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Cycle performance of alternative refrigerants for domestic air-conditioning system based on a small finned tube heat exchanger

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HIGHLIGHTS

- Comparisons are made in the air conditioner system based on 5 mm tube fin heat exchanger.
- The R22 system has a similar performance to others in heating mode while a huge difference in cooling mode.
- The optimal charge of R290 is reduced with nearly no decline in the capacity and COP.
- SLHX is attached to the system of R290 and successfully promote safety and capacity.
- Heat loads are taken into account to evaluate the advantages and disadvantages of R290 and R32.

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ABSTRACT

In order to find alternative refrigerants which exhibit both favorable cycle performance and environmental friendliness, R32 and R290 were utilized to contrast to R22 and R410A as substitutes in the present study. The experiments were conducted with a 5 mm finned tube heat exchanger based on the enthalpy method in a small split household air conditioner. The results showed that in nominal cooling conditions, the COP_R of R32 and R290 were 26.8% and 20.4% higher than R22, 7.3% and 2.1% higher than R410A. And in nominal heating conditions, the COP_{HR} of R32 and R290 were both 11.0% higher than R22, 5.3% higher than R410A. The systems with R290 and R32 have similar capacities to that with R22 and R410A in heating mode, but a relatively huge difference of capacities in cooling mode. In consideration of charge amount, R290 could be considered as the most superior alternative refrigerant in air conditioners with the small finned tube heat exchanger.

1. Introduction

Since the HCFCs were firstly invented by Thomas Midgley and Albert Henne in 1930, they have become the dominant types of refrigerants. And chlorodifluoromethane (R22) has been predominantly used, in the past few decades, in domestic air-conditioners and heat pumps due to its preferable characteristics. However, it still contains ozone depleting chlorine and causes environmental problems [1], in spite of its lower ODP value compared to CFCs [2]. The Montreal protocol has made regulations for HCFCs production in the developed countries from 1996 and decided to abandon R22 as well as other HCFCs which are harmful to the environment in 2020 eventually [3]. So researches on finding alternatives to replace R22 have become hot issues.

In the past years, various substitutes have been studied as working fluids in refrigerating devices [4,5]. At the moment, replacements for R22 in household air-conditioners and heat pumps can be categorized into three types: HFC (hydro-fluorocarbons represented by R410A and R407C) [6], HC (hydrocarbons represented by R290) and other natural substances represented by CO_2 and NH_3. R410A is a binary mixture refrigerant composed of R32/R125 (50/50 wt%). Many countries persisted in using R410A in early years to replace R22, which does no harm to the ozone layer but even has a higher GWP value than R22. And at this time, R410A and R407C were already being used in some countries in place of R22 [7]. However, there have been studies accomplished by some influential agencies, claiming that the emissions of HFCs, mainly R410A, will undoubtedly exacerbate the greenhouse effect in 2050 [8]. Furthermore, the stability and other physical properties of the HCFC mixtures can hardly be determined under various states. Therefore, attention of experts has been drawn to the pure HCFC

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Nomenclature

COP	coefficient of performance
GWP	global-warming potential
ODP	ozone-depletion potentials
SLHX	suction line heat exchanger
EEL	energy efficiency labels
LFL	lower flammable limits
UFL	upper flammable limits
Q	capacity (W)
t	temperature (C)
p	pressure (Pa)

Subscripts

dis	discharge
suc	suction gas
e	evaporating
c	condensing
sup	supheat
sub	subcooling
R	refrigeration
HP	heat pump

with negligible environmental impacts or HCs, especially R32 and R290.

As a component of many working refrigerants (such as R410A and R407C), R32 has zero ODP value and a nearly same GWP value as R22. Except its superior physical properties, many experimental results have also indicated a good performance of R32 in the field of refrigerating. Zhao et al. [9] investigated the performance of some new refrigerant mixtures (R32/125/152a, R32/290 and R32/125/290) as replacements for R22 in both theory and experiment. Their study indicated that the compositions of the mixtures should be optimized along with the variation of operating conditions of the unit applications. Xuan et al. [10] had an experimental testing of the mixture of R161/R32/R125, the new ternary mixture was proved to be equipped with many merits in thermo-physical properties as an alternative refrigerant. Many researches have shown that R32 performed commendably as a composition of operating refrigerants in air conditioners [11], but the discussion on pure R32 as a working medium seems to be relatively few. Anowar Hossain et al. [12] studied the condensation heat transfer and pressure drop of R32 in a horizontal smooth tube with inner diameter of 4.35 mm. However, they did not study the cycle performance of R32 in an integral air-conditioning system. Yu et al. [13] presented a theoretical study on an R32 cycle with a two-stage suction ejector. The theoretical study showed that the developed cycle gave both a higher cooling (heating) capacity and a higher COP. Although the newly developed cycle could make a contribution to the application of refrigerant R32 in air-conditioner systems, experimental researches are still needed to confirm the superiority of R32.

R290 has zero ODP and a negligible GWP value, as a natural substance, and also behaviors friendly to the environment [7]. It exhibits obvious advantages being a substitute in characteristics of good thermo-physical and transport property, extensive source and low cost, which is also compatible with the lubricants used in air conditioning [14]. Many researches have indicated that R290 operates even better than R22. However, R290 is still restricted as an applied refrigerant because of its high flammability which may trigger risky incidents if not properly handled, even worse, the explosion may take place in rooms when a leakage occurs inside the house. Some international organizations tend to take its applications seriously and even forbid any use once [15]. But as a tendency of pursuing environmentally friendly refrigerants in the future, people have finally put their consideration back on R290.

James and Missenden [16] tested several refrigerators charged with R290 for 'bomb in cabinet' incident, and found out that even in the worst case the explosion and fire were unable to fire up the combustible liner of the refrigerators. However, the maximum charge of the objects they conducted in the experiment was only 40 g. Devotta et al. [17] experimentally studied a window air conditioner, which had a cooling capacity of 5.13 kW, COP_R of less than 2.5, and heat exchangers of 10 mm tubes, under lower and higher working conditions charged with R290 and R22. They found that the R290 system, compared to the R22 system, showed 6.6% and 9.7% lower in cooling capacity, respectively, but 7.9% and 2.8% higher in COP_R, respectively. Several adjustments had been conducted by Padalkar et al. [18] in a 5.13 kW capacity split air conditioner charged with R290, his work indicated that the larger condenser led to a 1.6% lower cooling capacity and a 10% higher COP_R in contrast to the original R22 system, meanwhile, the higher capacity compressor caused an improvement of cooling capacity by 2.8% and a reduction of COP_R by 1.1%. Zhou and Zhang [19] studied the cycle performance of R290 in a split air conditioner with a capacity of 3.2 kW, COP_R of 2.4, the condenser with 9.53 mm smooth tubes and the evaporator with 7 mm internally spiral groove tubes. They declared that the R290 system had a 4.7–6.7% lower cooling capacity and an 8.5% higher COP_R compared to the original R22 system. Wongwises et al. [20] investigated R290 as a component of hydrocarbon mixtures to replace HFC-134a in an automotive air conditioning system, the results indicated that every ratio of hydrocarbon mixture yields higher COP than HFC-134a.

These literature above proved that no matter the pure R290 or the mixtures containing R290 can perform well to be an appropriate substitute for R22 in air conditioners, but their studies still had some shortcomings needed to be conquered. With the growing public environmental awareness and scientific progress, the regulations of residential air conditioners are becoming increasingly strict. The energy efficiency labels (EEL) published in 2007 claimed that COP of a split air conditioner launched on the market with a capacity of less than 4.5 kW ought to be not less than 3.2. Moreover, reducing raw materials in manufacture appears to be urgent for the shortage of global copper resources [25], which demands the less copper cost per air conditioner without a reduction of cooling capacity and COP. Nevertheless, currently studies focus little on the split domestic air conditioners of high COP and small finned tube heat exchanger with lower copper cost, while most of the existing attentions are drawn on the air conditioners of low COP and heat exchangers of tubes larger than a diameter of 7 mm. Wu et al. [21] had a study on experimental performance of a small wall room air conditioner retrofitted with R290 with COP_R of 3.2 and heat exchangers of 7 mm tubes. Their study showed that the alternative systems all had higher increase rates and greater increment in both cooling capacity and COP_R, but the optimum charge of R290 optimized by performance was far beyond the safety standard. Tubes with small diameters can not only decrease the copper cost but also reduce the charge of a flammable refrigerant such as R290. Therefore, in the present study, cycle performances of a small air conditioner with a 5 mm finned tube heat exchanger in the indoor unit are experimentally detected under different working conditions. R32 and R290 are charged into the system to make a comparison with R410A and R22. An experimental test of suction line heat exchanger (SLHX) on the R290 system is operated to promote safety. This study provides experimental support of applications of alternative refrigerants in domestic air conditioners with small finned tube heat exchangers.