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Impact of Water Mass Flow Rate and Refrigerant Inlet Temperature on LMTD and Heat Transfer in Shell-and-Tube Heat Exchangers for Heat Pumps Using R407C

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***Abstract* - This paper presents an experimental investigation into the heat transfer performance of a shell-and-tube heat exchanger using refrigerant R407C. The study focuses on the Log Mean Temperature Difference (LMTD) and heat transfer rate at varying mass flow rates and refrigerant temperatures. The results show that the rate of heat transfer increases as the mass flow rate increases, with a range of 8.78 kW to 10.72 kW as the mass flow rate changes from 0.08 kg/s to 0.1 kg/s. The increase in heat transfer rate is between 13.6% to 17.8%, with the highest observed at 82°C. The LMTD also increases with rising refrigerant temperature, ranging from 22.98°C to 26.87°C, with the highest value recorded at 84°C. These findings highlight the relationship between mass flow rate, refrigerant temperature, and heat transfer efficiency, offering valuable insights for optimizing heat pump system performance.**

Keywords: Heat pump, Refrigerants, Heat Transfer Rate, Log Mean Temperature Difference (LMTD), Shell-and-Tube Heat Exchanger.

I. INTRODUCTION

Heat pumps are essential in various thermal systems for heating and cooling applications, relying on the refrigeration cycle to transfer heat. This cycle involves four key processes: compression, condensation, expansion, and evaporation, with refrigerants facilitating heat absorption and release. The performance of heat pumps significantly depends on the efficiency of the heat exchangers, particularly the condensers, which play a crucial role in thermal energy transfer. The Log Mean Temperature Difference (LMTD) is a critical parameter in evaluating heat exchanger efficiency, accounting for temperature variations along its length. This paper investigates the heat transfer performance of a shell-and-tube heat exchanger, focusing on refrigerant R407C. The goal is to understand how different mass flow rates and refrigerant temperatures affect LMTD and heat transfer rates, offering insights for optimizing the heat pump's operation.

1.1 Basic Heat Pump Cycle

The basic principle of a heat pump is based on the thermodynamic concept of the refrigeration cycle. The cycle consists of four processes: compression, condensation, expansion, and evaporation. The refrigerant, which is a substance that can absorb and release heat, circulates through a closed loop system, and undergoes these processes to move heat from one location to another. [1- 3].

II. EXPERIMENTAL SET-UP

Figure 1: Experimental set up of heat pump

2.1 Apparatus

The experimental apparatus is shown in Figure1. The system is a heat pump composed of the following main parts: compressor, evaporator, condenser, expansion valve. Miscellaneous equipment is added, including Temperature-

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and pressure-measuring instruments are attached to the system. Also fitted are the heat source and heat sink units,

The condenser is a shell and tube type heat exchanger of area of 0.785 m^2 is used for experimentation [6,10].

III. CALCULATIONS

The following equations were used to calculate different parameters to analyze the performance of the refrigerants.

3.1 LMTD (Log Mean Temperature Difference)

Logarithmic Mean Temperature Difference (LMTD) is a crucial parameter in analyzing and designing heat exchangers [11], including condensers in heat pump systems. It calculates the average temperature difference between the hot and cold fluids across the heat exchanger, accounting for temperature variations along its length. This approach ensures accurate estimation of heat transfer rates, vital for the efficient operation of condensers in heat pumps.

$$LMTD = \frac{(\theta_1 - \theta_2)}{\ln(\theta_1/\theta_2)} \quad (1)$$

$\theta_1 = Th_1 - Tc_2$
$\theta_2 = Th_2 - Tc_1$

3.2 Rate of heat exchanged in a heat exchanger (Q)

$$Q = M_w * C_{pw} * (T_{c2} - T_{c1}) \quad (2)$$

Th_1= Refrigerant inlet temperature in ° C
Th_2= Refrigerant outlet temperature in ° C
Tc_1= Water inlet temperature in ° C
Tc_2= Water outlet temperature in ° C
M_w= Mass flow rate of water in kg/s
C_{pw} = specific heat of water in kJ/kg °C

The results of experiments conducted with a shell-and-tube type heat exchanger (area = 0.785 m^2) are shown below in Table- 1.

Table 1: Experimental values for AREA =0.785m^2

	407C		
Mw (kg/s)	Refrigerant temperature (°C)	LMTD (°C)	Q (kW)
0.08	81	22.98	8.78
0.085	81	23.32	9.04
0.09	81	23.41	9.50
0.095	81	23.66	9.79
0.1	81	24.00	9.97
0.08	82	24.13	9.11
0.085	82	24.35	9.50
0.09	82	24.40	10.02
0.095	82	24.75	10.26
0.1	82	24.93	10.63
0.08	83	25.14	9.11
0.085	83	25.41	9.47
0.09	83	25.63	9.84
0.095	83	25.94	10.10
0.1	83	26.03	10.55
0.08	84	25.70	9.45
0.085	84	26.15	9.68
0.09	84	26.33	10.10
0.095	84	26.51	10.50
0.1	84	26.87	10.72

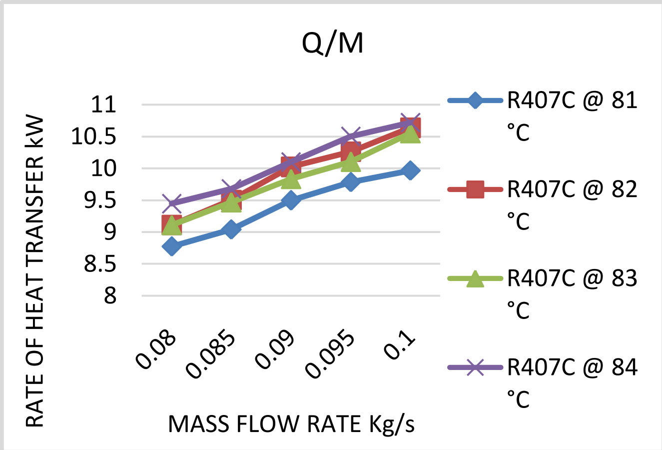

Figure 2: Rate of Heat Transfer for different mass flow rate for R407C

Figure 2 represents the relationship between the mass flow rate (kg/s) and the rate of heat transfer (kW) for the refrigerant R407C at different temperatures (81°C, 82°C, 83°C, and 84°C). The rate of heat transfer increases as the mass flow rate increases for all temperatures. Higher temperatures result in higher heat transfer rates. The rate of heat transfer increases by 13.6% to 17.8% as the mass flow rate increases from 0.08 kg/s to 0.1 kg/s. The most significant increase (17.8%) is observed at 82°C [12,13].

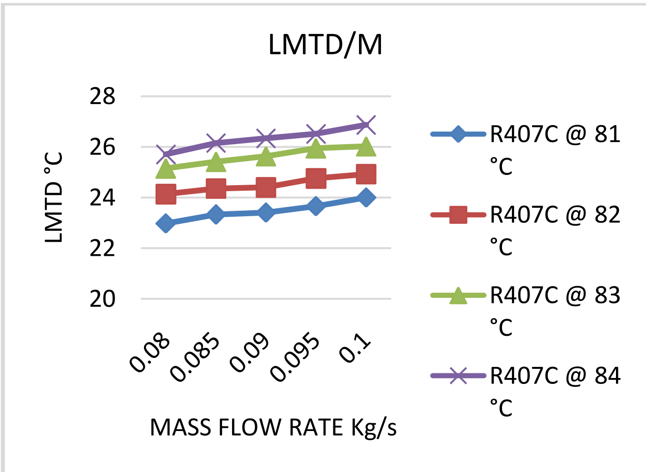

Figure 3: LMTD for different mass flow rate for R407C

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Figure 3 illustrates the Log Mean Temperature Difference (LMTD) in °C against the mass flow rate (kg/s) for R407C at different temperatures (81°C, 82°C, 83°C, and 84°C). As the refrigerant temperature rises from 81°C to 84°C, the LMTD values increase. The highest LMTD is observed for R407C at 84°C, and the lowest for R407C at 81°C. Higher refrigerant temperature results in higher LMTD, improving heat transfer efficiency. Increasing mass flow rate leads to a slight increase in LMTD, but the effect is less significant compared to temperature changes [12,13].

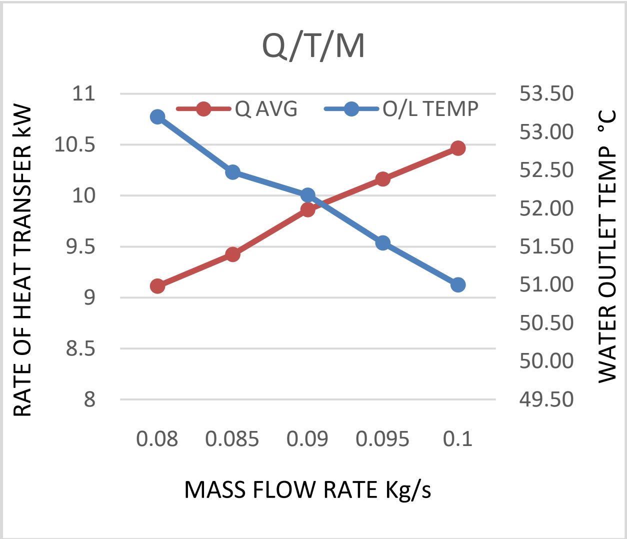

Figure 4: Rate of Heat Transfer and outlet temperature of water for different mass flow rate for R407C

Figure 4 represents the relationship between mass flow rate (kg/s), rate of heat transfer (kW) and water out let temperature (°C). As the mass flow rate increases from 0.08 kg/s to 0.1 kg/s, the heat transfer rate (Q AVG) increases. This is expected because a higher mass flow rate allows more heat to be transferred efficiently. The outlet water temperature decreases as the mass flow rate increases. This happens because, at higher mass flow rates, the water spends less time in the heat exchanger, reducing the temperature gain per unit mass. At 0.09 kg/s, both parameters have similar values, indicating a balance point where the heat transfer rate and outlet temperature are optimized [12,13].

IV. CONCLUSION

The experimental results confirm that both mass flow rate and refrigerant temperature significantly influence the heat transfer performance in a shell-and-tube heat exchanger using R407C. As the mass flow rate increased from 0.08 kg/s to 0.1 kg/s, the rate of heat transfer (Q) improved, ranging from 8.78 kW to 10.72 kW, with a percentage increase in heat transfer rate of 13.6% to 17.8%. The largest increase (17.8%) was observed at a refrigerant temperature of 82°C. In terms of LMTD, the values ranged from 22.98°C at 81°C to 26.87°C at 84°C, demonstrating a consistent increase in LMTD with a rising refrigerant temperature. At higher refrigerant temperatures, the efficiency of heat transfer improved. Additionally, the outlet water temperature decreased as the mass flow rate increased. At 0.08 kg/s, the outlet temperature was 24.00°C, while at 0.1 kg/s, it dropped to 26.87°C, indicating the trade-off between the heat transfer rate and temperature gain. Overall, these findings underscore the importance of optimizing operational parameters, such as refrigerant temperature and mass flow rate, to maximize the efficiency of heat pump systems.

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