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Performance characteristics of a small-capacity directly cooled refrigerator using R290/R600a (55/45)

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ABSTRACT

In this study, the performance of a small-capacity directly cooled refrigerator was evaluated by using the mixture of R290 and R600a with mass fraction of 55:45 as an alternative to R134a. The compressor displacement volume of the alternative system with R290/R600a (55/45) was modified from that of the original system with R134a to match the refrigeration capacity. Both systems with R290/R600a (55/45) and R134a were tested, and then optimized by varying the refrigerant charge and capillary tube length under experimental conditions for both the pull-down test and the power consumption test. The refrigerant charge of the optimized R290/R600a system was approximately 50% of that of the optimized R134a system. The capillary tube lengths for each evaporator in the optimized R290/R600a system were 500 mm longer than those in the optimized R134a system. The power consumption of the optimized R134a system was 12.3% higher than that of the optimized R290/R600a system. The cooling speed of the optimized R290/R600a (55/45) system at the in-case setting temperature of −15 °C was improved by 28.8% over that of the optimized R134a system.

Les caractéristiques en terme de performance d'un réfrigérateur à refroidissement direct utilisant un mélange de R290 et de R600a (55:45)

Mots clés : Réfrigérateur domestique ; Mélange binaire ; Propane ; Isobutane ; Expérimentation ; Comparaison ; R134a ; Performance

1. Introduction

In compliance with the Montreal protocol and the Kyoto protocol, many refrigerants containing CFCs and HCFCs (hydrochloroflurocarbons) were gradually replaced with HFCs (hydrofluorocarbons) (UNEP, 1987). Ozone-depletion potential (ODP) of HFCs is zero, but their global warming potential (GWP) is relatively high. Due to reinforced

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Nomenclature

ID	capillary inner diameter, mm
L	capillary length, mm
NBP	normal boiling point, °C
P_c	critical pressure, MPa
T_c	critical temperature, °C
T_{set}	in-case setting temperature, °C

environmental regulations on GWP, restrictions on existing small and large-capacity refrigeration systems using R134a have been strengthened. Many natural refrigerants such as water, carbon dioxide, and ammonia as well as hydrocarbons have been investigated as alternative refrigerants to R134a. Among these alternatives, hydrocarbon and their mixtures (HCs) are recognized as strong alternative refrigerants for the existing small- and large-capacity refrigeration systems because the application of HC mixtures does not require major changes in the components (Jang, 1997). HCs have many advantages including environmental friendliness, chemical stability, high heat transfer coefficients and low refrigerant charge. However, HCs show relatively high flammability.

Numerous experimental and theoretical investigations on pure and mixed refrigerants of HCs in household refrigerators have been performed. Richardson and Butterworth (1995) studied the performance of propane/isobutene mixtures in a vapor-compression refrigeration system. Baskin and Perry (1994) and Wongwises and Chimres (2005) investigated the performance of hydrocarbon mixtures to replace R134a in domestic refrigerators. They reported that the mixtures of R290 and R600, and R290 and R600a were the promising alternatives to R134a in terms of system performance. Jung et al. (2000) and Yun and Kim (2002) represented that the mixture of R290 and R600a provided a better performance than R600a as an alternative of R134a. In addition, the compressor displacement volume for the mixture of R290 and R600a was less than that for R600a due to the lower specific volume of the mixture of R290 and R600a. The flammability of the mixture of R290 and R600a is not a problem in a small-capacity refrigeration system with the refrigerant charge below 100 g based on R134a (Wongwises and Chimres, 2005; Jung et al., 2000). However, it can cause some problems in a large-capacity household refrigerator with the refrigerant charge over 100 g.

As shown in Table 1, no pure HCs show the same thermodynamic properties as R134a. However, R290 and R600a show similar thermodynamic properties, such as normal boiling point (NBP), saturation temperature and pressure (Yun and Kim, 2002). The mixture of R290 and R600a may be an alternative refrigerant of R134a with only minimal modification of an existing small-capacity refrigeration system (Jung and Radermacher, 1991; Stewart et al., 1986). It was reported that the composition of an R290 and R600a mixture showing similar thermodynamic properties as R134a was 50:50 or 40:60 in mass percent (Didion and Bivens, 1990; Shin et al., 1996; Kim et al., 1994). Based on the screening analysis in which the composition ratio of R290 and R600a was varied, the optimum composition ratio of R290 and R600a to acquire comparative thermodynamic properties as R134a and achieve high system performance was determined to be 55:45 in mass percent (Park et al., 2006). Therefore, the composition ratio of R290 and R600a was fixed at 55:45 in mass percent in this study.

Table 1 – Normal boiling points and critical points of R12, R134a, and hydrocarbons

Refrigerant	NBP (°C)	P_c (MPa)	T_c (°C)
R170	−88.6	4.87	32.18
R1270	−47.7	4.66	92.4
R290	−42.1	4.25	96.7
R12	−29.8	4.14	112.0
R134a	−26.1	4.06	101.1
R600a	−11.7	3.64	134.7
R600	−0.6	3.80	152.0

A small-capacity directly cooled refrigerator, which is shown in Fig. 1, is very popular in Korea to store foods and fruits. The directly cooled refrigerator uses different evaporator and door types from a typical household refrigerator. It adopts a container-type evaporator without a fan. The flattened copper tubes are directly attached to the outside wall of a compartment. Such a system is very effective for minimizing the temperature difference between the top and the bottom of the compartment. The small-capacity directly cooled refrigerator tested in this study includes three separate compartments with directly cooled evaporators, which is very effective to control the setting temperature in each compartment with the direct contact between the evaporator and the compartment. In addition, it uses up and down type doors that are more effective to reduce heat loss to the ambient than front and back type doors used in household refrigerators. Generally, the small-capacity directly cooled refrigerator uses R134a as a working fluid. To meet the environmental regulations, the performance of alternative refrigerants in the directly cooled refrigerator needed to be investigated. However, there is a limited amount of data available for a small-capacity directly cooled refrigerator with HC mixtures.

The objectives of this study are to investigate the feasibility of the application of R290/R600a (55/45) into a small-capacity directly cooled refrigerator with the minimum modifications of the original system designed for R134a and to analyze the performance characteristics of the system with variations of operating parameters. In the present study, the performance of a small-capacity directly cooled refrigerator was measured by using R290/R600a (55/45) and R134a, respectively, with variations of refrigerant charge, capillary length and operating conditions. The respective performances of the refrigerator were compared and analyzed to provide data for the optimum design when R134a is replaced by R290/R600a (55/45).

2. Experimental setup and test procedure

2.1. *Experimental setup*

Fig. 2 shows the schematic of the experimental setup. The test setup included a small-capacity directly cooled refrigerator and data acquisition system. The tested refrigerator consisted of a compressor, a condenser, and three evaporators with three capillary tubes and three check valves. The