ISSN (Online) 2456-1290
International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE)
Vol 11, Issue 5, May 2024

IoT-BASED Performance and Monitoring of Counter Flow and Parallel Flow of Double Pipe Heat Exchangers

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Abstract— ***The main objective of this work focused on developing a multi-user remote system that utilizes IoT technology with a Raspberry Pi microcontroller. In specific, IoT-based monitoring is applied to the double-pipe heat exchanger, a thermal device. The heat exchanger is a device in which the transfer of heat takes place from one high-temperature fluid to another low-temperature fluid. Monitoring the performance of such heat exchangers using networking is a trending research area for heat exchanger-based researchers. Heat exchanger assembly consists of two inputs a hot hot-water inlet (T1) and a cold-water inlet (T3). Two outputs such as the hot water outlet (T2) and the cold-water outlet (T4). The IoT system proposed in this study can identify deviation of such input and output parameters from normal operating values. It can also monitor heat exchanger performance via inaccessible (private) firmware running on the cloud.***

Keywords: Raspberry Pi, Arduino uno board, IoT, heat exchanger, python, embedded.

I. INTRODUCTION

The Internet of Things (IoT) is a network of hardware devices embedded with electronics, software, sensors, actuators, and connectivity that enables these things to connect, collect, and exchange data. The advantages of IoT include easy tracking of quality, reduced time spent on monitoring, easy decision-making, and flexible operations. IoT applications include smart homes, industrial automation, agriculture, healthcare, smart cities, logistics and supply chains, and energy management.

A double-pipe heat exchanger is a promising industrial thermal device that uses IoT to monitor and control various devices. There are two types of double-pipe heat exchangers: parallel flow and counterflow. Parallel flow allows both hot and cold fluids to flow in the same direction, while counterflow maximizes the temperature difference. Both configurations offer flexibility in terms of design and construction.

In summary, IoT is a crucial tool for various industries, including smart homes, industrial automation, agriculture, healthcare, urban environments, logistics and supply chain, and energy management.

Double pipe heat exchangers are versatile devices used in various industries, including HVAC systems, chemical and food industries, oil and gas, pharmaceuticals, and wastewater treatment. They have a compact design, offering high heat transfer efficiency due to their concentric tube arrangement. They are flexible, allowing for customization and modification to meet specific process requirements. The counterflow configuration maximizes the temperature difference, resulting in more efficient heat transfer. Double pipe heat exchangers are often more cost-effective due to their simple design, easy installation, and use of standard materials. They are also easy to maintain, with the inner pipe easily removed for cleaning or replacement without disrupting the system. They are commonly used in HVAC systems, chemical and food industries, oil and gas industries, pharmaceuticals, and wastewater treatment plants. A proposed IoT-based monitoring system can identify, sensing, computing, and networking process parameters associated with heat exchanger operations.

Figure 1: double pipe heat exchanger setup.

Table 1. Double Pipe Heat Exchanger system operating conditions

Sensor Type	Parameter	Location	Permissible range
Temperature sensor 1	T1	Hot inlet	$50C^0 – 70C^0$
Temperature sensor 2	T2	Hot outlet	$29C^0 – 34C^0$
Temperature sensor 3	T3	Cold Inlet	$25C^0 – 30C^0$
Temperature sensor 4	T4	Cold outlet	$30C^0 – 35C^0$
Flow sensor 1	M1	Hot Outlet	1Kg/min-6Kg/min
Flow sensor 2	M2	Cold Outlet	1Kg/min-6Kg/min

II. GENERAL SPECIFICATIONS

The Internet of Things (IoT) is the network of hardware devices embedded with electronics, software, sensors, actuators, and connectivity which enables these things to connect, collect, and exchange data. The system is shown above in a diagram in Figure 2.

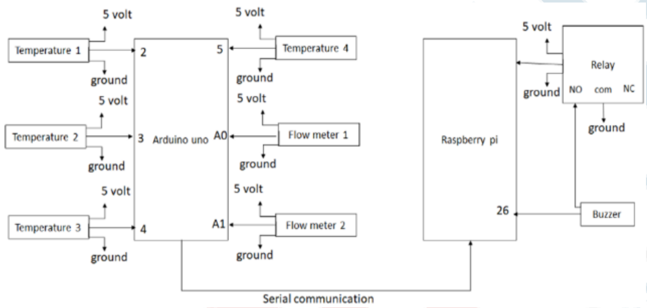

Figure 2: Iot system connection for dphe

The equations used for calculating the heat transfer for both hot and cold fluid are as follows

$Q_h = m_h * C_{ph} * (T_1 – T_2)$ (1)

$Q_c = m_c * C_{pc} * (T_3 – T_4)$ (2)

Table.2 Hardware components used in the IoT-based heat exchanger system

S.no	Name of the components	Specifications	Requirements
1	Raspberry PI 3(model B)	Quad Core 1.2GHz	1
2	One wire temperature sensor ds18b20	55°C to +125°C (-67°F to +257°F)	4
3	Mass flow sensor	Robodo 1/2" Water Flow Hall Sensor	2
4	Power supply	22.5W power brick	1
5	Arduino-Uno microcontroller	ATmega328P	1
6	PCB board	150mm	1
7	Voltage regulator	5V - 12V (input), 1.27 - 10 V (output) at up to 5A	1
9	Jumper wires,	150mm	1
10	Resistors	10 Ohm	4
11	Keyboard	Wired keyboard	1
12	Mouse	2.4Ghz wireless	1
13	Display	Hp 24inch	1
14	Buzzer	3-12V	1

III. FIGURES

The following graphs are plotted between the temperature and time length for different cases-

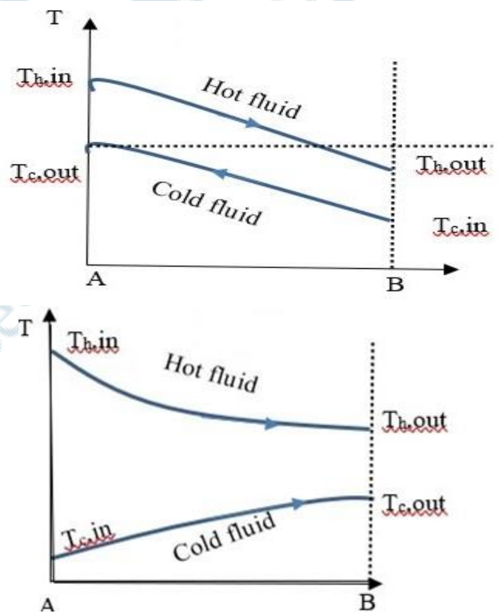

Figure 3: For a plain DPHE with for parallel and counter flow

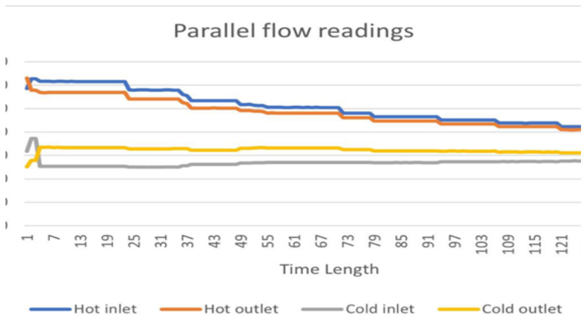

Figure 4. For DPHE integrated with IoT sensors for parallel flow

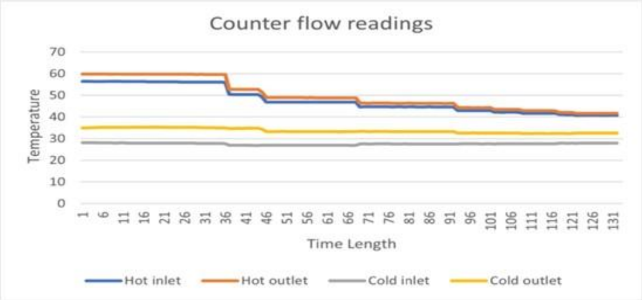

Figure 7. For DPHE integrated with IoT sensors for counterflow

Figure 5. DPHE Setup integrated with IoT

Figure 6. DPHE Setup

IV. RESULTS AND SUMMARY

This section assesses the dependability and efficiency of the heat exchange process inside a heat exchanger using Internet of Things concepts. Four temperature and two mass flow rate data were obtained from the experimental setup and fetched into the cloud. The front-end SCADA system provides information when the mass flow rate and temperature exceed the required operating conditions, as indicated in Table 1. The server is run via Python script code at varying intervals. These programs run an assignment on the file extension to download the revised file after updating and authenticating the server. In this paper, a novel IoT-based monitoring system for DPHE was designed. Such a system was successfully installed at the PMR laboratory at PES University, Bangalore, India. This IoT system was found to more efficient and accurate method to monitor the DPHE with parallel flow. It was observed that the effectiveness of a DPHE that was integrated with IoT sensors was more as compared to the other cases. Some of the features of the newly designed system are

a. The data can be easily stored and analyzed
b. It is simple and flexible
c. Remote monitoring of the system is possible.

Nomenclature

T1 - Hot water inlet temperature (°C)
T2 - Hot water outlet temperature (°C)
T3 - Cold water inlet temperature (°C)
T4 - Cold water outlet temperature (°C)
mh - Mass flow rate of Hot fluid (Kg/min)
mc - Mass flow rate of Cold fluid (Kg/min)
C_{ph} - Specific heat capacity of hot fluid (J/K)
C_{pc} - Specific heat capacity of Cold fluid (J/K)
Qh - Heat transfer rate of hot fluid (W)
Qc - Heat transfer rate of cold fluid (W)

Abbreviations

DPHE - Double Pipe Heat Exchanger
IoT - Internet of Things
SCADA - Supervisory control and data acquisition

V. CONCLUSION

The DPHE setup that was used for this study had a temperature range of 30 °C to 70 °C, and a mass flow rate range of 1 kg/min to 6 kg/min . With the given permissible ranges, the proposed DPHE can be used for the following applications.

Application Industry	Permissible Temperature Range(°C)	Permissible Mass flow rate Range (Kg/sec)
Domestic Water Heating Systems	40 °C – 70 °C	0.05 – 5 Kg/sec
Power Plants (Condensers)	30 °C – 45 °C	Varies with plant Capacity
Brewing and Beverage Production	Up to 30 °C	0.1 – 1 Kg/sec

As a part of future work, another IoT unit can be added to the system that consists of actuators to control the motors and implement Data Analytics.

Controllers:

- A microcontroller or programmable logic controller (PLC) collects data from all the sensors.
- The controller compares the collected data with predefined set points for temperature, flow rate, and pressure.

ISSN (Online) 2456-1290

International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE)

Vol 11, Issue 5, May 2024

- Based on the comparison, the controller sends signals to the actuators to adjust the heat transfer rate.

Actuators:

- Valves control the flow rate of each fluid by opening or closing partially.
- Variable speed pumps can adjust the flow rate of each fluid.

Data collected from Raspberry Pi 3 (counter flow)

DATE & TIME	ENTRY ID	T - 1	T - 2	T - 3	T - 4	m - 1	m - 2
2023-11-30T1 5:53:14+05:30	862	43.75	42.31	27.44	31.5	21.98	4.53
2023-11-30T1 5:53:44+05:30	863	43.81	42.31	27.44	31.5	4.44	4.32
2023-11-30T1 5:54:11+05:30	864	43.81	42.31	27.44	31.5	17.15	4.23
2023-11-30T1 5:54:41+05:30	865	43.81	42.25	27.38	31.5	17.61	4.24
2023-11-30T1 5:55:09+05:30	866	43.81	42.25	27.44	31.44	17.61	4.4
2023-11-30T1 5:55:27+05:30	867	43.81	42.31	27.44	31.5	4.45	4.35
2023-11-30T1 5:55:56+05:30	868	43.81	42.25	27.44	31.44	6.88	4.42

Data collected from Raspberry Pi 3 (Parallel flow)

DATE & TIME	ENTRY ID	T - 1	T - 2	T - 3	T - 4	m - 1	m - 2
2023-11-30T15 :57:15+05:30	871	42.38	41	27.63	31.13	7.48	4.28
2023-11-30T15 :57:46+05:30	872	42.31	40.94	27.63	31.13	8.48	4.2
2023-11-30T15 :58:02+05:30	873	42.31	40.94	27.69	31.13	8.48	4.35
2023-11-30T15 :58:20+05:30	874	42.31	41	27.63	31.13	8.48	4.34
2023-11-30T15 :58:51+05:30	875	42.31	41	27.69	31.13	9.82	4.35
2023-11-30T15 :59:20+05:30	876	42.31	41	27.63	31.13	10.95	4.28

Graphs drawn from the data collected from Raspberry Pi 3

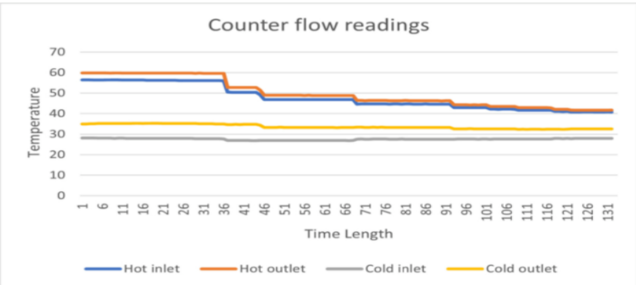

Fig : Temperature vs Time graph for counter flow in DPHE

Graphs drawn from the data collected from Raspberry Pi 3

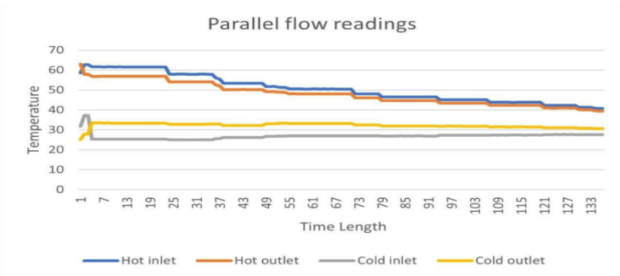

Fig : Temperature vs Time graph for parallel flow in DPHE

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