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ABSTRACT

Due to environmental concerns, refrigerants with a low global warming impact are gaining importance in the refrigeration industry. Refrigerant R1234yf has a low global warming potential of 4, compared to 1430 for R134a, and has thermodynamic properties similar to R134a, making it a desirable choice for future automotive refrigerants. R1234yf has a significant potential to be a drop-in replacement for R134a in the near future. Additionally, R410A is another commonly used refrigerant, and comparisons can be made between R1234yf and R410A to determine whether R1234yf has any drop-in potential for systems designed for R410A. Comparisons are made between R1234yf, R134a, and R410A, and simulations are conducted to determine the feasibility of using R1234yf as a replacement for R134a or R410A. This paper will present a comparison between the thermophysical properties of R1234yf and R134a and R410A, and will present the results of simulations using the three refrigerants in tube-fin and microchannel heat exchangers.

1. INTRODUCTION

For the past several decades, refrigerants with high global warming potentials have been used as refrigerants in a variety of applications. In 1987, the Montreal Protocol (UNEP, 1987) established that such refrigerants with a high global warming potential were deteriorating the ozone layer, and proposed the replacement of such refrigerants with refrigerants with a low global warming potential. Further, the European Union (EU) has essentially banned the use of R134a in mobile air conditioners of new models, effective January 1, 2011.

Refrigerant R134a is a commonly used refrigerant in vapor compression cycles, especially in automotive air conditioning systems. The global warming potential of R134a is 1430 as compared to CO_2, which, under the terms of the Montreal Protocol, means it needs to be phased-out by 2013 and automotive air conditioning systems need to find a new refrigerant with a lower global warming potential.

R1234yf has been proposed as a replacement for R134a in mobile air conditioning systems (Minor and Spatz, 2008). R1234yf has a global warming potential of 4, which will meet the EU requirements. R1234yf has comparable thermodynamic properties to R134a, which makes it ideal as a replacement, as it may be possible for few or no required alterations in order to replace R134a with R1234yf in a pre-designed system. Additionally, R410A is commonly used in refrigeration systems, and R1234yf may be a possible replacement for that refrigerant as well.

This paper will assess the potential of R1234yf to be a drop-in replacement for a pre-designed system. First, thermophysical properties of R134a, R1234yf, and R410A will be compared to determine how similar the refrigerants are. Then, simulations will be conducted to determine how much variance occurs between results of the same system with the three different refrigerants.

2. PROPERTY COMPARISON

In order for R1234yf to be a suitable replacement for currently used refrigerants, R1234yf need to have similar thermodynamic properties. Table 1 below shows a comparison between the thermodynamic properties of R134a, R1234yf, and R410A. The properties for R1234yf used in this study were determined from the recently released NIST fluid file (NIST, 2010) utilized in REFPROP (Lemmon, et al., 2007). The properties for the remaining refrigerants were found from ASHRAE Fundamentals (2005).

Table 1. Thermodynamic Properties for Various Refrigerants

Thermodynamic Property	R1234yf	R134a	R410A
Chemical Formula	$C_3F_4H_2$	CF_3CH_2F	n/a
Molar Mass (kg/kmol)	114.04	102.03	72.59
Boiling Point at 1 atm (K)	243.70	247.08	221.71
Freezing Point (K)	unknown	169.85	n/a
Critical Temperature (K)	367.85	374.21	344.51
Critical Pressure (MPa)	3.38	4.06	4.90
Critical Density (kg/m3)	478.01	511.90	459.53

Table 1 shows the thermodynamic properties of the commonly used automotive refrigerants. R1234yf and R134a have very similar values for critical temperature and molar mass, making R1234yf a good candidate for a drop-in replacement for R134a. Alternatively, R410A has a similar critical temperature and a close critical pressure to R1234yf, but the molar mass is not very similar.

Vapor pressure is a critical property to have aligned when considering the drop-in replacement capability of a refrigerant in a vapor compression system. Refrigerants with similar vapor pressures will evaporate and condense at the same pressure. Therefore, a vapor compression cycle designed with a particular high-side and low-side pressure would perform comparably for two refrigerants with comparable vapor pressures.

A convenient way to compare vapor pressures for multiple refrigerants is on an inverse temperature – pressure plot. Please refer to Figure 1 below for an inverse temperature – pressure plot of R1234yf, R134a, and R410A.

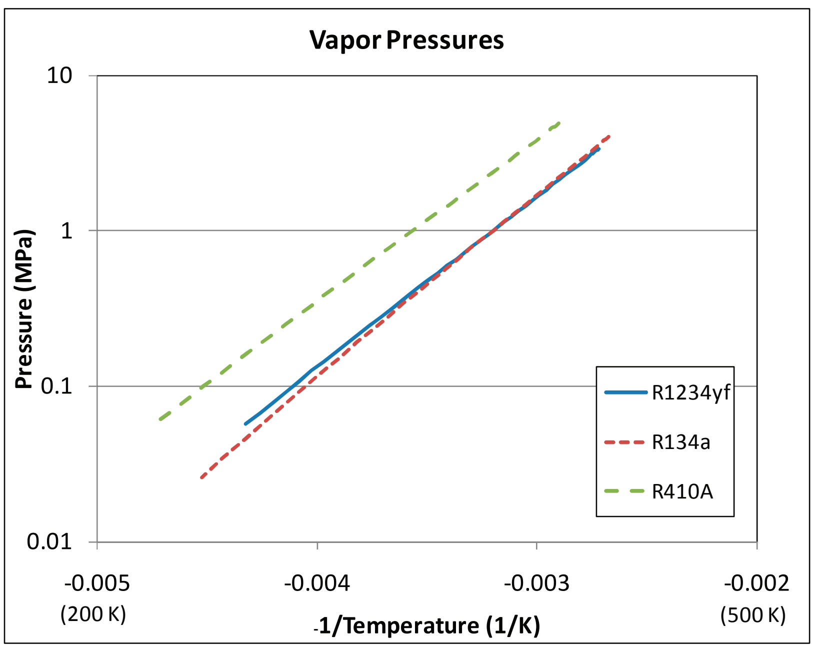

Figure 1. Vapor Pressure Plots for Various Refrigerants

As shown above in Figure 1, the vapor pressures of R1234yf and R134a are very similar. The lines are nearly identical for the temperature range shown. This is a strong indicator that R1234yf may be an acceptable drop-in replacement for R134a in vapor compression systems, because similar performance can be expected. Figure 1 also shows the vapor pressure line of R410A, which is significantly higher than those of R134a and R1234yf. Therefore, it appears that R1234yf has the potential to be a good drop-in replacement for R134a, but not necessarily so for R410A. The following simulation results show a more detailed comparison between the refrigerants.

3. HEAT EXCHANGER DESIGNS

In order to compare the performance of R1234yf to other commonly used refrigerants, the refrigerants were simulated via heat exchanger simulation software (Jiang *et al.*, 2002, 2006 and Singh *et al.*, 2009) using typical heat exchanger configurations. The heat exchangers chosen were from the 2004 short course at Herrick Laboratories (Herrick Laboratories, 2004) and will be described again below.

3.1 Tube-Fin Condenser

The condenser was an inline configuration, with 1 row of 30 tubes with louver fins. The condenser specifications and the correlations used in simulation are shown below in Table 2, and a coil diagram is given below in Figure 2.

Table 2. Tube-Fin Condenser Specifications

Parameters		**Correlations – Heat Transfer**	
Tube Length	45 in	Air Side	Chang Wang
Tube Outer Diameter	0.396 in	Refrigerant Liquid	Gnielinski
Tube Thickness	0.012 in	Refrigerant Two Phase	Dobson
Tube Vertical Spacing	1.0 in	Refrigerant Vapor	Gnielinski
Tube Horizontal Spacing	0.75 in		
FPI	20	**Correlations – Pressure Drop**	
Fin Thickness	0.004 in	Air Side	Chang Wang
Louver Pitch	2.0 mm	Refrigerant Liquid	Churchill
Louver Height	1.0 mm	Refrigerant Two Phase	Friedel
Actual CFM	2200 cfm	Refrigerant Vapor	Churchill

3.2 Tube-Fin Evaporator

The evaporator design is a staggered divergent coil with 3 tube banks of 28 tubes and louver fins. The coil specifications and the correlations used in simulation are given below in Table 3, and a coil diagram can be seen below in Figure 2.

Table 3. Tube-Fin Evaporator Specifications

Parameters		**Correlations – Heat Transfer**	
Tube Length	17.8 in	Air Side	Chang Wang
Tube Outer Diameter	0.396 in	Refrigerant Liquid	Dittus-Boelter
Tube Thickness	0.012 in	Refrigerant Two Phase	Jung-Radermacher
Tube Vertical Spacing	1.0 in	Refrigerant Vapor	Dittus-Boelter
Tube Horizontal Spacing	0.75 in		
FPI	15	**Correlations – Pressure Drop**	
Fin Thickness	0.0045 in	Air Side	Chang Wang
Louver Pitch	2.0 mm	Refrigerant Liquid	Churchill
Louver Height	1.0 mm	Refrigerant Two Phase	Friedel
Actual CFM	1250 cfm	Refrigerant Vapor	Churchill

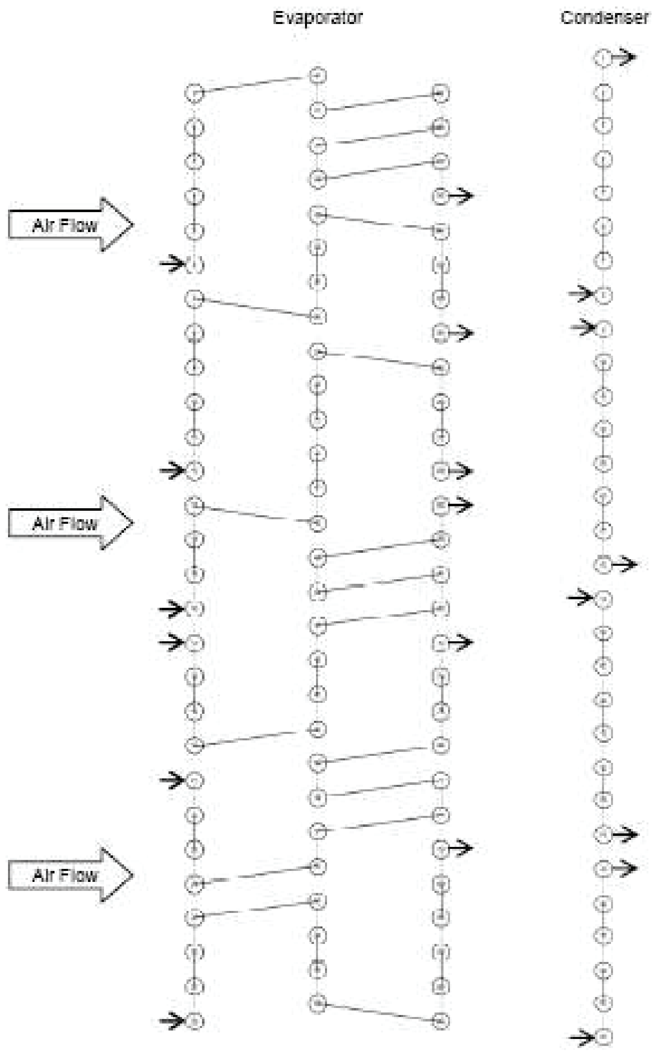

Figure 2. Evaporator and Condenser Coil Figures

3.3 Microchannel Condenser

The Microchannel has a parallel flow configuration with 3 passes, 71 tubes per bank and 1 tube bank and louver fins. There are 19 ports per tube, and each port is 1 mm by 1 mm. The coil specifications are given below in Table 4 along with the correlations used in simulation.

Table 4. Microchannel Specifications

Parameters		**Correlations – Heat Transfer**	
Tube Length	30 in	Air Side	Chang Wang
Tube Height	2.0 mm	Refrigerant Liquid	Gnielinski
Tube Width	20.0 mm	Refrigerant Two Phase	Dobson
Tube Vertical Spacing	1.0 in	Refrigerant Vapor	Gnielinski
Tube Horizontal Spacing	0.75 in		
FPI	20	**Correlations – Pressure Drop**	
Fin Thickness	0.00394 in	Air Side	Chang Wang
Louver Pitch	1.0 mm	Refrigerant Liquid	Churchill
Louver Length	6.0 mm	Refrigerant Two Phase	Friedel
Louver Angle	30°	Refrigerant Vapor	Churchill
Fin Depth	20.0 mm		
Actual CFM	2400 cfm		

4. Coil Performance Results

All coils were designed in the heat exchanger simulation software and simulated with the three refrigerants of interest; R1234yf, R134a, and R410A. The refrigerants' performance was compared assuming each was used in a vapor compression system with identical capacity and air inlet temperatures.

In order to properly analyze the drop-in replacement potential, the inlet conditions for each coil first need to be determined. A simple thermodynamic model was analyzed for each refrigerant to determine the inlet conditions for each coil. All cycles maintained the same saturated suction temperature, saturated discharge temperature, subcooling and superheating, and cooling capacity. The values for these parameters were determined from the ARI-540 standard (ARI, 1999). For the purpose of this study, the air side inlet conditions were not varied between refrigerants. The simple thermodynamic model then determined the appropriate pressures and mass flow rates for each refrigerant. The results of the analysis are shown below in Table 5. The thermodynamic model analysis was performed via vapor compression system simulation software (Richardson *et al.*, 2002, Winkler *et al.*, 2008).

Table 5. Thermodynamic Model Results

	Refrigerant	**R134a**	**R1234yf**	**R410A**
In puts	Saturated Suction Temperature [K]	280.4	280.4	280.4
	Saturated Discharge Temperature [K]	327.6	327.6	327.6
	Condenser Outlet Subcooling [K]	5	5	5
	Evaporator Outlet Superheat [K]	11.1	11.1	11.1
	Suction Superheat [K]	11.1	11.1	11.1
	Cooling Capacity [W]	10140.3	10140.3	10140.3
	Isentropic Efficiency [%]	80	80	80
	Volumetric Efficiency [%]	90	90	90
	Condenser Sat. Temp. Drop [K]	1	1	1
	Evaporator Sat. Temp. Drop [K]	2	2	2
Outputs	Saturated Suction Temperature [K]	280.4	280.4	280.4
	Saturated Discharge Temperature [K]	327.6	327.6	327.6
	Suction Pressure [Pa]	377841.3	401284.6	999273.3
	Discharge Pressure [Pa]	1471621	1445810	3389095
	Evaporator Pressure Drop [Pa]	26479.7	26297.59	64157.67
	Condenser Pressure Drop [Pa]	35657.81	33283.82	67795.18
	Condenser Outlet Subcooling [K]	5	5	5
	Expansion Device Inlet Subcooling [K]	5	5	5
	Evaporator Outlet Superheat [K]	11.1	11.1	11.1
	Suction Superheat [K]	11.1	11.1	11.1
	Power Consumption [W]	2644.73	2757.28	2951.51
	Cooling Capacity [W]	10140.3	10140.3	10140.3
	COP (Cooling)	3.83	3.68	3.44
	Mass Flow Rate [kg/s]	0.0705	0.0914	0.0658
	Pressure Ratio	3.89	3.6	3.39
	Isentropic Efficiency [%]	80	80	80
	Volumetric Efficiency [%]	90	90	90

Using Table 5 above, the quality at the evaporator inlet can be determined from the condenser outlet conditions. The qualities at the evaporator inlet are shown in Table 6 below.

Table 6. Quality at Evaporator Inlet for Each Refrigerant

Refrigerant	R134a	R1234yf	R410A
Quality at Evaporator Inlet	0.296	0.353	0.323

For the condenser simulation, the condenser inlet temperature and pressure, along with mass flow rate, are used to get simulation results. For the evaporator, the inlet quality and pressure, as well as the mass flow rate, are used to get simulation results. These parameters are all given, or can be determined by, the results of the thermodynamic model. The results of the simulation for the three coils with the three refrigerants are shown below in Tables 7 through 9.

Table 7. Tube-Fin Condenser Results

Parameter	R134a	R1234yf	R410A
Refrigerant Side Pressure Drop (Pa)	6590.9	9202.77	2955.3
Average Refrigerant Outlet Temperature (K)	322.0	320.5	319.1
Total Heat Load (W)	12744.0	13057.3	13434.5

Table 7 above displays the results of the tube-fin condenser. The heat load of R134a and R1234yf are very close and vary by approximately 300 W, or 2.4%. Further, the refrigerant outlet temperature varies by less than 2 K. However, the pressure drop across the condenser varies rather significantly. The pressure drop of R1234yf is approximately 40% higher than the pressure drop of R134a. The results of R410A vary more than R1234yf.

Table 8. Tube-Fin Evaporator Results

Parameter	R134a	R1234yf	R410A
Refrigerant Side Pressure Drop (Pa)	12819.1	17806.5	5699.9
Average Refrigerant Outlet Temperature (K)	288.5	288.5	288.6
Total Heat Load (W)	9919.3	9858.8	9619.1

Table 8 above displays the results of the tube-fin evaporator. As with the tube-fin condenser, the heat loads of R134a and R1234yf are very close (varying by approximately 60 W, or less than 1%), and the refrigerant outlet temperature doesn't vary at all. However, the refrigerant side pressure drop varies by almost 5000 Pa, or almost 40%. The refrigerant outlet temperature of R410A varies significantly from that of R134a. Furthermore, the heat load of R410A is significantly smaller than that of R134a and R1234yf.

Table 9. Microchannel Condenser Results

Parameter	R134a	R1234yf	R410A
Refrigerant Side Pressure Drop (Pa)	3443.6	3427.1	1242.0
Average Refrigerant Outlet Temperature (K)	320.8	321.9	321.1
Total Heat Load (W)	12875.7	12856.5	13167.3

Table 8 above displays the results of the microchannel condenser. The results of R134a and R1234yf are very close. The pressure drop, refrigerant outlet temperature, and total heat load all vary by very small amounts. On the other hand, the refrigerant side pressure drop and heat load of R410A varies significantly from that of R134a, while the refrigerant outlet temperature of both are very close to the temperatures of R134a and R1234yf.

5. Conclusions

This paper has investigated the thermophysical properties of R1234yf and compared the values to those of R134a and R410A to determine the drop-in replacement potential of R1234yf in systems designed for these other refrigerants. In general, the thermophysical properties of R1234yf are very similar to those of R134a, and not as similar to those of R410A. This trend is most readily observed in the pressure curves of these refrigerants, as shown in Figure 1. Furthermore, the refrigerants have been simulated in sample heat exchangers. These simulations have shown that R134a and R1234yf have similar results for outlet refrigerant temperature and heat load, however the pressure drop does vary and changes to the heat exchanger design and piping in these systems may be required, as variations around 40% were observed. Furthermore, the results of the simulation showed that R1234yf would not be a very good drop-in replacement for, as the variation in the results was substantial. Further analysis would be required on individual systems to determine whether R1234yf would infact be a suitable drop-in replacement, due to the slight variances observed above, and ensure piping would uphold the new requirements, as pressure changes were notable.

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