

Experimental transient performance of a heat pump equipped with a distillation column

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Abstract

A series of experiments were conducted on a heat pump equipped with a distillation column. The system was operated with R32 and with a 30/70% by mass mixture of R32/134a to examine the difference between the transient performance trends with a pure fluid (R32), and those with a zeotropic mixture (R32/134a). Additionally, the effects of varying heat transfer fluid mass flow, compressor speed, and accumulator sump heat input were examined. Each test was 1 h in duration. The heat pump capacities did not generally achieve steady state during the R32/134a tests. Steady state was generally achieved during the R32 tests. As a percentage of the final (end-of-test) capacity, the rate of capacity increase was greater during the R32/134a tests than during those conducted with the pure fluid. The R32/134a tests exhibited capacity oscillations early in each transient that were not present during the R32 tests. The results show that circulating refrigerant mass and composition are the primary controlling factors with regard to transient capacity.

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Keywords: Heat pump; Experiment; Refrigerant; R32; Binary mixture; R134a; Transient; Distillation; Performance

Performance transitoire expérimentale d'une pompe à chaleur munie d'une colonne de distillation

Mots clés : Pompe à chaleur ; Expérimentation ; Frigorigène ; R32 ; Mélange binaire ; R134a ; Régime transitoire ; Distillation ; Performance

1. Introduction

The steady-state measure of how well a heat pump utilizes electrical energy input to heat or cool an occupied

space is the coefficient of performance (COP). In heating mode, this is typically calculated from

$$\text{COP} = \frac{\dot{q}_{\text{cd}}}{\dot{w}_{\text{cp}}} \quad (1)$$

But COP is only a partial indication of the overall performance of a heat pump. Over the course of a season, heat pumps cycle on and off numerous times. Better insight to the impact of cycling on a customer's electrical consumption

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Nomenclature

COP	Coefficient of performance	$\dot{q}$	Rate of heat transfer (heat exchanger capacity) [W]
c_{pr}	Constant pressure specific heat of the heat transfer fluid [$\text{J kg}^{-1} \text{ } ^\circ\text{C}^{-1}$]	$\dot{q}_{cd}$	Rate of heat output from the condenser [W]
HSPF	Heating seasonal performance factor [$\text{Btu W}^{-1} \text{ h}^{-1}$]	$\dot{q}_{sp}$	Rate of heat input to the sump [W]
HTF	Heat transfer fluid	rpm_{cp}	Compressor speed [rpm]
$\dot{m}_f$	Heat transfer fluid mass flow rate [kg s^{-1}]	τ_{cp}	Compressor drive shaft torque [N m]
$\dot{m}_{f_{cd}}$	Heat transfer fluid mass flow rate through the condenser [kg s^{-1}]	$T_{f_{in}}$	Heat transfer fluid inlet temperature [$^\circ\text{C}$]
$\dot{m}_{f_{ev}}$	Heat transfer fluid mass flow rate through the evaporator [kg s^{-1}]	$T_{f_{out}}$	Heat transfer fluid outlet temperature [$^\circ\text{C}$]
		$\dot{w}_{cp}$	Compressor power [W]

is gained by evaluating the heating seasonal performance factor (HSPF).

$$\text{HSPF} = \frac{\text{Seasonal building heat load (Btu h}^{-1}\text{)}}{\text{Seasonal power input (W)}} \quad (2)$$

HSPF is calculated using a procedure established by the National Institute of Standards and Technology [1].

Generally, the HSPF calculation procedure requires experimental heat pump startup/shutdown testing to determine the expected cyclic losses in terms of a “cyclic degradation coefficient,” which is then included in the HSPF calculation. The HSPF calculation procedure also allows the use of a default degradation coefficient that represents an experience-based estimate of the aggregate effects of cycling. The value of the default degradation factor was established using R22, a single component refrigerant, and was designed to be conservative.

Mulroy and Didion [2] showed that cyclic losses are largely attributable to the lack of circulating charge during startup. In fixed area expansion device systems, the refrigerant migrates to the accumulator during the off-cycle, and the time required to reach maximum performance depends on how long it takes the refrigerant to re-establish its steady-state distribution throughout the system.

Because of the lack of single component direct R22 replacements, refrigerant mixtures have received attention as alternatives in heat pumps. Zeotropic refrigerant mixtures, in particular, present certain thermodynamic advantages over pure fluids. Mulroy et al. [3] and Domanski et al. [4] showed that the average temperature differences between the heat transfer fluid (HTF) and the refrigerant in counterflow condensers and evaporators can be reduced when using zeotropic mixtures. This leads to reduced irreversibilities and, therefore, improved COP. Additionally, Cooper and Borchardt [5] and Gromoll and Gutbier [6] showed that zeotropic mixtures could be used to modulate heat pump capacity by varying the volatility of the circulating refrigerant. Furthermore, Rothfleisch [7] demonstrated that capacity modulation could be passive. Rothfleisch conducted

experiments using a zeotropic mixture in a system equipped with a fixed area expansion device in heating mode. As the outdoor temperature decreased, more and more refrigerant was stored in the accumulator. Due to vapor–liquid equilibrium, this caused the circulating composition to become richer in the more volatile component. As a result, the heating capacity decrease associated with decreasing outdoor temperature was attenuated. Rothfleisch also incorporated a heater and distillation column to enhance the composition shift further.

Because of the impact of circulating composition on steady-state performance, it is reasonable to expect that transient changes in circulating refrigerant composition also would affect transient performance. As is the case for circulating mass [2], this should have an impact on the HSPF cyclic degradation factor. However, no experimental work was found in the open literature comparing transient heat pump characteristics when charged with zeotropic mixtures with the characteristics when charged with a pure refrigerant. Also, no work examining heat pump transient behavior due to changing circulating composition was found.

The goal of the present investigation was to experimentally examine the transient characteristics of a heat pump equipped with a distillation column charged with a single component refrigerant and with a zeotropic mixture (R32 and R32/134a, respectively). The experiments were conducted using variations in four design parameters.

2. Experimental apparatus and procedures

The distillation heat pump consisted of a refrigerant loop and two water–ethylene glycol HTF loops (Fig. 1). A variable-speed reciprocating compressor pumped the refrigerant through the condenser and evaporator, which were counterflow heat exchangers composed of annular tubes. The heat exchangers were of the same design as those described by Kedzierski and Kim [8,9]. The expansion device was a needle valve. A distillation column, refrigerant storage accumulator (sump), and electrical heat source were

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