

Experimental Investigation of the Performance of a Laminate Evaporator with HFO-1234yf as the Working Fluid

2011-01-1170

Published
04/12/2011

Gursaran D. Mathur
CalsonicKansei North America Inc.

Copyright © 2011 SAE International

doi:10.4271/2011-01-1170

ABSTRACT

Tests were conducted with a laminate evaporator for an automotive application. The tests were conducted with HFO-1234yf as the working fluid on an AC system bench. A laminate evaporator from MY 2008 medium sized sedan was used for this investigation. Tests were first conducted with R-134a and were then repeated by maintaining each test condition by changing the working fluid from R-134a to HFO-1234yf. Charge determination tests were also conducted with the new refrigerant. The refrigerant was used as “drop-in” refrigerant in the existing system. All original OEM parts were used with the alternate refrigerant. Same TXV set-point and lubricant type and quantity was used with HFO-1234yf. The new refrigerant has advantages due to the refrigerant thermodynamic properties that helps reduce the pressure ratio. Detailed test results have been presented in this paper.

INTRODUCTION

Refrigerant HFO-1234yf is currently being considered in the automotive industry as an alternate replacement for R-134a to address the global warming concerns. This refrigerant (Hydro Fluoro Olefin) has been developed jointly by DuPont and Honeywell. This refrigerant has excellent environmental properties, low toxicity (similar to R-134a); and system performance is similar to that of R-134a. [Figure 1](#) shows a schematic of an AC system and [Figure 2](#) shows a comparison ([Spatz. et. al, 2008](#)) of R-134a and HFO-1234yf AC cycles on the p-h diagram along with vapor density at suction temperatures. The latent heat of vaporization is lower for HFO-1234yf in comparison to R-134a system. Hence, for the same cooling capacity, the refrigerant mass flow rate for HFO-1234yf should be higher than R-134a system. A larger magnitude of the vapor density at suction temperature also

indicates that the refrigerant mass flow rate will be higher for HFO-1234yf in comparison to R-134a system. Typical evaporating saturation pressures for HFO-1234yf are higher than R-134a; HFO-1234yf pressure equals to R-134a pressure at 37.8°C; and HFO-1234yf pressure is lower than R-134a beyond 37.8°C. Hence, in comparison to R-134a, a slightly higher evaporating pressure for HFO-1234yf along with slightly lower condensing pressure for HFO-1234yf reduces the pressure ratio, thereby, improving system COP. A number of OEMs, suppliers including SAE ([Spatz. et. al, 2008](#); [Koban, 2009](#); [Meyer, 2008](#); [Mathur 2010a, 2010b](#); [Stehouwer, 2010](#); [Seybold & Hill, 2010](#)) have also been conducting independent testing with HFO-1234yf.

In this paper, experimental investigations have been carried out to determine the performance of a laminate evaporator by using R-134a and HFO-1234yf as the working fluids. Detailed test results have been presented in this paper.

PRINCIPLE OF OPERATION OF A LAMINATE EVAPORATOR

A typical laminate type evaporator ([Mathur, 2000b](#)) is shown in [Figure 3](#). It consists of a number of stamped plates and louvered fins. The plates have clad material on both sides. The plates and fins are stacked and then either vacuum brazed or brazed in controlled atmospheric brazing (CAB) process. The advantage of using CAB process is that it is a continuous process in comparison to vacuum brazing that is a batch process. The plate design is such that when brazed, internal flow passages for refrigerant are created. The plates have diagonal ribs (or multiple dimples) to augment the heat transfer and provide strength. These plates have central partitioning ribs that facilitate the reversal of refrigerant flow

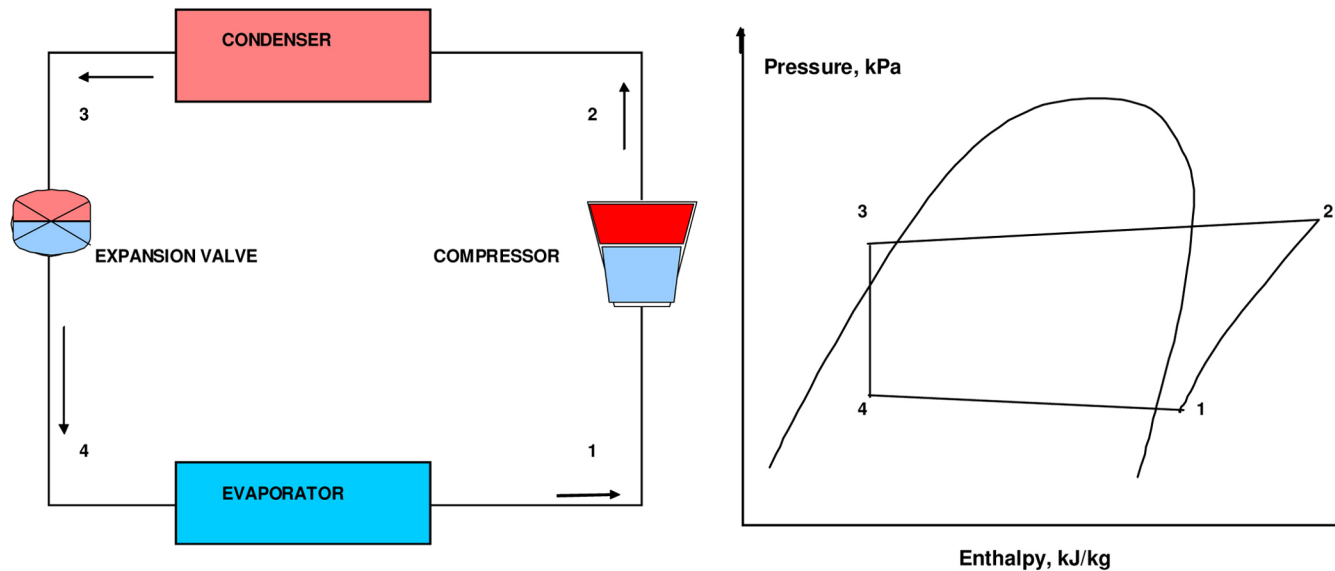


Figure 1. Schematic & p-h diagram for an air conditioning system

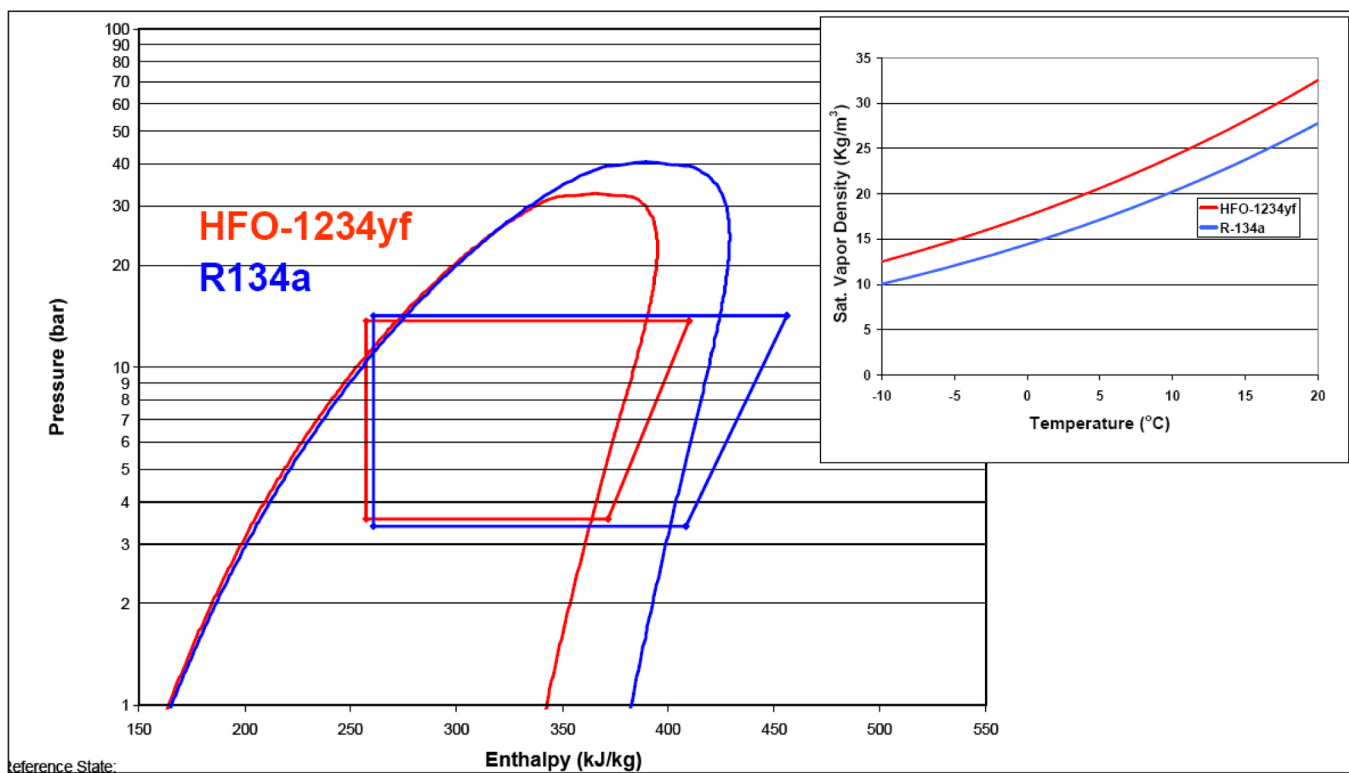


Figure 2. Comparison of Thermodynamic Cycle between base case (R-134a) and HFO-1234yf (Spatz et. al., 2008)

direction. In some of the new designs, an insert is used between plates to augment heat transfer. This also helps in improving the strength of the evaporator as the inserts braze to both sides (inside) of the plates. Also, some of the suppliers have started using micro-channel tubes (Grosse, 2006) for evaporators. These evaporators may have tank on either ends or on one end only. For a same airflow area, a

single tank evaporator has a better performance in comparison to a double tank evaporator, as the available heat transfer area is greater. In other words, the ratio of the total heat exchange area to the total volume of the core is more for evaporators with single tanks. Laminate evaporators typically have 4 to 6 refrigerant passes. For a same cooling capacity, the average refrigerant velocities in a 6 pass evaporator are

higher than a 4 pass resulting in a better temperature profile for the evaporator core. Figure 4 shows an automotive evaporator with a 6 pass flow configuration. The two-phase refrigerant enters the evaporator through the inlet pipe and vapor exits the evaporator through the outlet pipe. The two-phase refrigerant enters the evaporator through the tank and moves upwards in multi-flow channels (or plates) in pass 1 and then exits the evaporator as vapor from pass 6. The details of the heat transfer modes and flow patterns are discussed in “Results & Discussions” section.



Figure 3. Photograph of the evaporator used for the current investigation

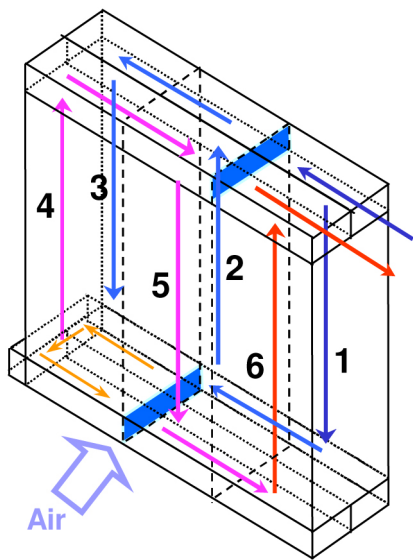


Figure 4. Refrigerant flow pass configuration of a typical evaporator

A laminate evaporator operates as a cross-flow heat exchanger in which the air flows normal to the refrigerant.

The performance of laminate evaporators is superior to the serpentine (Mathur, 1998) or finned tube (Mathur, 1997) evaporators. This is due to higher heat transfer coefficients. Laminate evaporators are lighter in comparison to other types of evaporators. The rate of heat transfer per unit weight (and volume) is more for laminate evaporators in comparison to other types of evaporators. The depth of laminate evaporators currently varies from 50 to 90 mm. However, the automotive industry is making an effort to reduce the volume of the evaporator core by decreasing the depth of the core in the range of 35~50mm (Nakamura, 2003). The evaporators are typically coated with hydrophilic coating (Casenave, 2004) for effective drainage properties (Mathur 1999, 2000a). Some of the evaporator designs may be prone to accumulation of lubricating oil in the plates at part load conditions (Mathur, 2004). Lubricating oil typically affects both thermal and hydrodynamic performance (Mathur, 1993). Moisture in the AC loop can also adversely affect system performance (Mathur & Goswami, 1996).

Evaporator performance is dependent on the following design parameters: tube and fin design, tube and fin pitch, height, length and depth of the tube and fin, number of pass; materials of components; and location of the inlet and outlet connections. A good evaporator design should have relatively small areas for partial dryout and single-phase vapor flows, and area for the two-phase flow should be maximized (Mathur 1997, 1998, 1999, 2001; Rohsenow, 1973; Wallis, 1969; Stoecker, 1982).

The performance of evaporator can be defined by the following parameters:

- refrigerant mass flow rate
- heat transfer
- refrigerant pressure drop
- air side pressure drop
- conductance
- overall heat transfer coefficient
- operating pressure
- wall temperature
- refrigerant temperature

The above parameters will be discussed here to quantify the performance of the evaporator. Note that evaporator air side pressure drop is strictly a function of tube and fin design and is not dependent on the type of refrigerant used in the system. For same airflow rate and operating conditions, the magnitude of the air side pressure drop will be same. Hence, this parameter will not be discussed in this paper.

Table 1. Details of Laminate Heat Exchanger

Variable	Magnitude
Height (mm)	270
Width (mm)	300
Depth (mm)	48
Fin Design	Louvered
Tube Design	Stamped Dimpled



Figure 5. Photograph of the test facility - the room on the left side simulates the cabin interior; and the room on the right simulates the engine compartment.

Average evaporator conductance ([Incropera, 1981](#)) is defined by the following equation:

$$U_c = Q / [A_{cond} (T_{average\ wall} - T_{Saturation, exit})] \quad \dots(1)$$

The above parameter, conductance, is essentially the average tube side heat transfer coefficient. However, this is based on the average evaporator wall temperature and the evaporator outlet saturation temperature. It should be noted that the local heat transfer coefficients ([Mathur, 2000b](#)) are determined by using local thermodynamics thermo-physical properties, flow pattern, pressure gradient and void fraction. For the above equation, the thermal resistance for the tube is assumed to be negligible. This assumption is reasonable as the thermal conductivity of aluminum is very large resulting in a negligible tube wall thermal resistance. [Table 1](#) shows the design details of the evaporator that is used for this study. The following section presents the details of the experiments.

EXPERIMENTAL TESTS

Tests were conducted in the system bench test facility. The test facility is instrumented in accordance with the ASHRAE standard ([ASHRAE, 1997](#); [ASHRAE Standard 42.1, 1987](#); [ASHRAE Standard 37, 1988](#)). The facility is capable of measuring the performance of the system using air-enthalpy and refrigerant-enthalpy methods. The test facility is fully instrumented to record the operating parameters, e.g., pressure and temperatures of the refrigerant, and dry and wet bulb temperatures at the strategic points. This test facility consists of two rooms (See [Figure 5](#)) - one simulating the vehicle cabin ([Figure 6](#)) and the other room simulating the engine compartment as shown in [Figure 7](#). The HVAC unit is placed in the room simulating the vehicle cabin while the condenser and compressor are placed in the room simulating the vehicles engine compartment. All parts are assembled in these two rooms based on the vehicle configuration. Evaporator freeze is controlled by cycling the compressor via a thermister located in the evaporator.