United States Environmental Protection Agency
National Risk Management Research Laboratory
Cincinnati, OH 45268
Research and Development
EPA/600/SR-98/037 April 1998

Project Summary

Transport Property Measurements of HFC-236ea

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A candidate to replace 1,2-dichlorotetrafluoroethane (CFC-114) in surface craft and submarine chiller units is 1,1,1,2,3,3-hexafluoropropane (HFC-236ea). This study is an evaluation of transport properties of HFC-236ea, with liquid viscosity and thermal conductivity being the two main transport properties of interest. In addition, the specific heat and density of refrigerant/lubricant mixtures are also provided in this study.

This study used a novel method for simultaneously measuring viscosity and thermal conductivity by using inline property sensors in series with a heat transfer measurement system. Specifically, viscosity was measured with an inline torsional oscillation viscometer, while thermal conductivity was measured from the knowledge of single-phase heat transfer characteristics of a heated test-section.

The viscosity and thermal conductivity measurements for CFC-114 were compared with American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) data, with agreement being within ±5% for thermal conductivity and ±2% for viscosity. For HFC-236ea, the measured data were compared with REFPROP, a theoretical prediction package developed by the National Institute of Standards and Technology (NIST), with average deviations being within +15% in thermal conductivity and -5% in viscosity.

The properties of HFC-236ea mixed with a lubricant (Castrol oil SW68) were also investigated. The results showed that thermal conductivity increased with lubricant concentration at lower temperatures, while it decreased slightly at higher temperatures. However, at high temperatures there was no significant difference of thermal conductivity of refrigerant/lubricant mixtures between various lubricant concentrations. For the viscosity of HFC-236ea and lubricant mixtures, the results showed significant increases at higher lubricant concentrations, especially at lower temperature ranges.

[This work was funded through the U.S. Department of Defense's Strategic Environmental Research and Development Program (SERDP).]

This Project Summary was developed by the 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

HFC-236ea is a possible replacement candidate for CFC-114. There are several reasons that this refrigerant shows promise to replace CFC-114. First, the thermophysical properties were investigated and found to be similar to those of CFC-114. Second, according to simulation results, the performance of HFC-236ea is similar to that of CFC-114 which makes it attractive as a replacement refrigerant for surface craft or submarine chiller refrigerant. The EPA, in cooperation with the U.S. Navy, has also shown that HFC-236ea would have other favorable characteristics with respect to Navy applications.

Objective

The objective of this study was to measure the transport properties of HFC-236ea with and without lubricant (Castrol oil SW68), using a new methodology. The transport properties of particular interest are thermal conductivity and viscosity, with density and specific heat also being measured. Measured data for pure refrigerant were compared with other theoretical data sources such as REFPROP. The methodology was verified, using the properties of CFC-114.

Scope

The scope of this study was:

- Design and construct a test rig for measuring transport properties with emphasis on thermal conductivity based on the knowledge of single-phase heat transfer.
- Install a viscometer in series with a heat transfer test-section for simultaneously measuring viscosity and thermal conductivity.
- Calibrate heat transfer and heat loss characteristics of the test-section by using refrigerants of known properties.
- Verify the accuracy of viscometer with fluids of known viscosity.
- Measure the viscosity and thermal conductivity of CFC-114 and compare them with ASHRAE standard handbook data.
- Measure the viscosity and thermal conductivity of HFC-236ea and compare them with theoretical prediction data (i.e., REFPROP).
- Measure the viscosity and thermal conductivity of HFC-236ea with lubricant.
- Develop prediction equations from measured properties.

In this study, density, D , and specific heat, C_p, for the refrigerants of interest were also measured and discussed.

Experimental Test Facility

The experimental test rig was established for the purpose of measuring liquid transport properties of pure refrigerants, refrigerant mixtures, and refrigerant/lubricant mixtures. The approach used was a combination of commercially available sensors (in the case of viscosity and density) in series with an electrically heated and instrumented test section. Convection heat transfer coefficients were measured in the electrically heated test section and from these measurements, thermal conductivity and specific heat data were obtained.

The test-section was a 3/8-in. (0.95 cm) inner diameter by 2-m long smooth copper tube. The measured quantities were tube wall temperature, inlet/outlet fluid temperatures, absolute and differential pressures, viscosity, and mass flow rate. To measure heat transfer coefficients, temperature sensors were installed at various points in the test section. Specifically, 11 T-type thermocouples were installed on the outer wall of the tube at equal distances of 0.2 m, starting from the inlet point and ending at the outlet point, along the 2-m long test section. To get more average temperature measurements at the inlet and outlet locations, two additional thermocouples were placed 0.1 m from the inlet and the outlet points on the outer tube wall. Moreover, one thermocouple was placed on the outer insulated wall surface for measuring the temperature there. Two resistance temperature detectors (RTDs) were placed at the inlet and outlet points of the test section to measure the respective fluid temperatures. All thermocouples and RTDs were calibrated to ±0.05°C.

Results and Discussion

This study used a new approach for simultaneously measuring several thermophysical properties (e.g., thermal conductivity, viscosity, specific heat, and density). This approach used single-phase in-tube heat transfer knowledge to obtain thermal conductivity. Viscosity was measured by a viscometer placed in-line with the heat transfer test section. There are two approaches: Approach 1, the Nusselt number (*Nu*) method; and Approach 2, the Prandtl number (*Pr*) method. The uncertainty analysis was presented in this study. Approach 2 seems to have less uncertainty than Approach 1, and inlet temperature, T_i, and temperature differential,)*T*, do not significantly affect the uncertainties. However, the average temperature difference between the average wall temperature of the test section and the average fluid temperature of the test section ()T_{wf}) is a significant parameter that affects the uncertainties.

In Approach 1, the determination of a calibration function (*CF*) by experiments using fluids with known properties was shown to be important for accurate thermal conductivity measurements. Three *Nu* correlations were used for calculating thermal conductivity in this study, and they were examined and discussed. Four refrigerants--HCFC-22, CFC-12, CFC-113, and CFC-114--were used for calibration and verification purposes which cover the *Pr* from 3 to 9 and Reynolds number based on diameter *D* (Re_D) from 8,000 to 180,000. Based on the calibration results, the *CF* functions were found for three correlations examined in this study. Approach 2 bypasses the *Nu*, and thermal conductivity was found from *Pr* which is directly related to Re_D and non-dimensional temperature,)*T**. This approach was shown to be more accurate and convenient to use because less variables were involved. A theoretical uncertainty analysis also showed this approach to have less uncertainty than Approach 1. The measured results were also compared and discussed for both approaches.

Viscosity was measured by a torsional oscillation inline viscometer. The accuracy of the viscosity measurement was verified with CFC-113, CFC-12, and pure water and shown to be within ±2% when compared with the ASHRAE data. Other measured properties including specific heat, density, viscosity, and thermal conductivity were also examined for CFC-114, compared with ASHRAE data, and shown to be matched closely to within ±5% for thermal conductivity, ±3% for specific heat, and ±1% for density.

For HFC-236ea property measurements, REFPROP-4.0 data were used as a comparison with the measured data. The deviations of measured properties from REFPROP-4.0 are +4.8% for specific heat, -5.0% for viscosity, ±1% for density, and +15% for thermal conductivity.

A lubricant (Castrol oil SW68) was selected to be mixed with HFC-236ea. Properties were measured for five lubricant concentrations over a temperature range of -10 to 60°C. Thermal conductivity effects due to adding lubricant seemed to be more significant at low temperatures than high temperatures. For example, the thermal conductivity was found to increase up to 40% compared with the pure refrigerant at a low temperature (-10°C), while this increase of thermal conductivity was less than 8% at a high temperature (60°C). Viscosity was obviously affected by lubricant concentration, especially at a low temperature and high lubricant concentration. It increased over 300% from the pure mixture at the low temperature for a lubricant concentration of 11.6% while it increased less than 100% at the high temperature. Curve fit equations for both one variable (temperature) and two variables (temperature and lubricant concentration) were provided for convenient use. Other properties such as density, specific heat, thermal diffusivity, and *Pr* were also determined.

Conclusions

Using the measuring method developed in this study, viscosity and thermal conductivity data for CFC-114 were compared with ASHRAE data with agreement being within ±5% for thermal conductivity and ±2% for viscosity.

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Viscosity and thermal conductivity measurements were affected by lubricant addi tion to HFC-236ea, especially at low temperatures and high lubricant concentrations. At the low temperature (-10°C) for example, viscosity increased less than 50% as oil was added to the pure refrigerant to a lubricant concentration of 7.4%, while it increased about 100% at the high temperature (50°C) for the same mixture concentration change. It should also be noted that the viscosity at the lower temperature was about triple that at the higher temperature for the pure refrigerant. At the mixture concentration with 7.4% (by mass) oil, the viscosity at the lower temperature was nearly quadruple that at the higher temperature. Thermal conductivity decreases at a temperature of 50°C while thermal conductivity at -10°C increases as the mixture changes from a pure refrigerant to one having 7.4% oil.

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The complete report, entitled "Transport Property Measurements of HFC-236ea," (Order No. PB98-137185; Cost: $44.00, subject to change) will be available only from:
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