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Project Summary

A Transient and Steady State Study of Pure and Mixed Refrigerants in a Residential Heat Pump

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The report gives results of an experimental and theoretical investigation of the transient and steady state performance of a residential air-conditioner/heat pump (AC/HP) operating with different refrigerants. The project was motivated by environmental concerns related to the replacement of stratospheric ozone depleting refrigerants as required by international agreement and U.S. law. Hydrochlorofluorocarbon (HCFC)-22, a medium pressure refrigerant, is scheduled to be phased out of production and must be replaced. Significant empirical data are available on HCFC-22, but relatively little data exist on the transient performance of any of the zeotropic mixtures being considered as HCFC-22 replacements.

The experimental work, conducted by testing an AC/HP in environmental chambers, documented refrigerant performance for steady state, cyclic, and seasonal performance, evaluated various equipment modifications, and measured changes in the concentrations of refrigerant mixtures as a function of time. A computer model capable of modeling the transient and steady state performance of an AC/HP was developed. This model is the first capable of representing the significant transient and steady state physics of an AC/HP operating with pure and mixed refrigerants while using minimal empirical data. The simulation was used to study several system configurations transiently and at steady state with both HCFC-22 and mixtures.

This Project Summary was developed by EPA's National Risk Management Research Laboratory's Air Pollution Prevention and Control Division, Research Triangle Park, NC, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

The transient and steady state performance of a vapor compression system operating with pure and mixed refrigerants was investigated. This was accomplished both experimentally and theoretically by examining the performance of a residential air-conditioner/heat pump (AC/HP) operating with different refrigerants. The experimental investigation involved testing an AC/HP in environmental chambers designed and built for this purpose. The theoretical investigation involved a computer simulation which was developed for this work. In the work, the effects of various system configurations were also investigated.

Background

The project was motivated by environmental concerns related to the replacement of stratospheric ozone depleting refrigerants as required by international agreement and U.S. law. Hydrochlorofluorocarbon (HCFC)-22, a medium pressure refrigerant used in heating, cooling, and refrigeration applications, is scheduled to be phased out of production and must be replaced. Currently, no pure nonflammable refrigerant has been identified as an acceptable replacement for HCFC-22. However, several suitable zeotropic mixtures of hydrofluorocarbons (HFCs) have been identified. Most notable, the mixture of HFC-32, -125, and -134a in the proportions of 23/25/52 wt % (industry-designated as R-407C) is the refrigerant most likely to replace HCFC-22 in retrofit applications.

The steady state performance of a vapor compression system is of interest since it represents the ideal mode of operation. As such, it is an upper limit for the performance of any vapor compression system. Transient operation of a vapor compression system is of interest since an overwhelming majority of these units control capacity and temperature by cycling the system on and off. Hence, to develop control equipment, it is important to understand the transient aspects of these systems. System reliability is also affected by transient operation. For example, at start-up, a system will typically pump some fraction of liquid into the compressor. If too much liquid is pumped into the compressor, the compressor is likely to fail. Furthermore, cycling results in capacities and energy efficiencies which are roughly 75% of their steady state values. Hence, real world performance is significantly lower than that predicted by steady state system evaluation.

Significant empirical data are available on the steady state performance of HCFC-22 and its replacements. Relatively little data are available on the transient performance of HCFC-22 and no data are available on the transient performance of any of the zeotropic mixtures being considered as HCFC-22 replacements. It was the goal of this work to address these deficits. Specifically, the experimental aspects of this work were to (a) measure the steady state, cyclic, and seasonal performance of R-407C relative to HCFC-22, (b) evaluate the effects of vapor-to-liquid-line heat exchange and different expansion devices on performance, and (c) measure the circulated concentration of refrigerant mixtures. The theoretical aspects of the work were to (a) develop a detailed simulation capable of modeling the steady state and transient behavior of an AC/HP using pure and mixed refrigerants, and (b) accurately model the effects of different system configurations.

Results

The experimental work documented the performance of R-407C relative to HCFC-22 for steady state, cyclic, and seasonal performance. The combination of steady state and cyclic performance showed that R-407C had a 4.3% lower cooling seasonal performance factor (CSPF) than HCFC-22 and a 1.5 to 7% lower heating seasonal performance factor (HSPF) than HCFC-22. The lower energy efficiency of R-407C contributes to greater generation of global warming gases at the power plant. The performance of a vapor-to-liquid-line heat exchanger was also evaluated with both refrigerants. While this equipment had no impact on steady state performance, it did marginally improve the cyclic performance of both fluids. The cyclic and steady state performance of the heat pump was quantified with both short tube restrictors (STRs) and thermostatic expansion valves (TXVs). When the AC/HP used the STR, it had a 3.6% lower CSPF and a 0 to 3.9% lower HSPF than when the TXV was used. Furthermore, the STR significantly increased the sensitivity of system performance to the amount of refrigerant charge. The concentrations of two refrigerant mixtures, R-407C and a yet-to-be-designated mixture of 30% HFC-32 and 70% HFC-134a, were measured in the system as a function of time. Although the concentrations changed with time as the system was started up, the steady state circulated concentration was reached within about 3 minutes. The circulated concentration was also not equal to the charged concentration, the concentration of both refrigerant mixtures shifting away from the less volatile component. This concentration shift was attributed to the velocity difference between the phases in the heat exchangers.

On the theoretical side, a fully implicit, distributed parameter simulation computer model was developed, capable of modeling the transient and steady state performance of an AC/HP. This model is the first capable of representing the significant transient and steady state physics of an AC/HP operating with pure and mixed refrigerants while using minimal empirical data. The simulation was used to study several system configurations transiently and at steady state with both HCFC-22 and mixtures. The model demonstrated that R-407C is more sensitive to counter and parallel flow geometries in the heat exchangers than is HFC-22. It also predicted the shift in the circulated concentration shown in the experimental work. The penalty associated with having long connecting piping between the outside and inside components of an AC/HP was studied with the model and was shown to be significant due to transient effects. The major energy losses associated with transient operation were shown to be due to reducing the temperature in the evaporator and redistributing the refrigerant, with little loss due to overcoming the inertia in the compressor.

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The complete report, entitled “A Transient and Steady State Study of Pure and Mixed Refrigerants in a Residential Heat Pump,” (Order No. PB97-117741; Cost: $49.00, subject to change) will be available only from
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