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Performance of Alternative Refrigerant R430A on Refrigeration System of Water Purifiers

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ABSTRACT

In this study, thermodynamic performance of R430A is examined numerically and experimentally in an effort to replace HFC134a used in refrigeration system of domestic water purifiers. Even though HFC134a is used predominantly in such a system these days, it needs to be phased out in near future in Europe and most of the developed countries due to its high global warming potential. To solve this problem, cycle simulation and experiments are carried out with a new refrigerant mixture of 76%R152a/24%R600a using actual water purifiers. This mixture is numbered and listed as R430A by ASHRAE recently. Test results show that the system performance is greatly influenced by the amount of charge due to the small internal volume of the refrigeration system in water purifiers. With the optimum amount of charge of 21 to 22 grams, about 50% of HFC134a, the energy consumption of R430A is 12% lower than that of HFC134a. The compressor dome and discharge temperatures and condenser center temperature of R430A are very similar to those of HFC134a for the optimum charge. Overall, R430A, a new long term environmentally safe refrigerant, is a good alternative for HFC134a in domestic water purifiers requiring no major change in the system.

1. INTRODUCTION

For the past few decades, CFCs have been widely used in various refrigeration and air-conditioning applications. They, however, were found to be responsible for the destruction of the stratospheric ozone layer and thus in 1987, the Montreal protocol was proposed to phase out the ozone depleting substances (UNEP, 1987). Thanks to the Montreal protocol, CFCs were entirely phased out in developed countries from 1996 while they will be completely removed from 2010 in developing countries.

In order to fill the gap caused by the phase out of CFCs, refrigeration and air-conditioning industry has carried out extensive research and development activities to find alternative refrigerants whose ozone depletion potential (ODP) is 0. As a result of these efforts, HFC134a has been successfully developed and adopted in new domestic refrigerators and water purifiers for the past decade. HFC134a is known to have a similar vapor pressure and performance to those of CFC12.

Recently, global warming has been the one of the most important issues facing mankind and in 1997, Kyoto protocol was proposed to control greenhouse gases including HFCs (GECR, 1997). Consequently, HFC134a was identified as one of the controlled greenhouse gases. The global warming potential (GWP) of HFC134a is 1300 as compared to that of CO₂. Therefore, it needs to be replaced by more environmentally safe long term refrigerant in the near future. In fact, EU F-Gases regulation and auto mobile air-conditioner directive ban the use of HFC134a from 2011 in auto mobile air-conditioners of newly manufactured vehicles for environmental protection (OJEU, 2006). The same auto mobile air-conditioner directive specifically prohibits the use of refrigerants whose GWP is higher than 150.

Due to the rapidly changing environmental and energy situation, more energy efficient domestic refrigerators and water purifiers charged with a refrigerant whose GWP is less than 150 are essential these days. Also in order to maintain the system change to a minimum level for cost effective manufacturing of such products, the conventional vapor compression refrigeration technology with similar compressor size and technology is necessary. One way of achieving this goal successfully with present technology is to use refrigerant mixtures of low GWPs.

Because of this trend to ban the use of HFC134a in refrigeration and air conditioning equipment, many countries have adopted flammable hydrocarbon refrigerants. Traditionally, flammable refrigerants have not been accepted in normal refrigeration and air-conditioning applications due to a safety concern. This trend, however, is somewhat relaxed these days due to an environmental mandate. Therefore, some of the flammable refrigerants have been applied to specified applications as pure working fluids or as one of the components of mixed working fluids (Kruse, 1996; Jung *et al.*, 2000). For instance, R600a (isobutane) has dominated the European refrigerator/freezer sector for the past decade (IEAHPC, 2002). In fact, hydrocarbons are known to offer such advantages as no ODP, low GWP (typically less than 3), low cost, availability, and compatibility with the conventional mineral oil (Kruse, 1996; Jung *et al.*, 2000).

Some studies have shown that it is difficult to find pure alternatives fluids to replace existing refrigerant unless a major change including a compressor re-design is undertaken. One of the ways of avoiding a major system change is the use of refrigerant mixtures which can tune the thermodynamic properties such as vapor pressure to provide similar capacity. Such refrigerant mixtures as R407C and R404A are good examples, which are used popularly these days for R22 and R502 applications. For these mixtures, similar size compressors can be used in the same system. Especially, refrigerant mixtures of small temperature glide during the phase change, often called near-azeotropes, with similar vapor pressure would be the best choice due to a decreased chance of fractionation caused by a leakage in the system.

The objectives of this paper are to measure the performance of a new refrigerant mixture of R430A in the refrigeration system of domestic water purifiers in an attempt to substitute HFC134a. R430A is almost an azeotrope composed of 76% of R152a and 24% of R600a by mass with a temperature glide of less than 0.1 °C and is recently listed by ASHRAE (2007). It has no ODP with relatively low GWP of 107 and hence can be used as a long term alternative refrigerant in water purifiers.

2. THERMODYNAMIC CYCLE ANALYSIS

Before experiments were carried out, thermodynamic performance of R430A was compared to that of HFC134a by cycle analysis. Figure 1 shows a simplified 2-dimensional sketch of the water purifier. A water container is placed at the top of the purifier and evaporator coil is located inside the water container. As the refrigeration operation begins, water gives out heat to the refrigerant in the direct contact evaporator and finally ice is formed on the outside the evaporator coil. A hermetic compressor is used for cooling and a capillary tube is used as an expansion device. A natural draft condenser is placed at the back of the purifier.

Figure 2 shows a schematic of a typical single-evaporator refrigeration system for water purifiers. Due to the heat exchange with the water in the water container, evaporation occurs and usually superheated vapor leaves the evaporator at state 1. During evaporation the refrigerant temperature rises for mixtures (gliding temperature effect) while the temperature remains constant for pure components if pressure drop is not considered. The vapor is compressed with work addition and becomes superheated vapor at high pressure and temperature (state 2). This vapor is desuperheated and condensed in the condenser and usually subcooled liquid or slightly saturated two-phase fluid leaves the condenser at state 5. Finally, expansion occurs through a capillary tube to complete the cycle and two-phase refrigerant enters the evaporator at state 6.

In thermodynamic simulation, a simple UA model was employed with a constant cooling load for both HFC134a and R430A as was done similarly by Jung and Radermacher (1991). In the model, the evaporator and condenser are specified by the product of an overall heat transfer coefficient and an area (UA). Typically, the evaporator and condenser saturation temperatures for HFC134a are -5 °C and 50 °C respectively and UA values are adjusted to yield the similar temperatures for HFC134a. For R430A, the same UA values are imposed in the condenser.

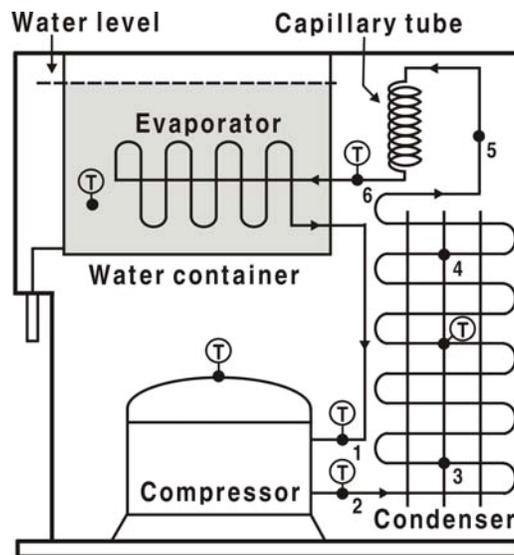


Figure 1: Refrigeration system for domestic water purifier

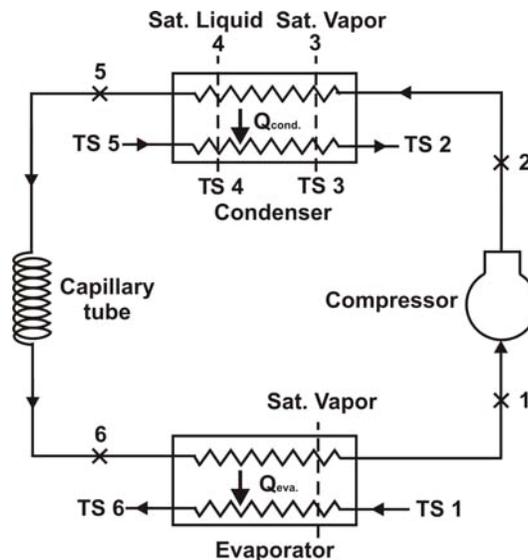


Figure 2: Schematic of a single evaporator refrigerator for water purifiers

The compressor is modeled by simply specifying an isentropic efficiency. Finally, the unknowns were determined by solving a set of nonlinear equations by Newton-Raphson's (NR) method. NR method requires initial guesses for the variables and iteratively find the solution by forcing the residual equations to be zero. More detailed information regarding the modeling is available elsewhere (Jung and Radermacher, 1991).

The cycle analysis was performed for both HFC134a and R430A. All thermodynamic properties needed for the simulation were computed by REFPROP program (2007). Table 1 summarizes the simulation results. Cycle simulation indicates that R430A offers significant increases in COP and capacity while the compressor discharge temperatures are similar.

Table 1: Simulation results

Refrigerant	COP	Diff. in COP (%)	VC(kJ/m ³)	Diff. in VC (%)	T _{dis} (°C)
HFC134a	1.836		1348		93.2
R430A	2.187	19.1	1527	13.3	95.4

3. EXPERIMENTS

In this work, refrigeration performance of R430A and HFC134a was measured on actual water purifiers. For this, pull-down tests were performed to compare the cooling capacity and energy consumption of these two refrigerants. For tests, water purifiers were placed inside an environmental chamber with 8.2 liter of water in the water container. The chamber was maintained at 35 °C with relative humidity of 50%. Test units were placed in the chamber for more than 3 hours for complete soaking before pull-down tests. And then, the pull-down was initiated with the supply of the power until a certain temperature set by the thermostat was reached. Typically, the set temperature is around 5.6 °C for the units.

During the pull-down tests, instantaneous power input to the compressor and 6 temperatures were measured every 30 seconds by a digital Watt meter of 0.2% accuracy and calibrated thermocouples attached at locations shown in Figure 1. Finally, the total power consumption was obtained by integrating the instantaneous power.

During the study, no change was made to the system including compressor, oil, and capillary tube since the objective of this study was to examine the drop-in feature of R430A. As for the tests of reference fluid of HFC134a, commercial mass production units currently available were chosen without any change.

4. RESULTS AND DISCUSSION

Table 2 lists the test results for HFC134a and R430A. For these refrigerants, tests were repeated at least three times to confirm the data. All data in Table 2 have good repeatability showing less than 1% scatter. Usually, the refrigerant charge is directly proportional to the liquid density at condenser temperature. An initial guess for the amount of charge for R430A can be taken with the consideration of liquid density ratio of these fluids. The liquid densities of HFC134a and R430A are 1102 and 699 kg/m³ at 50 °C respectively. Thus, the initial charge for R430A was determined to be 26 grams. With this charge, the system was overcharged and the charge was reduced by 1 gram and pull-down tests were performed with several charges for R430A. Table 2 shows the results for 4 different charges.

Table 2: Summary of test results

Refrigerant	Charge (g)	Starting temp. (°C)	Ending temp. (°C)	Operating time (min.)	Energy consumption (W·h)	Diff. in EC (%)	T _{dis} (°C)
HFC134a	42	30.23	5.61	109.7	228.2		93.5
R430A	19	30.19	10.37	149.5	222.6	-2.4	86.7
	20	30.21	8.58	149.5	238.8	4.7	89.3
	21	30.19	5.61	114.7	197.5	-13.4	93.5
	22	30.25	5.63	101.0	203.0	-11.0	95.3

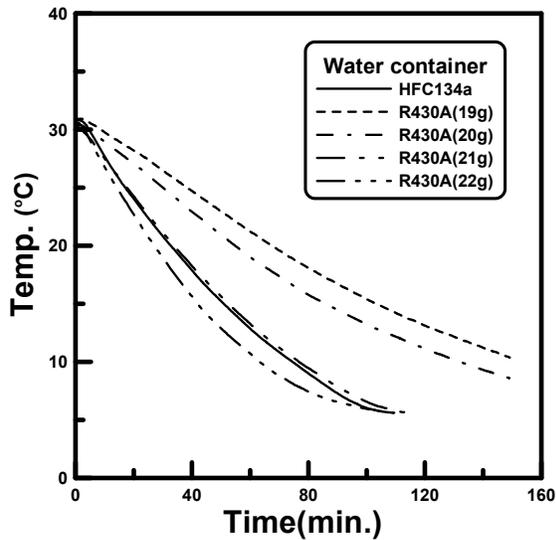


Figure 3: Water temperature during pull-down tests

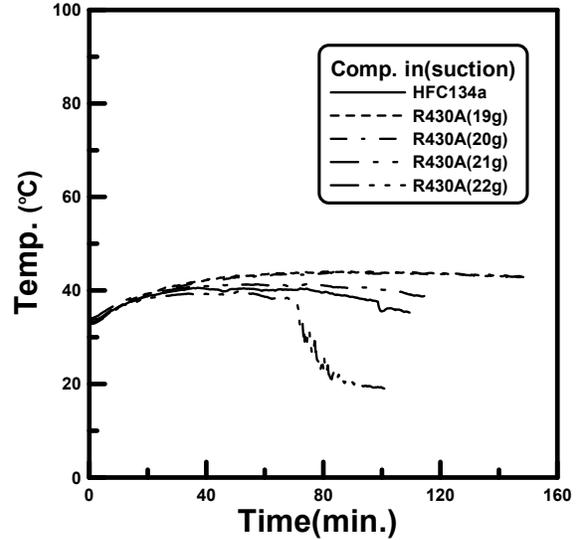


Figure 4: Evaporator exit temperature during pull-down tests

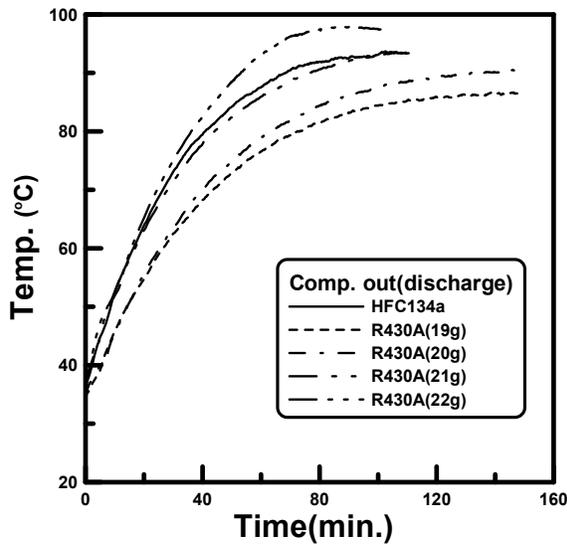


Figure 5: Compressor discharge temperature during pull-down tests

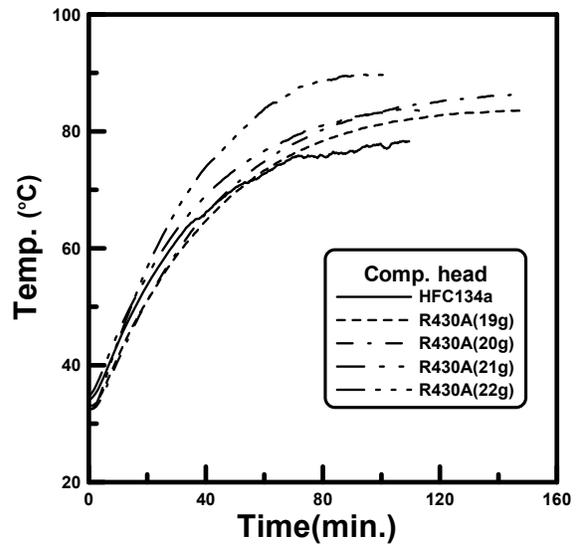


Figure 6: Compressor dome temperature during pull-down tests

Figure 3 shows the water temperature inside the container during the pull-down tests. As seen in Figure 3, the pull-down was greatly influenced by the amount of charge. Since the internal volume of the refrigeration system was very small, even 1 gram made a big difference in pull-down test results. Tests results indicate that the optimum charge for R430A would be around 21 to 22 grams. For these charges, the pull-down time would be similar to that of HFC134a and the energy consumption (EC) would be 12% lower than that of HFC134a. The cycle simulation prediction showed that the coefficient of performance (COP) of R430A would be 19.1% higher than that of HFC134a. But actual performance data showed 12% increase in energy efficiency. The difference may be explained by the capillary tube optimization and proper selection of the lubricant. As mentioned above, no change was made to the original HFC134a system.

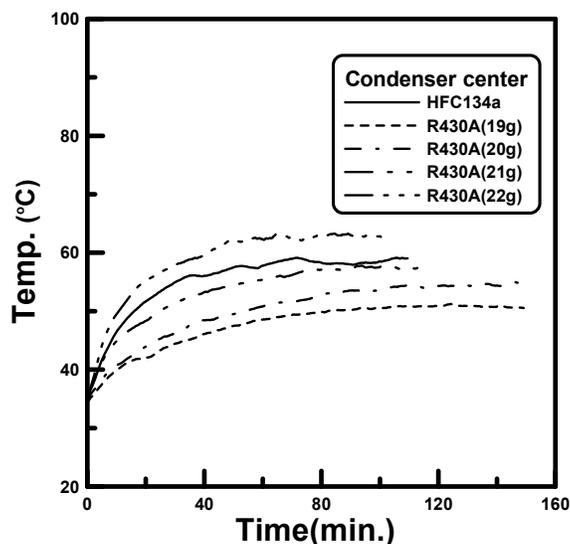


Figure 7: Condenser center temperature during pull-down tests

Figures 4 and 5 show the compressor discharge and dome temperatures during the pull-down tests. The average discharge temperature for R430A was similar to that of HFC134a. Cycle simulation results also showed the similar trend. Compressor dome temperature also showed the similar trend as seen in Figure 5.

Figure 6 shows the temperature at the evaporator exit (just before the compressor suction). For 19 and 20 grams of charge, the system was undercharged which was indicated by the significant amount of superheat. As the charge increased, the superheat decreased and for 21 grams of charge, the evaporator exit temperature is similar to that of HFC134a.

Finally, Figure 7 shows the temperature at the center of the condenser. Once again, for 21 grams of charge, R430A showed the similar trend of the condenser saturation temperature to that of R134a.

5. CONCLUSIONS

In this study, the performance of new refrigerant of R430A and HFC134a was measured in an environmental chamber during the pull-down tests. Based upon the test results, following conclusion can be drawn.

- Due to the small internal volume of the refrigeration system in water purifiers, the system performance was greatly influenced by the amount of charge.
- With the optimum amount of charge of 21 to 22 grams, about 50% of HFC134a, the energy consumption of R430A was 12% lower than that of HFC134a.
- The compressor dome and discharge temperature of R430A were very similar to those of HFC134a for the optimum charge.
- Condenser center temperature of R430A was also very similar to that of HFC134a.
- Overall, R430A, a new ASHRAE listed long term environmentally safe refrigerant, is a good alternative for HFC134a in domestic water purifiers requiring no major change in the system. Capillary tube optimization and the use of proper lubricant may increase the system performance further.

NOMENCLATURE

COP	coefficient of performance		Subscripts
EC	energy consumption	(W·h)	dis discharge
T	temperature	(°C)	
VC	volume capacity	(kJ/m ³)	

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