Retrofit of R-410A in Air to Water Heat Pumps: Test of Two Low GWP Candidates

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ABSTRACT

This paper presents an experimental evaluation of two low GWP refrigerants candidates for the replacement of R-410A in an "air to water" heat pump.

The baseline is evaluated following the ANSI/AHRI Standard 551/591. For both low GWP candidates (ARM-70a and DR-5), tests are performed following the same standard for three refrigerant charges.

Both heat capacity and coefficient of performance are compared for the baseline and the tests with the low GWP refrigerants. The results show that for the best refrigerant charge, both heat capacity and COP are improved by 5 to 10%. The best refrigerant charge is found for both replacement candidates.

INTRODUCTION

R-410A is one of the main refrigerants used for air conditioning and heat pump systems. This refrigerant has a high GWP and it is nowadays question of phasing it out (European F-gas directive). In japan, R-32 is considered as a potential replacement for R-410A (Yajima et al., 2011). This refrigerant permits to reduce the GWP from 2090 kg_{eq} CO_2 to 675 kg_{eq} CO_2. HFO refrigerants gained attention recently especially with the European mobile air conditioning regulation. These refrigerants have a GWP lower than 10 (Arimoto et Al, 2011) but have lower heating capacity than R-410A and flammability issues (Barve and Cremaschi, 2012). Refrigerant manufacturers are currently developing new refrigerant blends permiting to match heating capacity of R-410A with low GWPs (Biswas and Cremaschi,2012) (Wang et al., 2012).

Among these refrigerants, we can cite ARM-70a (GWP=470) and DR-5 (GWP=490). The present paper describes drop in tests realized in an air to water heat pump using these blends. The tested heat pump is bought charged with R-410A blend.

Tests are first realized with the heat pump as bought following the AHRI551/591-2011 standard conditions. These tests are considered as reference for the comparison with the drop in tests.

DESCRIPTION OF THE SYSTEM AND TEST SETUP

The Experimental setup

The experimental set up is presented in the **Figure 1** hereafter.

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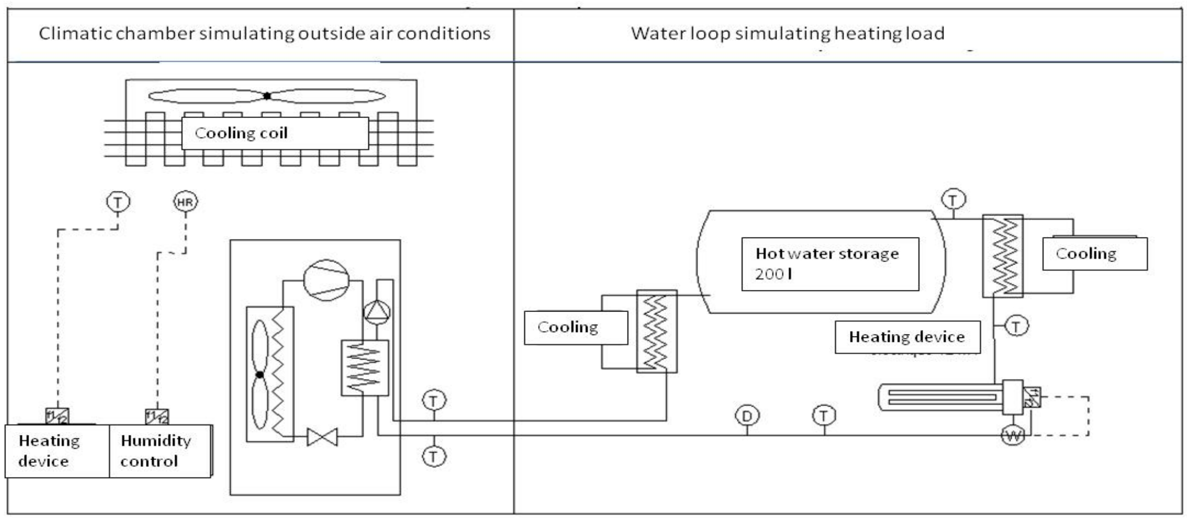

Figure 1 Experimental set up for the air to water heat pump characterization

It is composed of a climatic chamber simulating the outside ambient conditions and a water loop simulating the heating load.

The climatic chamber has an ultra sound humidifier permitting to control air humidity and a cooling and heating device for temperature control. Air temperature is measured at 2 positions in the climatic chamber using PT100 temperature sensors with an accuracy of ±0.05°C and relative humidity is measured with an accuracy of ±1%.

The water loop is equipped with:

- A first cooling section;
- A water capacity of 200 l simulating the thermal inertia of hydronic systems in case of partial load tests;
- A second cooling section needed for high capacity heat pumps;
- And a heating device permitting a fine control of water return temperature to the heat pump.

Inlet and outlet temperatures of water at the heat pump condenser are measured using intrusive PT100 sensors with an accuracy of ±0.05°C. Water mass flow rate through the condenser is measured using an electromagnetic mass flow meter with an accuracy of ±1%.

Heating capacity of the heat pump is then derived at full load operation and after reaching the steady state condition. In case of defrost cycles, heat capacity is evaluated only out of the defrost periods as shown in the equation below.

$$(q_{cd})_{avg} = \frac{1}{\tau_2 - \tau_1} \int_{\tau_1}^{\tau_2} q_{cd} \cdot \delta_\tau = \frac{1}{\tau_2 - \tau_1} \sum_{i=1}^{n} (q_{cd})_i \cdot \Delta\tau_i \qquad (1)$$

Where

q : heat produced out of the defrost period (W)

τ_1 : cycle starting time (s) ; τ_2 : cycle final time (s) ; Δ_{τ_i} : data acquisition time span (s)

Description of the system and the conducted tests

The tested equipment is an air to water heat pump that has the following characteristics:

- Nominal heating capacity 6.26 kW/21360 Btu/h (7°C/44.6 F DB air temp. and 75% RH and inlet water temperature of 35°C/95 F)
- Baseline refrigerant R-410A

- Refrigerant charge 1.50 kg/3.3 lb

The drop in tests were conducted without any change to the equipment. For each tested low GWP blend, tests are repeated for three different refrigerant charges.

Tests are conducted following the AHRI 551/591-2011 standard. Heat pump is tested at full capacity for the following conditions:

- TC1: Air DB temperature -8°C/17.6 F, -9°C/15.8 F WB and water inlet temperature to the heat pump of 35°C/95 F;
- TC2: Air DB temperature 8°C/46.4 F, 6°C/ 42.8 F WB and water inlet temperature to the heat pump of 35°C/95 F;
- TC3: Air DB temperature 8°C/46.4 F, 6°C/42.8 F WB and water inlet temperature to the heat pump of 45°C/113 F;

RESULTS AND DISCUSSIONS

For each testing condition, the return temperature to the heat pump is set at the desired value. The water mass flow rate at the condenser is kept unchanged. First the Heat pump is tested as bought for the three testing conditions. For each, test condition, the heating capacity is calculated and two coefficients of performances are determined:

- COP is defined as the ratio of the heating capacity to the compressor power input

$$\mathrm{COP} = \frac{\text{Heating capacity}}{\text{Compressor power input}} \tag{2}$$

- System COP is defined as the ratio of the heating capacity to the system power input which includes the condenser pump.

$$\mathrm{COP}_{\text{system}} = \frac{\text{Heating capacity}}{\text{Compressor power input+fan power+pump power}} \tag{3}$$

Results for the Base case using R-410A

Table 1. Results for the base case using R-410A

	Test Condition 1	Test Condition 2	Test Condition 3	Unit
Condenser				
Water flow rate	0.30/0.08	0.30/0.08	0.30/0.08	[L/s]/[gal/s]
Tin water	35.2/95.3	34.9/94.8	45.0/113	[°C]/[F]
Tout water	37.4/99.3	39.9/103.8	49.7/121.4	[°C]/[F]
Evaporator				
Air flow rate	N/A	N/A	N/A	
Room air temp. 1 (DB)	-8.6/16.5	7.5/45.5	7.5/45.5	[°C]/[F]
Room air temp. 2 (DB)	-7.6/18.3	7.4/45.3	7.5/45.5	[°C]/[F]
Room WB temp.	-8.8/16.1	5.5/41.9	5.5/41.9	[°C]/[F]
Compressor Power Input	1631.2	1752.6	2165.1	[W]
Total System Power Input	1943.2	2062.7	2484.4	[W]
Heating capacity	4040.7/13,788	6396.8/21,827	5908.8/20,162	[W]/[Btu/h]
COP	2.48/8.46	3.65/12.4	2.73/9.32	[W/W]/[Btu/W.hr]
System COP	2.08/7.10	3.10/10.6	2.38/8.12	[W/W]/[Btu/W.hr]

Results using the ARM-70a

Three refrigerant charges are tested with the ARM-70a for each of the three operating conditions. These are: 1.35 kg /2.97 lb, 1.50 kg/ 3.3 lb and 1.65 kg /3.63 lb. Table 2 presents the results obtained for the three test conditions with the refrigerant charge that gives the best COP.

Table 2. Results for the ARM-70a

	Test Condition 1	Test Condition 2	Test Condition 3	Unit
Best refrigerant charge	1.5/3.3	1.35/2.97	1.35/2.97	Kg/lb
Condenser				
Water flow rate	0.30/0.08	0.30/0.08	0.30/0.08	[L/s]/[gal/s]
Tin water	35.4/95.7	34.6/94.3	44.9/112.8	[°C]/[F]
Tout water	38.7/102	39.7/103	49.8/122	[°C]/[F]
Evaporator				
Air flow rate	N/A	N/A	N/A	
Room air temp. 1 (DB)	-8.0/15.3	8.4/47.1	7.9/46.2	[°C]/[F]
Room air temp. 2 (DB)	-8.6/16.5	8.3/46.9	8.2/46.8	[°C]/[F]
Room WB temp.	-9.3/15.2	6.2/43.1	5.7/42.2	[°C]/[F]
Compressor Power Input	1625.2	1657.0	2088.5	[W]
Total System Power Input	1946.1	1974.5	2413.1	[W]
Heating capacity	4204.2/14345	6395.1/21821	6205.8/21176	[W]/[Btu/h]
COP	2.59/8.84	3.86/13.17	2.97/10.13	[W/W]/[Btu/W.hr]
System COP	2.16/7.37	3.24/11.06	2.57/8.77	[W/W]/[Btu/W.hr]

Results with the DR-5

Three refrigerant charges are tested with the DR-5 for each of the three operating conditions. These are: 1.4 kg/3.1 lb, 1.5 kg/ 3.3 lb and 1.6 kg/ 3.5 lb. Table 3 presents the results obtained for the three test conditions with the refrigerant charge that gives the best COP.

Table 3. Results for the DR-5

	Test Condition 1	Test Condition 2	Test Condition 3	Unit
Best refrigerant charge	1.4/3.1	1.4/3.1	1.4/3.1	Kg/lb
Condenser				
Water flow rate	0.30/0.08	0.30/0.08	0.30/0.08	[L/s]/[gal/s]
Tin water	35.3/95.5	34.5/94.1	44.8/112.6	[°C]/[F]
Tout water	38.9/102	39.9/104	50.2/122	[°C]/[F]
Evaporator				
Air flow rate	N/A	N/A	N/A	
Room air temp. 1 (DB)	-7.8/18.0	7.2/45.0	7.7/45.9	[°C]/[F]
Room air temp. 2 (DB)	-8.4/16.9	7.4/45.3	7.1/44.8	[°C]/[F]
Room WB temp.	-9.2/15.4	5.5/41.9	5.3/41.5	[°C]/[F]
Compressor Power Input	1628.4	1871.5	2253.1	[W]
Total System Power Input	1950.4	2188.5	2577.1	[W]
Heating capacity	4589.5/15662	6757.8/23059	6761.8/23073	[W]/[Btu/h]
COP	2.82/9.62	3.61/12.32	3.00/9.62	[W/W]/[Btu/W.hr]
System COP	2.35/8.02	3.09/10.54	2.62/8.02	[W/W]/[Btu/W.hr]

Discussion

Both low GWP blends ARM70a and DR5 have shown a higher heating capacity and system COP.

Figure 2 compares the heating capacity obtained with R-410A, ARM-70a (3 refrigerant charges) and DR-5 (3 refrigerant charges).

DR-5 presents the highest heating capacities between the three refrigerants and its optimal charge with regard to the heating capacity is 1.5 kg.

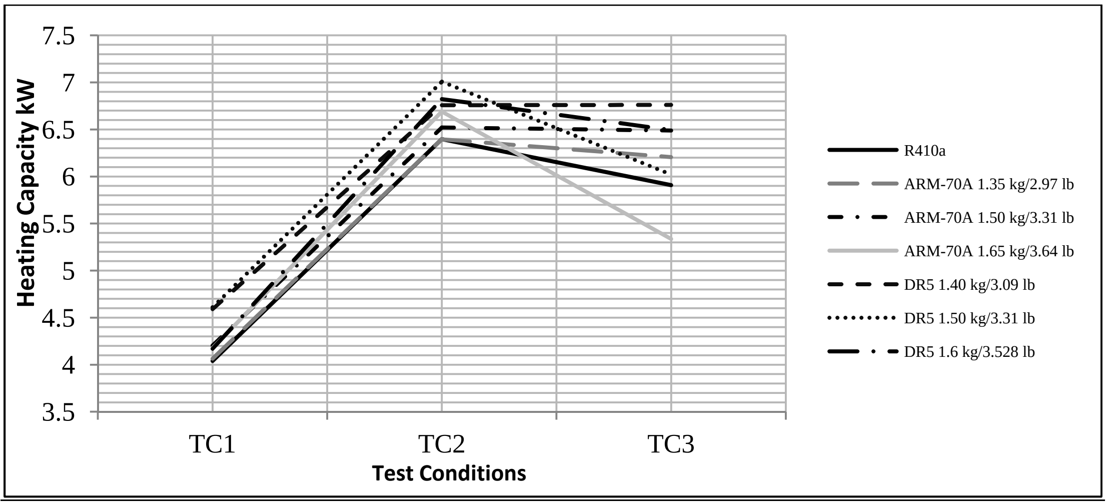

Figure 2 Heating capacity comparison

Figure 3 compares the system COP obtained in the all the tests performed. Both ARM70a and DR5 permit to obtain comparable results (10% higher for DR5 at test condition 1, 5% higher for ARM70a at test condition 2 and equivalent performances for the operating condition 3).

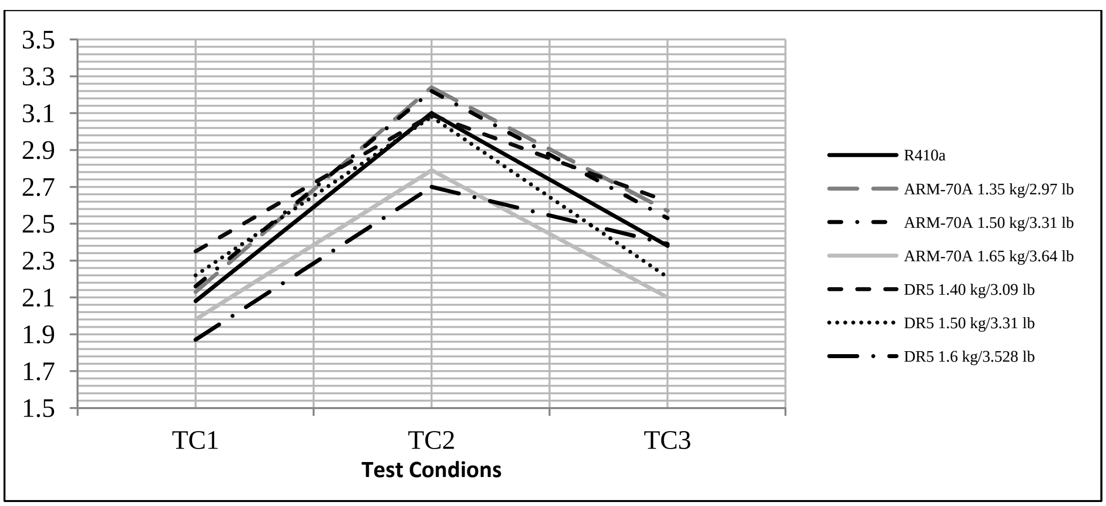

Figure 3 System COP comparison

CONCLUSIONS

Two low GWP refrigerants candidates for replacing R-410A are tested in an air to water heat pump. The tests conducted are drop in test without any modification of the equipment. Only refrigerant charge has been varied. Test results show that heating capacity is increased with the DR-5 about 10% compared to the R-410A. ARM-70a presents equivalent to higher heating capacities compared to R-410A.

For both alternative refrigerants, system COP is improved by 5 to 10%.

These results show interesting perspectives in a complex regulatory context especially in Europe where the new F-gas directive fixed the limits in term of GWP for refrigerants. Additional research is needed in order to derive heat transfer and pressure drop coefficients for these new refrigerants in order to supply manufacturers with design tools for their equipments.

NOMENCLATURE

COP = Coefficient of performance

DB = Dry bulb

Δ_{τ_i} = data acquisition time span (s)

GWP = global warming potential (kg_{eq} CO_2)

q = heat produced out of the defrost period (W)

RH = Relative Humidity (%)

τ = time (s)

WB = Wet bulb

Subscripts

avg = average

cd = condenser

REFERENCES

AHRI551/591. 2011. Performance Rating Of Water-Chilling and Heat Pump Water-Heating Packages Using the Vapor Compression Cycle

Arimoto H., Yamada Y., Tsuchiya T. and Shibanuma T. 2011. Environmentally friendly low GWP refrigerants for stationary AC&R applications. International Conference of Refrigeration. Prague, Czech Republic.

Atharva Barve and Lorenzo Cremaschi. 2012. Drop-in performance of low GWP refrigerants in a heat pump system for residential applications. International Refrigeration and Air conditioning conference at Purdue

Auvi Biswas and Lorenzo Cremaschi. 2012. Performance and capacity comparison of two new LGWP refrigerants alternative to R410a in residential air conditioning applications. International Refrigeration and Air conditioning conference at Purdue

Xudong Wang, Karim Amrane, Philip Johnson, 2012. Low global warming potential (GWP) alternative refrigerants evaluation program (Low-GWP AREP). International Refrigeration and Air conditioning conference at Purdue

Yajima R., Moriwaki M., Sugawa O., Imamura T. 2011. Experimental safety evaluation on flammability of R32 refrigerant. International Conference of Refrigeration. Prague, Czech Republic.