A1 REDUCED GWP REFRIGERANTS TO REPLACE R410A

Ankit Sethi*, Samuel F. Yana Motta*, Nacer Achaichia, Jean de Bernardi****
*** Honeywell International, Buffalo Research Laboratory, Buffalo NY (USA)**
****Honeywell Refrigerants Europe**

Introduction

R-410A is widely used in air-conditioning applications ranging from residential unitary air-conditioners to heat pumps and light commercial chillers. R-410A has relatively high GWP (GWP = 1942), and is increasingly becoming a target of many environmental regulations. In this context, several lower GWP R-410A replacements are under evaluation by the industry.

However, most of the new lower GWP refrigerants are flammable in nature (Zou et al. 2016), which restricts their early adoption by the HVACR community. The industry is investing heavily in understanding the use of flammable refrigerants, but it will be years before mandatory emission reductions can be realized. With a viable option of non-flammable lower GWP refrigerants with equivalent or better energy efficiency, actions can be implemented in the stationary air-conditioning segment with the potential to ensure carbon footprint reduction.

This study focuses on two non-flammable R-410A replacements: Blend 1, R-466A, and Blend 2 which are expected to be classified as A1 according to ASHRAE Standard 34.

Blend 1, R-466A, has GWP less than 750, Blend 2 has GWP less than 400, which may be a long-term replacement for R-410A. A reversible heat pump system was selected to evaluate the performance of these two refrigerants.

Thermodynamic Analysis

A thermodynamic analysis was performed to understand the impact of using a given refrigerant on the operating pressures, flow rate of refrigerants, cooling capacity, and efficiency. This type of analysis was performed at typical air conditioning conditions using thermodynamic data from NIST database REFPROP 9.1 [7].

Table 1 shows the results of this analysis at ambient temperature of 35°C. The theoretical performance of the two refrigerant blends is compared with R-410A: Blend 1, R-466A, may offer a close match in performance to R-410A with capacity within 1% of R-410A and 2% higher efficiency than R-410A when Blend 2 may have a capacity within 7% of R-410A and 2% higher efficiency than R-410A.

In this analysis, both refrigerants have lower suction and discharge pressures than R-410A while the compression ratios are very similar to R-410A. The compressor discharge temperature for Blend 1, R-466A, is about 8°C and for Blend 2 is about 11°C higher than R-410A. It indicates that the discharge temperature mitigation might not be required. In this study, the theoretical results show that both Blend 1, R466A, and Blend 2 may have slightly higher mass flow rate than R-410A by 5% and 8% respectively.

Table 1. Thermodynamic Analysis of R410A and its substitutes

Name	GWP AR4 (AR5)	Cap.	Eff.	Flow Rate	$T_{discharge}$ [°C]	$P_{discharge}$	Comp. Ratio	Evap Glide [°C]
R-410A	2088 (1924)	100%	100%	100%	BASE	100%	100%	0.1
R-466A (Blend 1)	733 (696)	99%	102%	105%	+8.0	95%	99%	1.2
Blend 2	399 (389)	93%	102%	108%	+10.8	89%	100%	3.8

Tcond=45°C; SC=5.5°C; Tevap=+7°C; Evaporator SH=5.5°C; Suction line SH=0°C; η_{vol} = 100%; η_{isen} = 70%

Experiments in a 3TON ducted split heat pump

An experimental investigation of a ducted split heat pump system was conducted to evaluate those two R-410A replacements under both cooling and heating conditions. The system has a capacity of 9.6 kW at rating conditions and is equipped with a fixed speed scroll compressor. Details on the design, measurements and rating conditions are accessible in bibliography (Sethi et al. [11]).

Test Results

Fig. 1 shows the experimental results in the cooling and heating modes. The results of capacity and efficiency for the equipment are presented relative to the performance of R-410A. The results indicate that Blend 1 shows a 100% matched capacity at the A condition and a 100% matched efficiency at the B condition. Blend 1, R-466A, shows an improvement in performance compared to R-410A at high ambient conditions. At the extreme ambient condition, the capacity is 102% and efficiency is 105% of R-410A. Blend 2 shows a capacity of 95% at the A condition and efficiency of 102% at the B condition. Blend 2 also shows an improvement in performance compared to R-410A at high ambient conditions with a capacity of 102% and efficiency of 109% at the extreme condition. Comparing the experimental results at A condition with the thermodynamic analysis in Table 1, the differences of capacity and efficiency are within ±2%.

At the heating condition H1, Blend 1, R-466A, shows a capacity of 97% and a 100% matched efficiency of R-410A. At the frost and low temperature conditions, the capacity and efficiency are similar which indicates that the small glide does not show significant impact on the performance. Blend 2 shows a slightly lower capacity of 93% and a slightly higher efficiency of 101% of R-410A at the H1 condition. The glide of Blend 2 also does not show significant impact on performance at the frost and low temperature conditions. By employing a larger displacement compressor while keeping the other components the same, Blend 2 may be able to match R-410A capacity and efficiency.

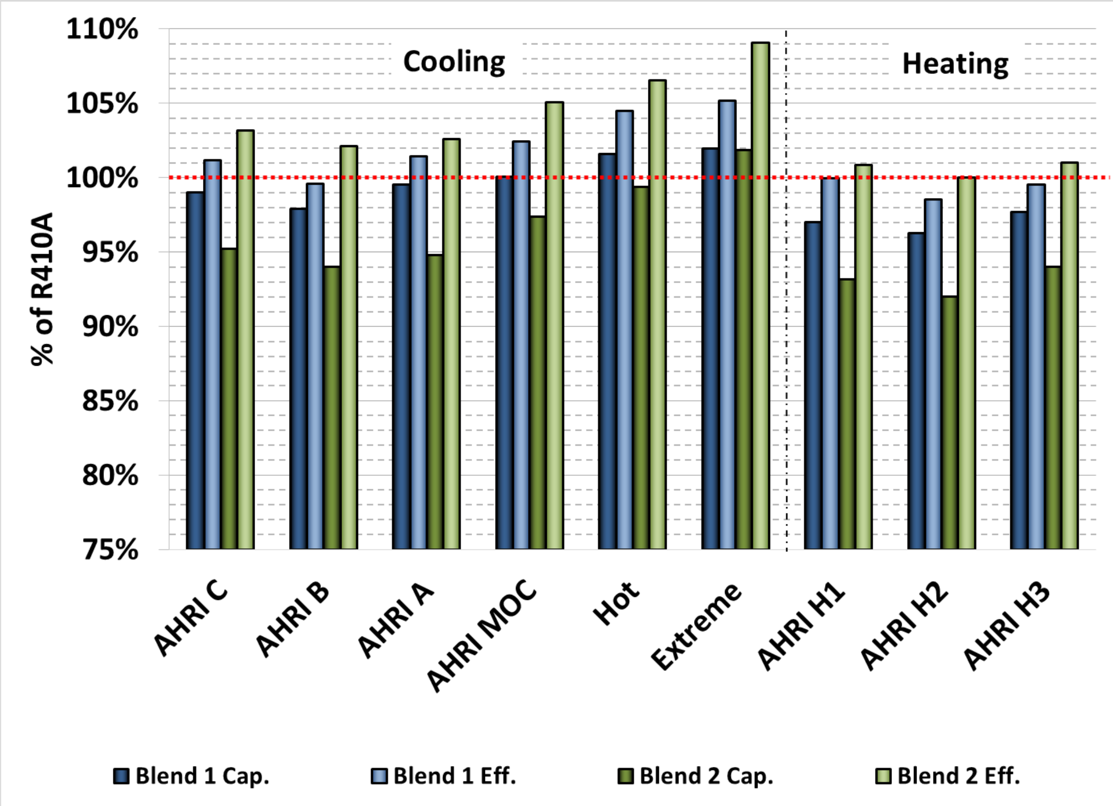

Figure 1. Measured performance of a 3-ton residential ducted split heat pump system

Environmental Impact: LCCP calculation in Kuwait in cooling (R466A vs. R410A)

Both the direct (refrigerant leakage) and indirect (energy consumption) emissions over the lifetime of the equipment need to be considered to compare the environmental impact of different refrigerants. This type of evaluation is commonly called Life-Cycle Climate Performance (LCCP) analysis. The direct effect is the amount of equivalent carbon dioxide (CO_2) emissions caused by the release of the refrigerant with its inherent GWP into the atmosphere. Indirect emissions result from the energy consumption of the equipment, which are directly related to the efficiency of the equipment/refrigerant system and the local emission factor, based on the electricity generation and its associated CO_2 emissions.

The power consumption of a typical 3 TON R-410A ducted split air conditioner (similar to the one tested in the previous section) over the course of a year was modelled by using a bin analysis using weather data produced by National Renewable Laboratory [4] for Kuwait which experiences high ambient temperature.

The CO_2 emissions factor for electricity production was taken to be 0.805 kg of CO_2 per kW-hr of electrical production for Kuwait [6]. Assumptions needed to complete this analysis were taken from ADL report [9]. This included a 2% annual leakage rate and a 15% end-of-life loss. A 15-year life was assumed. The impacts were determined by the following equations:

Direct Effect = Refrigerant Charge (kg) x (Annual loss rate x Lifetime + End-of-life loss) x GWP (1)

Indirect Effect = Annual Power Consumption x Lifetime x CO_2 per kW-hr of electrical production (2)

The running time of the ducted split air conditioner was based on assumption of load profile as shown in Figure 2. The indoor set point was 27°C for ambient temperature less than 35°C and the set point was floated to match capacity with load for ambient temperature greater than 35°C.

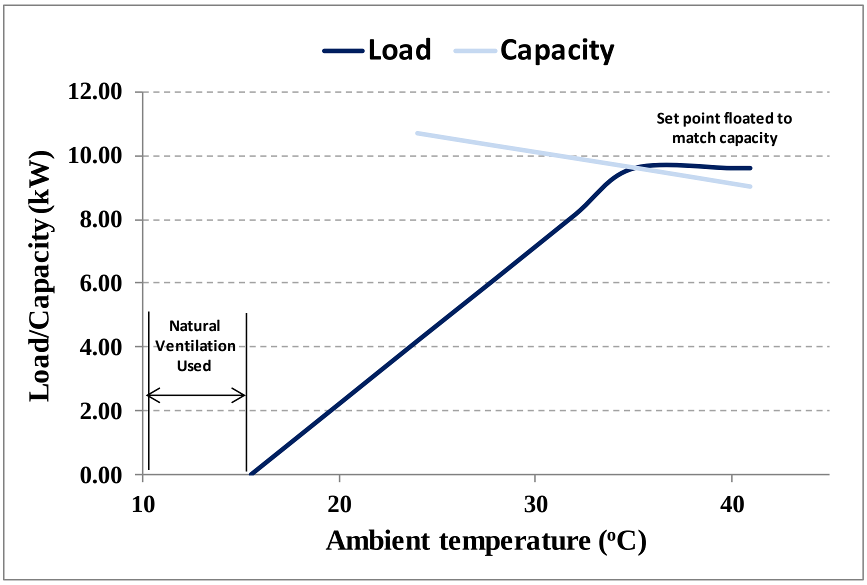

Figure 2. Load Profile vs System Capacity

Results

Fig. 3 shows LCCP results for 3-ton residential air-conditioning system. It was assumed that the system only provides air-conditioning, which is the prevailing type of installed systems in Kuwait. It is very clear that the indirect contributors dominate any contributions from refrigerant emissions. The results of the model indicate that lower GWP Blend 1, R-466A, may have total emissions reduction potential of about 3% compared to R-410A.

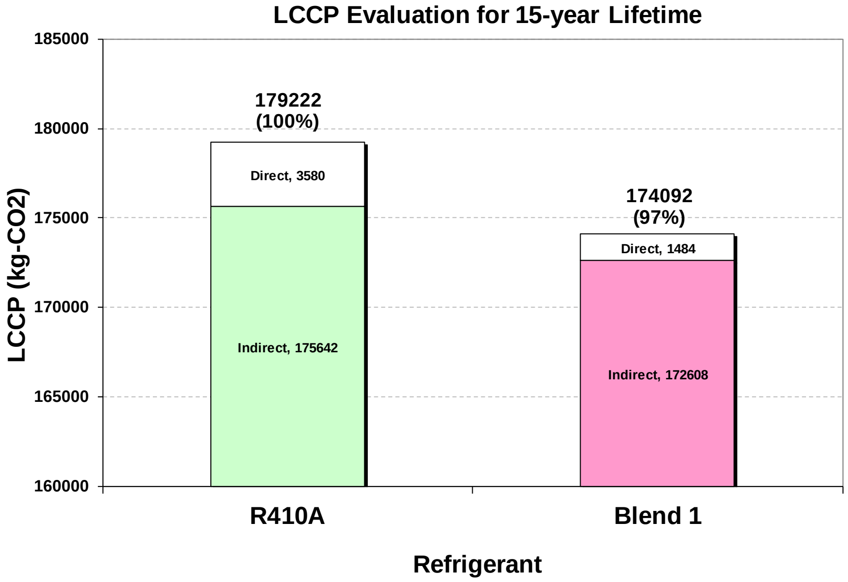

Figure 3. LCCP Analysis of 3-ton residential AC system in Kuwait

Concluding Remarks

This study presents two viable nonflammable lower GWP R-410A replacement refrigerants. Blend 1, R-466A, having GWP < 750, complies with existing regulations. Blend 2, having GWP < 400, could be used as a long-term solution for residential and commercial air-conditioning and heat pump systems.

Experimental system evaluation in a 3 TON R-410A residential ducted split heat pump system indicate that the lower GWP Blend 1, R-466A, and Blend 2 can match the performance of R-410A without significant system modification. At elevated ambient temperatures, Blend 1, R-466A, and Blend 2 show more than 5% higher efficiency than R-410A. The LCCP analysis shows Blend 1, R-466A, has lower environmental impact than R-410A. This is likely due to the excellent balance of lower GWP and equivalent or higher efficiency.

Different from other R-410A replacements in the market that are flammable, the nonflammable solutions offer additional benefits, including simple storage and handling, no requirement of additional flammability mitigation strategies, no additional training required for contractors and system operators, no significant change to assembly lines, full compliance with existing building codes, and lower expenses for both new installations and repair scenarios.

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