Performance Enhancement of Heat Pumps Through Selection of Refrigerants R134A and R410A in Shell-and-Tube Condenser

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Abstract:- This experimental study evaluates the performance of a Shell-and-Tube heat exchanger using refrigerants R134A and R410A, emphasizing the heat transfer rate and Log Mean Temperature Difference (LMTD). The experiments were conducted using a heat pump system featuring a condenser area of 0.785 m², at varying water mass flow rates (0.08 to 0.1 kg/s). Results indicated that both refrigerants exhibited increased heat transfer rates and LMTD values with rising mass flow rates. Specifically, R410A showed a heat transfer rate increase from approximately 10.46 kW to 11.32 kW (6.7%), while R134A demonstrated an increase from 9.71 kW to 10.53 kW (5.1%). LMTD values increased from 25.67°C to 27.45°C for R410A (6.7%) and from 24.17°C to 25.72°C for R134A (7.1%). R410A consistently outperformed R134A across all tested conditions, achieving maximum differences of 0.8 kW in heat transfer and 1.5°C in LMTD at the highest mass flow rate (0.1 kg/s). Thus, R410A is recommended for superior performance in Shell-and-Tube condenser applications.

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

1. Introduction

A heat pump system is a mechanical device that transfers heat from one location to another using electricity. It is an efficient way of heating and cooling homes, businesses, and other buildings. The system works by moving heat from a colder location to a warmer one, which requires less energy than creating heat from scratch. Heat pump systems have been used for many years, and with technological advancements, they have become even more efficient and cost-effective. During the heating season, the heat pump absorbs heat from the outside air or ground, and the refrigerant carries this heat indoors. In the summer, the heat pump reverses the cycle, and the refrigerant absorbs heat from indoors and rel)eases it outdoors, effectively cooling the space. This process is known as air conditioning.

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].

2. Experimental Set-up

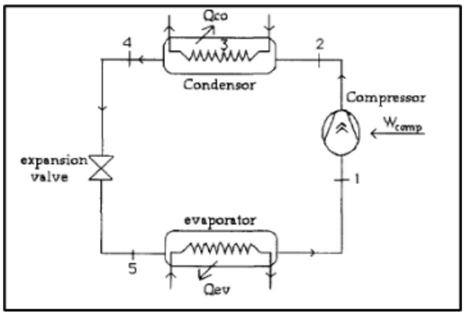

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Figure-1: Schematic diagram of Heat pump Figure-2: Experimental set up of heat pump

2.1 Apparatus

The experimental apparatus is shown in Figure 2. The system is a heat pump composed of the following main parts: compressor, evaporator, condenser, expansion valve. Miscellaneous equipment is added, including Temperature- 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 m2 is used for experimentation [6, 10].

3. 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.

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

θ_1= Th1-Tc2

θ_2= Th2-Tc1

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

$$Q=Mw*Cpw*(Tc2-Tc1) \quad (2)$$

Th1= Refrigerant inlet temperature in ° C

Th2= Refrigerant outlet temperature in ° C

Tc1= Water inlet temperature in ° C

Tc2= Water outlet temperature in ° C

Mw= Mass flow rate of water in kg/s

Cpw = specific heat of water in kJ/kg °C

4. Results and discussion

The results of experiments conducted with a shell-and-tube type heat exchanger (area = 0.785 m2) are shown below in Table- 1.

Table 1: Experimental values for AREA =0.785m2

	R134a			R410A		
Mw (kg/s)	**Refrigerant inlet temperature (°C)**	**LMTD (°C)**	**Q (kW)**	**Refrigerant inlet temperature (°C)**	**LMTD (°C)**	**Q (kW)**
0.08	86	19.68893	9.31	87	20.46955	9.91
0.085	86	20.02846	9.54	87	20.75328	10.25
0.09	86	20.29792	9.80	87	21.10497	10.48
0.095	86	20.69865	9.86	87	21.59203	10.50
0.1	86	21.02954	9.97	87	21.79896	10.80
0.08	87	20.22691	9.65	88	21.29768	10.42
0.085	87	20.53818	9.93	88	21.59213	10.78
0.09	87	20.84694	10.17	88	22.02956	10.97
0.095	87	21.11937	10.42	88	22.49795	11.06
0.1	87	21.52456	10.47	88	22.85456	11.22
0.08	88	20.89435	9.85	90	22.38288	10.55
0.085	88	21.24475	10.11	90	22.64057	10.96
0.09	88	21.66112	10.25	90	23.04214	11.19
0.095	88	21.90203	10.54	90	23.54756	11.26
0.1	88	22.27776	10.63	90	23.94044	11.39
0.08	90	21.38403	10.05	92	23.13446	10.99
0.085	90	21.79896	10.25	92	23.46808	11.35
0.09	90	22.14152	10.48	92	23.87216	11.61
0.095	90	22.34571	10.82	92	24.23614	11.85
0.1	90	22.61644	11.05	92	24.74058	11.89

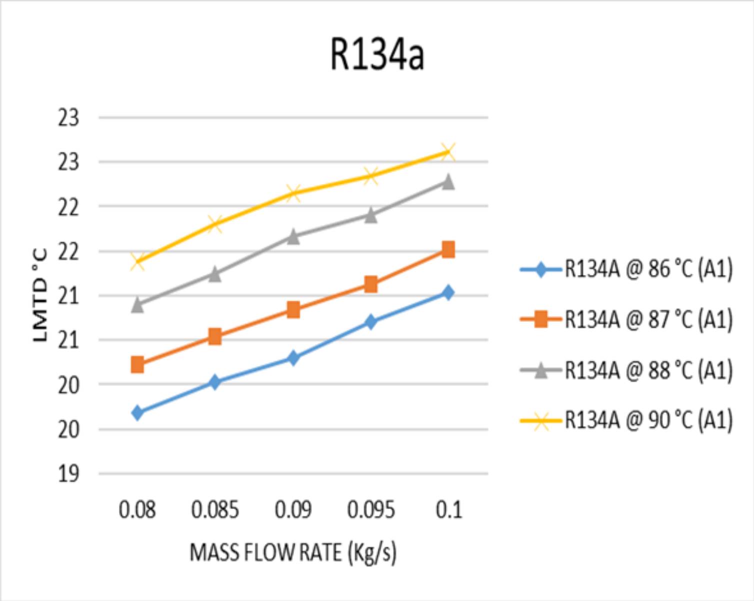

Figure-3: Rate of Heat Transfer for different mass flow rate for R134A

Figure 3 shows depicts the variation in heat transfer rate (kW) with mass flow rate (kg/s) for the refrigerant R134A at different temperatures (86°C, 87°C, 88°C, and 90°C).The heat transfer rate increases as the mass flow rate rises for all temperature conditions. Higher condenser temperatures contribute to improved heat transfer efficiency. The heat transfer rate increases by 5.3% to 8.8% as the mass flow rate rises from 0.08 kg/s to 0.1 kg/s. The highest percentage increase, 8.8%, is observed at 90°C [12,13].

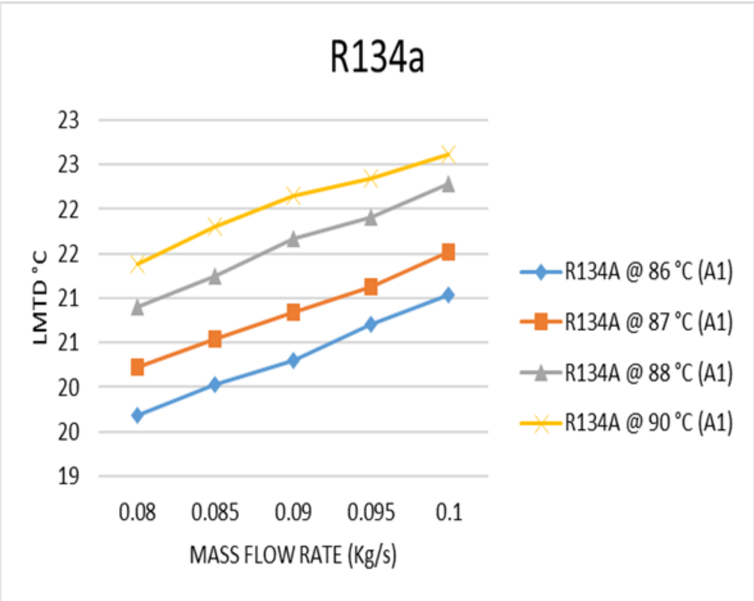

Figure-4: LMTD for different mass flow rate for R134A

Figure 4 presents the Log Mean Temperature Difference (LMTD in °C) against the mass flow rate (kg/s) for R134A at different temperatures (86°C, 87°C, 88°C, and 90°C). Higher refrigerant temperatures result in a higher LMTD.R134A at 90°C has the highest LMTD, while R134A at 86°C has the lowest. Higher refrigerant temperature significantly increases LMTD, leading to improved heat transfer efficiency. Mass flow rate has a minor effect on LMTD compared to temperature changes [12,13].

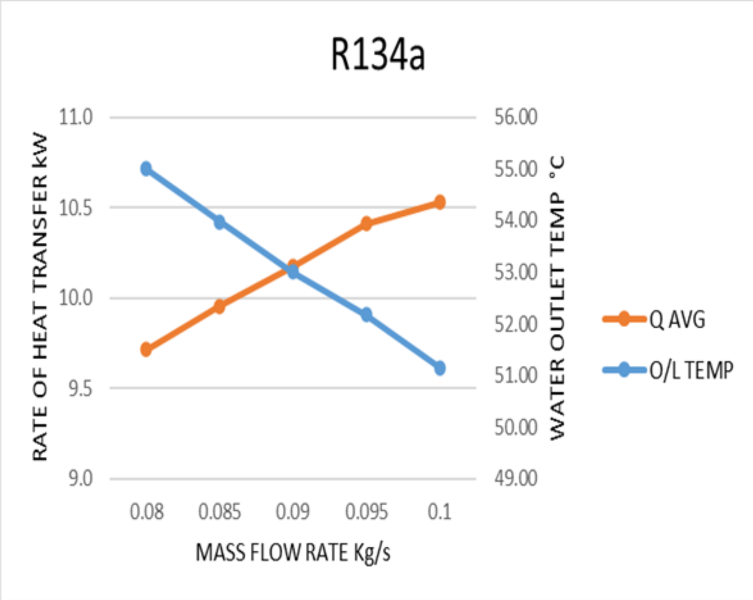

Figure-5: Rate of Heat Transfer and outlet temperature of water for different mass flow rate for R134A

Figure 5 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].

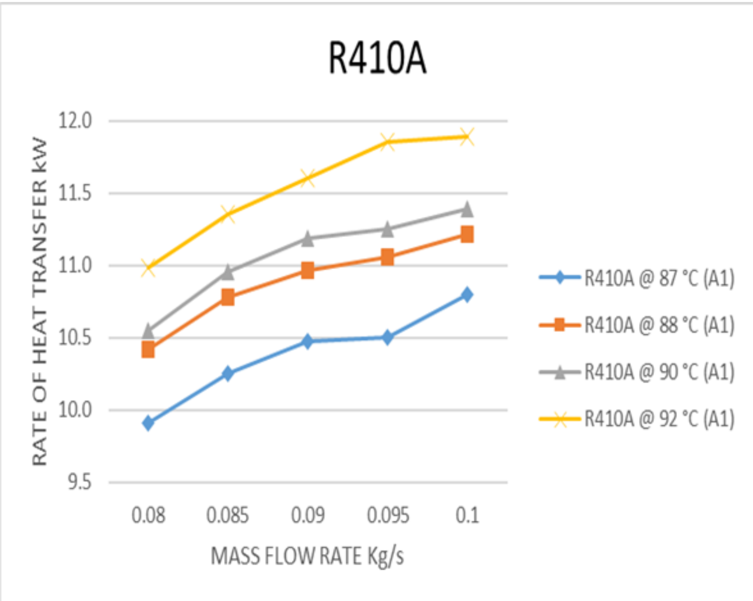

Figure-6: Heat transfer for different mass flow rate for R410A

Figure 6 shows the relationship between mass flow rate (kg/s) and heat transfer rate (kW) for the refrigerant R410A at various condenser temperatures (87°C, 88°C, 90°C, and 92°C).The heat transfer rate increases as the mass flow rate rises across all temperature levels. Higher condenser temperatures result in a greater heat transfer rate. The heat transfer rate increases by 10.5% to 13.0% as the mass flow rate rises from 0.08 kg/s to 0.1 kg/s. The most considerable improvement, 13.0%, is observed at 87°C [12,13,15].

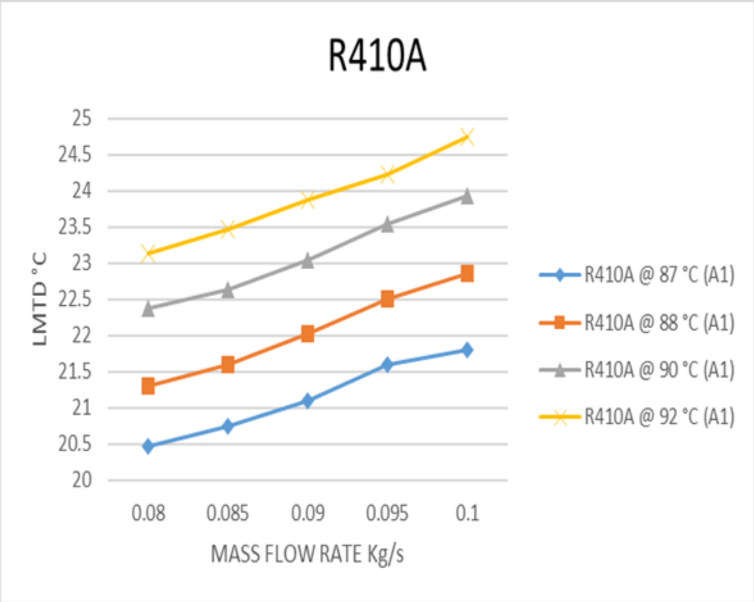

Figure-7: LMTD for different mass flow rate for R410A

Figure 7 illustrates the Log Mean Temperature Difference (LMTD) in °C against the mass flow rate (kg/s) for R410A at different temperatures (87°C, 88°C, 90°C, and 92°C).As the refrigerant temperature rises from 87°C to 92°C, the LMTD values increase.The highest LMTD is observed for R410A at 92°C, and the lowest for R410A at 87°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 [12,13,17,18].

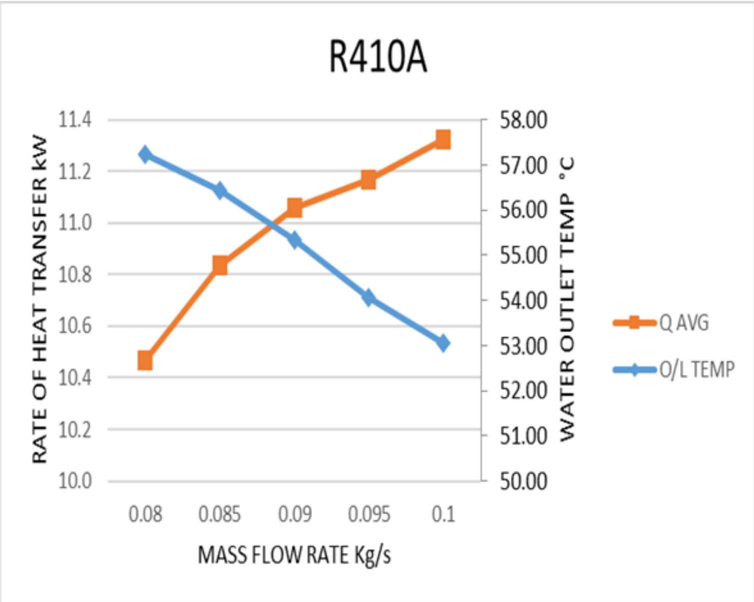

Figure-8: Rate of Heat Transfer and outlet temperature of water for different mass flow rate for R410A

Figure 8 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 [12,15,17,18].

Table 2: Average values LMTD and Rate of Heat Transfer for R407C, R134A and R410A

Mw	T_{c2} °C	LMTD °C	Q avg (kW)
R134A			
0.08	55	24.175	9.71384
0.085	53.975	24.591	9.956163
0.09	53	24.985	10.17441
0.095	52.175	25.313	10.4115
0.1	51.15	25.720	10.53031
R410A			
0.08	57.25	25.672	10.4675
0.085	56.45	26.016	10.837
0.09	55.35	26.485	11.05996
0.095	54.075	27.022	11.16725
0.1	53.05	27.451	11.32584

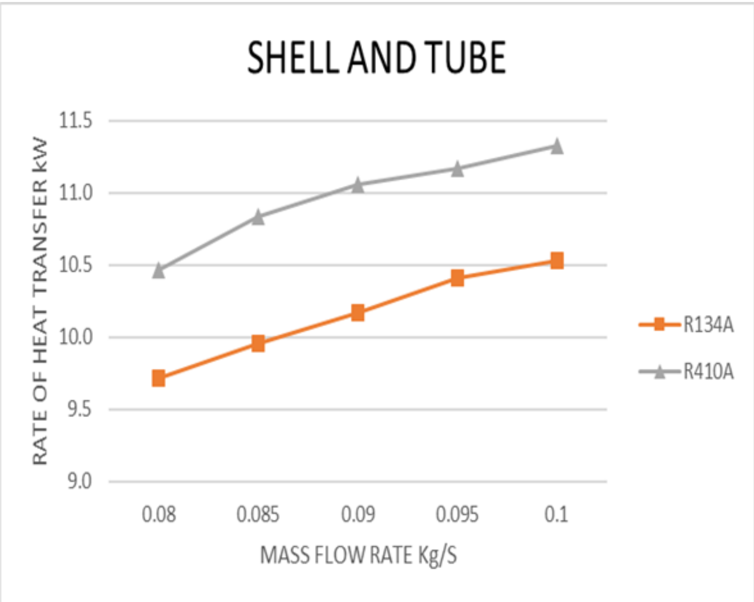

Figure-9: Comparison of average Rate of Heat Transfer for different mass flow rate

Figure 9 illustrates the relationship between mass flow rate and heat transfer rate for refrigerants R134A and R410A in a Shell and Tube condenser. It is observed that both refrigerants exhibit an increasing trend in heat transfer rate as the mass flow rate rises from 0.08 kg/s to 0.1 kg/s. Specifically, the heat transfer rate for R134A increases gradually from about 9.71 kW to 10.53 kW, marking an increase of around 5.1%. Meanwhile, R410A demonstrates a similar upward trend but with higher values, rising from roughly 10.46 kW to 11.32 kW, which corresponds to an approximate increase of 6.7%. Notably, R410A consistently delivers higher heat transfer rates compared to R134A at all measured mass flow rates, with the most significant difference of approximately 0.8 kW (around 8.7%) at the maximum mass flow rate of 0.1 kg/s. This clearly highlights the superior thermal performance of R410A in Shell and Tube condenser configurations relative to R134A [17-18].

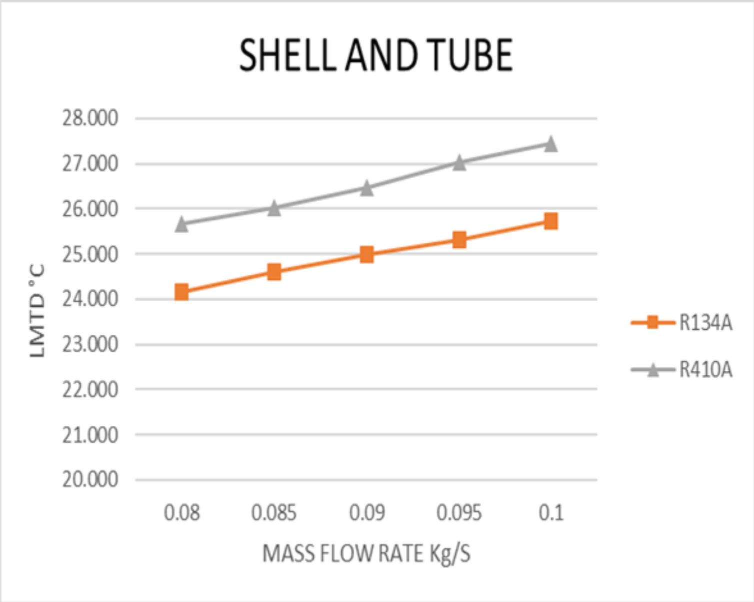

Figure- 10: Comparison of average LMTD for different mass flow rate

Figure 10 illustrates the variation of Log Mean Temperature Difference (LMTD) with respect to mass flow rate for refrigerants R134A and R410A in a Shell and Tube condenser. Both refrigerants exhibit an upward trend in LMTD values as mass flow rate increases from 0.08 kg/s to 0.1 kg/s. Specifically, R134A shows a gradual rise from 24.17°C to around 25.72°C, representing an increase of approximately 7.1%. Similarly, R410A demonstrates a steady increase in LMTD from 25.67°C to 27.45°C, which corresponds to an increase of approximately 6.7%. Notably, R410A consistently maintains higher LMTD values compared to R134A across all tested mass flow rates, with the maximum difference being approximately 1.5°C observed at the highest mass flow rate of 0.1 kg/s. This observation emphasizes the superior heat transfer performance of R410A in the Shell and Tube condenser configuration compared to R134A [17-18].

5. Conclusions

The experimental analysis conducted on a Shell-and-Tube condenser with refrigerants R134A and R410A revealed critical insights regarding their thermal performance characteristics. Both refrigerants showed improved heat transfer rates and LMTD with increasing mass flow rates, underscoring the effectiveness of higher mass flow rates for enhancing heat exchange. However, R410A consistently exhibited superior performance compared to R134A, with maximum heat transfer and LMTD values reaching 11.32 kW and 27.45°C, respectively, at a mass flow rate of 0.1 kg/s. This represented performance advantages of about 8.7% in heat transfer and 1.5°C in LMTD over R134A. Consequently, the findings suggest R410A as a more effective refrigerant choice for Shell-and-Tube heat exchangers due to its higher thermal efficiency and heat transfer capability.

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