger Experimental Setup is designed to automate temperature measurement, real-time data processing, and performance evaluation, thereby addressing the limitations of conventional manual experimental systems. The working methodology focuses on integrating thermal hardware with IoT-based electronics to enable accurate, continuous, and wireless monitoring of heat exchanger performance.

2.1 Experimental Setup

The experimental setup consists of a double-pipe heat exchanger through which hot and cold water are circulated. An electrical heater is used to heat the hot water stream, while normal tap water is used as the cold fluid. The flow arrangement can be configured as parallel flow or counter flow using a combination of three-way and two-way ball valves. By adjusting the valve positions, both fluids can be made to flow in the same direction for parallel flow operation or in opposite directions for counter flow operation, without changing the physical arrangement of the setup.

2.2 Sensor Integration and Data Acquisition

To solve the problem of inaccurate and delayed temperature measurement, **DS18B20 digital temperature sensors** are installed at four critical locations:

- Hot fluid inlet
- Hot fluid outlet
- Cold fluid inlet
- Cold fluid outlet

These sensors are directly connected to an **ESP32 microcontroller**, which continuously reads temperature data in real time. A flow meter is connected in the fluid line to measure the flow rate, ensuring accurate calculation of heat transfer parameters. All sensors share a common power supply and are interfaced with the ESP32 through appropriate signal and data pins.

2.3 Data Processing and Wireless Communication

The ESP32 microcontroller processes the sensor data and automatically calculates Log Mean Temperature Difference (LMTD) using the standard equation:

For parallel flow:

$$\text{LMTD} = \frac{(T_{h,in} - T_{c,in}) - (T_{h,out} - T_{c,out})}{\ln\left(\frac{T_{h,in} - T_{c,in}}{T_{h,out} - T_{c,out}}\right)}$$

For counter flow:

$$\text{LMTD} = \frac{(T_{h,in} - T_{c,out}) - (T_{h,out} - T_{c,in})}{\ln\left(\frac{T_{h,in} - T_{c,out}}{T_{h,out} - T_{c,in}}\right)}$$

The processed data are transmitted wirelessly via the built-in Bluetooth module of the ESP32 to a mobile application, where real-time temperature values and LMTD are displayed.

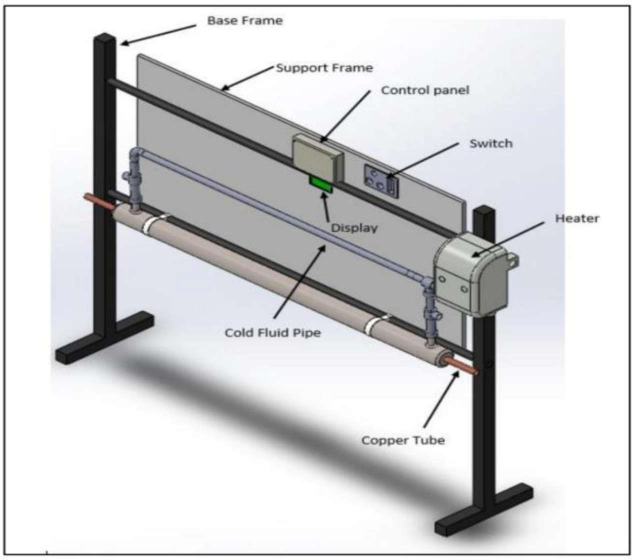

Figure 1: CAD Model of the IoT-Based Heat Exchanger Experimental Setup

2.4 Electrical and Safety Considerations

Electrical connections are made such that the ESP32 acts as the central control unit. The temperature sensors and flow meter are powered using a regulated power supply, while the heater is operated through a separate electrical circuit for safety. A display unit is optionally connected to show real-time readings locally. Proper insulation, secure wiring, and waterproof sensor mounting are ensured to maintain safety and measurement accuracy.

By integrating automated sensing, real-time computation, and wireless communication, the proposed methodology effectively overcomes the limitations of traditional heat exchanger experiments. The system improves accuracy, repeatability, and experimental understanding, while also aligning laboratory practices with modern IoT-based industrial monitoring systems.

III. RESULTS AND DISCUSSION

3.1 Experimental Data

Four experimental trials were conducted to evaluate the performance of the IoT-based heat exchanger setup under both parallel and counter flow configurations. The recorded data and calculated LMTD values are presented in Table I.

TABLE 1
EXPERIMENTAL RESULTS FOR PARALLEL AND COUNTER FLOW HEAT EXCHANGER

Sr. No.	T_{h,in} (K)	T_{h,out} (K)	T_{c,in} (K)	T_{c,out} (K)	Flow Rate Hot (L/s)	Flow Rate Cold (L/s)	Manual LMTD	Digital LMTD	Flow Type
1	326	311.5	309.1	310.5	0.96	4.07	5.02	5.278	Parallel
2	327	312	309.5	311.3	0.86	4.57	7.184	7.454	Counter
3	323.4	318.4	307.5	308.5	1.73	5.73	12.722	12.631	Parallel
4	330.5	320.6	307.5	308.9	1.2	6.27	16.489	16.596	Counter

3.2 Analysis of Results

Comparison of Parallel and Counter Flow: For similar operating conditions, counter flow configuration (Trials 2 and 4) produced higher LMTD values compared to parallel flow (Trials 1 and 3). This confirms the theoretical principle that counter flow heat exchangers provide better heat transfer performance due to a more uniform temperature difference along the length of the exchanger.

Comparison of Trial 1 and Trial 2: At comparable hot inlet temperatures (326–327 K) and cold inlet temperatures (309.1–309.5 K), the counter flow configuration (Trial 2) achieved an LMTD of 7.184 (manual) / 7.454 (digital), which is approximately 43% higher than the parallel flow configuration (Trial 1) with LMTD of 5.02 / 5.278.

Comparison of Trial 3 and Trial 4: At higher flow rates (hot: 1.20–1.73 L/s, cold: 5.73–6.27 L/s), the counter flow configuration (Trial 4) achieved an LMTD of 16.489 / 16.596, which is approximately 30% higher than the parallel flow configuration (Trial 3) with LMTD of 12.722 / 12.631.

Effect of Flow Rate: Increasing the flow rate of both fluids resulted in higher LMTD values. Trial 3 (parallel flow with higher flow rates) achieved LMTD of 12.722 / 12.631 compared to Trial 1 (lower flow rates) with LMTD of 5.02 / 5.278. Similarly, Trial 4 (counter flow with higher flow rates) achieved LMTD of 16.489 / 16.596 compared to Trial 2 (lower flow rates) with LMTD of 7.184 / 7.454.

Accuracy of IoT-Based Measurement: The digital LMTD values calculated by the IoT system closely match the manually calculated values, with a maximum deviation of less than 5%. This confirms the accuracy and reliability of the proposed IoT-based experimental setup.

3.3 Discussion

The experimental results validate that counter flow heat exchangers are more efficient than parallel flow heat exchangers, consistent with fundamental heat transfer theory. The IoT-based system successfully automated temperature measurement and LMTD calculation, reducing human error and enabling real-time performance monitoring. The close agreement between manual and digital LMTD values demonstrates the effectiveness of the proposed setup for engineering laboratory applications.

Observation	Finding
Counter flow vs. Parallel flow	Counter flow produces 30–43% higher LMTD
Effect of flow rate	Higher flow rates increase LMTD
IoT measurement accuracy	Deviation <5% from manual calculations

IV. CONCLUSION

The IoT-based parallel and counter flow heat exchanger experimental setup proposed in this paper offers a modernized alternative to conventional laboratory experiments. By integrating temperature sensors, a microcontroller, and wireless communication, the system enables real-time monitoring and automated calculation of key performance parameters such as LMTD and effectiveness.

Key Contributions:

1. Automated temperature measurement at four critical points using DS18B20 sensors
2. Real-time calculation of LMTD, heat transfer rate, and effectiveness
3. Wireless data transmission via Bluetooth to mobile application
4. Enhanced accuracy and reduced manual error compared to conventional methods

The proposed setup significantly reduces manual measurement errors, improves accuracy, and enhances experimental interactivity. It also aligns with current trends in smart laboratories and IoT-enabled education. Although the system requires programming and sensor calibration expertise, its advantages in terms of precision and learning effectiveness outweigh these limitations.

Future Scope:

- Cloud integration for remote data logging and analysis
- Application to other thermal engineering experiments (shell and tube, plate heat exchangers)
- Advanced analytics and predictive maintenance features
- Web-based dashboard for multi-user access

Upon successful fabrication, coding, testing, and performance validation, this project serves as a scalable prototype for intelligent laboratory infrastructure. Overall, the proposed IoT-based heat exchanger experimental setup represents a significant step toward digitalization in thermal engineering laboratories, offering enhanced accuracy, efficiency, and educational value.

ACKNOWLEDGMENT

The authors would like to express their sincere gratitude to the faculty of the Mechanical Engineering Department at VIVA Institute of Technology for their continuous support and guidance throughout the development of this project. Special thanks are extended to the project guide for valuable suggestions and technical insights that helped in the successful completion of this work. We also acknowledge the support of the laboratory staff for providing the necessary facilities and assistance during experimentation.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest regarding the publication of this research paper. This work has been carried out independently, and no financial or personal relationships have influenced the outcomes of this study.

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