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Novel HFO Refrigerant Blend R-474A for GWP <1 Automotive Heatpump Application

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Abstract

The introduction of novel Hydrofluorooelefin (HFO) component R-1132E allows for significant improvements in Global Warming Potential (GWP) and thermophysical performance of ultralow GWP refrigerant blends. This paper will provide laboratory test results with R-474A, a binary blend of R-1132E, R-1234yf and provide an comparison and LCCP. It was found that R-474A as a drop-in replacement demonstrated up to a 50% heating and cooling capacity increase compared to R-1234yf and a up to a 30% Coefficient of Performance (COP) increase over R-744 (CO_2)

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1. Introduction

The 1987 adoption of the Montreal Protocol for the protection of the ozone layer led to the ban of Chlorofluorocarbons (CFC's) and eventual phaseout of Hydrochlorofluorocarbons (HCFC's). However, the Hydrofluorocarbon (HFC) gases selected to replace the previous generation have been found to have high levels of global warming potential and are considered to be a contributor to climate change. The parties to the Montreal Protocol agreed to phase down the use of HFC's, as measured in equivalents of CO_2, under the Kigali Amendment ratified in 2016. The United States took action with the passing of the US AIM Act [1] in 2021, seeking an 85% reduction by 2036, measured in CO_2 equivalents, in the use of HFC's.

To lower the overall use of HFC's, new innovations in developing molecules with shorter atmospheric lifetimes and therefore lower GWP's are necessary. A class of unsaturated fluorocarbons or HFO's has been identified as meeting those requirements. Unfortunately, the same factors that create lower atmospheric lifetimes that reduce GWP, also have the potential to reduce thermal and chemical stability that was the foundational strength of HFC's. As an example, while having similar thermodynamic properties R-1234yf is less stable and more flammable than the low pressure HFC-134a which it replaced in automotive air conditioning applications.

End uses such as automotive, where previously ample waste heat was provided from internal combustion engines, are accelerating the move towards electrification, and thus to the proliferation of heat pumps. As these heat pumps are introduced there is a growing need to identify higher capacity and higher performance refrigerants to meet these additional performance demands. However, automotive was the first sector to move en-masse to GPW <5 solutions such as R-1234yf, thus any replacement alternative would need to not only improve on performance but also meet this extreme GWP threshold expectation.

In this study we will present laboratory test results of R-474A a refrigerant based on novel HFO molecule R-1132E ((E) 1,2, Difluoroethylene) as it compares to R-1234yf, R-134a and R-744. The physical properties of the R-1132 were first defined in studies by Higashi et. al [2] and Pererra et. al [3] and the critical parameters

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and equation of state for R-474A, a binary refrigerant blend of 23% by mass R-1132E and 77% by mas R-12347f, was determined by Akasaka et. al [4]. Table 1 summarizes relevant refrigerant properties.

Previous studies [5] have already covered theoretical modeling, material compatibility and stability of R-1132E Blend R-474A.

Table 1. List of Refrigerant Properties

Refrigerant	R-1132E	R1234yf	R-474A
GWP (AR4)	<1*	4	<3
Boiling Point (101.3kPa)	-52.5°C	-29.4°C	-44.6°C
Critical Temperature	75.6°C	94.7°C	87.1°C
Critical Pressure (MPa)	5.16	0.59	4.04
Pressure at 20°C (MPa)	1.46	0.59	0.94
ODP	0	0	0
Safety Class**	B2	A2L	A2L
LFL (Vol %)	4.3	6.2	5.5
BV WCF (cm/s)	32.9	1.5	2.9

*Evaluated under AR5 conditions **ASHRAE 34 Safety Group Classification

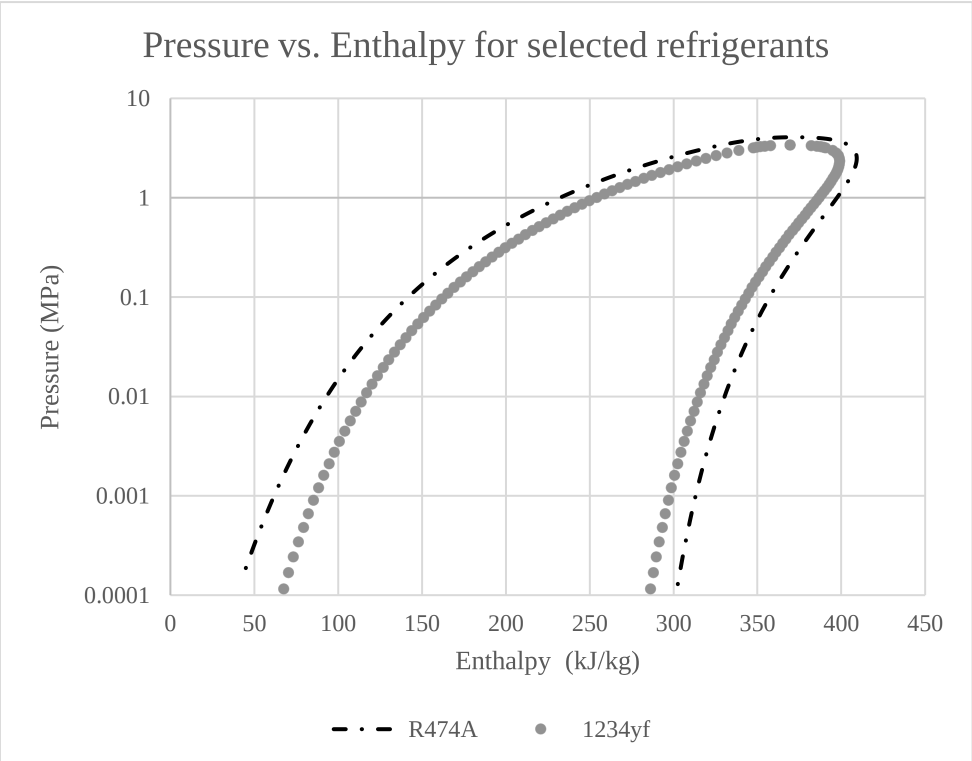


Figure 1: Pressure Enthalpy Diagram for R-1234yf and R-474A

2. Laboratory Tests

Two tests were performed in order to evaluate Refrigerant R-474A. First was an evaluation compared to R-1234yf using a standard compressor bench system at Ipetronik laboratories. The compressor calorimeter is shown in figure 2 system utilized a commercial off the shelf 34cc Brose compressor with PAG oil. The compressor tests included both heating and cooling conditions to estimate the compressor COP and capacity impacts of a refrigerant change.

Second, bench testing was performed utilizing two VW ID3 systems one a traditional R-1234yf AC only system with electric heat, and one utilizing an R-744 heat pump system. In the R-1234yf system the TXV was replaced with an electronic expansion valve. In both systems pressure, temperature and mass flow rate was measured as described in figure 3 and figure 4. Comparative testing was only performed in cooling mode.

Figure 2. Compressor Calorimeter

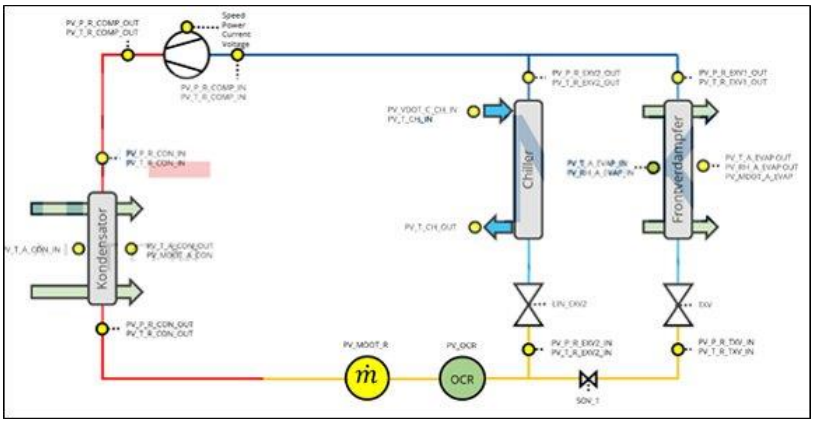


Figure 3. R-474A and R-1234yf Bench System Layout

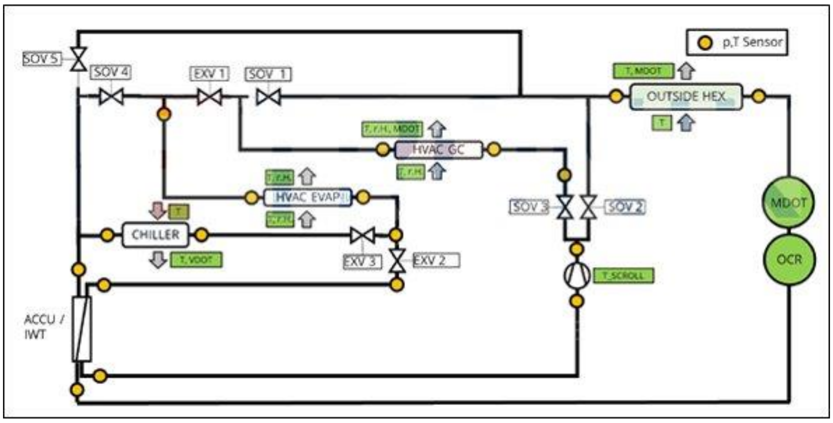


Figure 4. R-744 Bench System Layout

For the compressor calorimetry test, the conditions evaluated are identified in table 2.

Table 2: Compressor Calorimeter Test Parameters

Test	Condenser (°C)	Evaporator (°C)	Superheat (K)	Subcooling (K)
Cooling 1	40	-1.5	25	5
Cooling 2	69	-1.5	25	5
Heating 1	0	50	10	5
Heating 2	-10	60	10	5

For system bench evaluation, measurement points were selected from the list of tests available per SAE Standard J2765 [6]; The first set of tests, I60 through H35a were run as an evaluation of max performance / and at max allowable RPM; The second set of tests, I40a through I15 were run at a fixed cooling load to evaluate best case COP. Uncertainty and instrumentation tolerances are listed in section 4 of SAE J2765 for the test equipment and section 5 for the test room. In general, per J2765 section 1.5.2, the test apparatus is designed to give agreement within ±4% between two independent balances.

Lastly before evaluation for the bench system could be performed, a charge determination step was done by measuring superheat, subcooling pressure and temperature, and trying to identify the subcooling plateau. The test was performed with the condenser, coolant temperature and evaporator at 40°C; The compressor at max speed of 8500RPM. The charge determination graph is shown in figure 5 and indicates a 10% charge reduction with R-474A vs R-1234yf

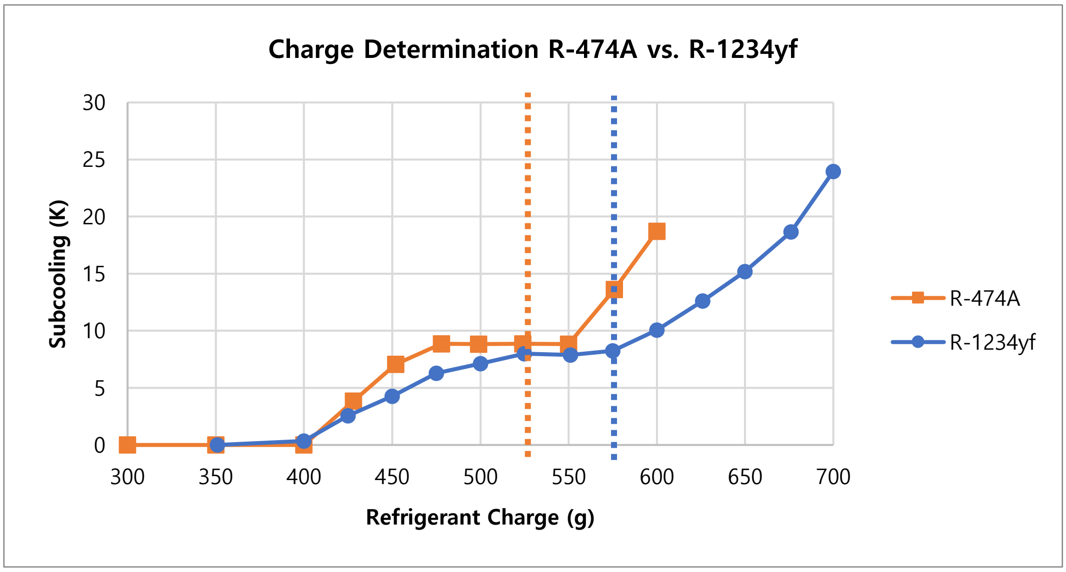


Figure 5. Bench System Charge determination

Table 3: Bench System Evaluation Points

Test	Condenser Air Temp (°C)	Condenser Air Flow (m/s)	Evaporator Air Temp (°C)	Evaporator Humidity (%)	Evaporator Air Mass Flow (kg/h)	Chiller Inlet Temperature (°C)	Coolant Flow Rate (l/min)	Air Temperature Target (°C)	Coolant ΔT (K)
I60	60	1.5	35	25	300	40	10	3	10
I45	45	1.5	35	25	300	40	10	3	10
M45	45	3	35	25	300	40	10	3	10
H45a	45	4	35	25	300	40	10	3	10
I50a	50	1.5	35	40	300	30	6.7	3	10
I35a	35	1.5	35	40	300	30	6.7	3	10
L35a	35	2	35	40	300	30	6.7	3	10
H35a	35	4	35	40	300	30	6.7	3	10
I40a	40	1.5	25	80	210	25	2.0	3	5
I25a	25	1.5	25	80	210	25	2.0	3	5
H25a	25	4	25	80	210	25	2.0	3	5
I40c	40	1.5	25	50	210	25	2.0	3	5
I25c	25	1.5	25	50	210	25	2	3	5
I30	30	1.5	15	80	210	Off	Off	3	Off
I15	15	1.5	15	80	210	Off	Off	3	Off

3. Results

Results for the compressor calorimeter test are summarized in table 4 where capacity is given in kW. In general R-474A showed a significant increase in capacity, almost 40-60% greater capacity than R-1234yf in heating mode. R-474A also demonstrated a significant improvement in COP over R-744 and R-1234yf in cooling mode while maintaining a 40% capacity improvement.

Table 4: Compressor Calorimeter Test Results

Cooling Point 1	Compressor RPM: 1500	3000	5000	7000	8500
1234yf COP	1.75	2.12	2.14	2.05	1.91
R474A COP	1.82	2.2	2.24	2.15	2.024
R134a COP	1.9	2.2	2.3	2.2	2.1
R744 COP		1.57	1.78	1.74	1.7
1234yf Capacity	1.19	2.54	4.45	6.23	7.41
R474A Capacity	1.71	3.63	6.24	8.72	10.41
R134a Capacity	1.39	2.96	5.10	7.15	8.53
R744 Capacity	0.00	2.57	4.76	6.88	8.49

Cooling Point 2	Compressor RPM: 1500	3000	5000	7000	8500
1234yf COP		0.92	1.01	1.02	0.98
R474A COP	0.76	0.97	1.08	1.09	1.05
R134a COP		2.2	3.7	5.2	6.2
R744 COP			0.91	0.91	0.91
1234yf Capacity		1.62	2.87	4.02	4.8
R474A Capacity	1.35	2.39	4.17	5.86	7.03
R134a Capacity		2.15	3.73	5.21	6.22
R744 Capacity			3.01	4.41	5.52

Heating Point 1	Compressor RPM: 1500	3000	5000	7000	8500
1234yf COP			1.02	0.97	0.92
R474A COP			1.14	1.1	1.05
R744 COP			1.2	1.2	1.2
1234yf Capacity			1.85	2.57	3.03
R474A Capacity			2.57	3.58	4.28
R744 Capacity			3.42	4.91	6.13

Heating Point 2	Compressor RPM: 1500	3000	5000	7000	8500
1234yf COP			0.57	0.55	0.52
R474A COP			0.67	0.66	0.637
R744 COP			1	0.98	0.97
1234yf Capacity			1.07	1.55	1.83
R474A Capacity			1.72	2.42	2.88
R744 Capacity			2.64	3.82	4.76

Results for the bench test when comparing max cooling are shown in figure 6. R-474A demonstrates a 1200 to 2200 watt improvement in cooling output across the test conditions as compared to both R744 and R1234yf and a small decrease in COP compared to R-1234yf and a significant increase in COP when compared to R-744

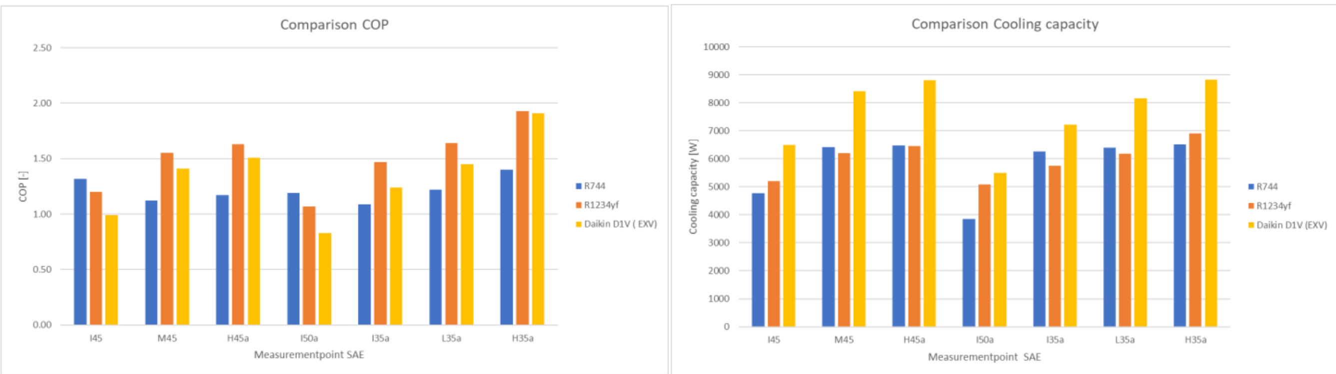
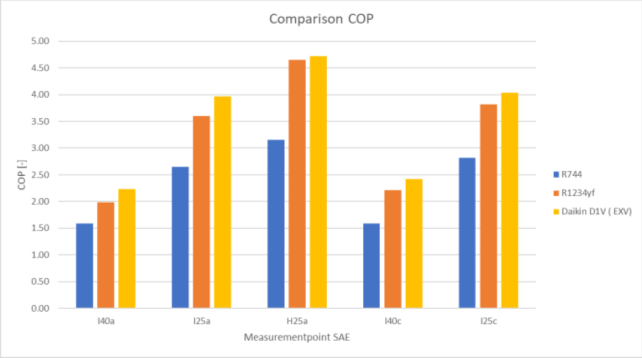


Figure 6. Bench System Max Load results

Results when matching cooling capacity are shown in figure 7. We note that R-474A shows an improvement in COP across the entire range of test conditions. We also observe a decrease in the COP of R744.



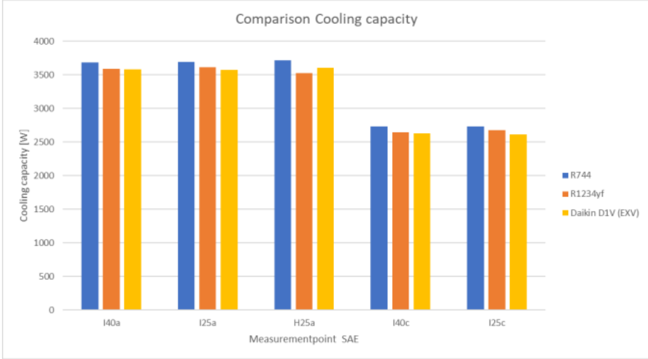


Figure 7. Bench System Max Load results

4. Conclusion

Based on the bench test results observed, R-474A is capable of extending the heating range of a traditional R-1234yf heatpump system beyond 0°C to -10°C and with this trend extending likely a significant amount of heat being available at -20°C. This indicates that a reduction in the quantity and use of PTC heaters Is possible as a potential weight and cost savings.

Additionally at mild cooling conditions when matching capacity, there is a significant improvement in COP, indicating that for a typical automotive drive cycle, there is opportunity to reduce total HVAC energy consumption and thus improve cruising range.

Furthermore, charge determination experiment indicates that the total refrigerant charge for an R-474A system when dropped into an existing commercial system can be as much as 10%.

Lastly, the significant observed improvement in capacity is shown at many of the test points. This can be utilized to either improve HVAC system noise vibration and harshness (NVH) characteristics by reducing RPM, which is significantly more important in generally quieter electric vehicles, or to down size the compressor.

Acknowledgements

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