別紙第 1 号様式　　　　　　　　　　No.1

博　士　論　文　の　要　旨

専攻名 Department of Science and Advanced Technology (システム創成科学専攻)

氏　名（本籍）**Dipayan Mondal** (Bangladesh)

博士論文題名

（外国語の場合は，和訳を付記する。）

Transport Properties Measurements of Next-Generation Refrigerants and Mixture

(次世代の純冷媒及び混合冷媒の輸送性質の測定)

要旨（２，０００字程度にまとめること。）

Concerns about the global warming potential (GWP) of conventional refrigerants have prompted researchers to seek out low-GWP alternatives having other suitable properties in terms of environmental context. With the awareness of the environmental issues, the reduction of greenhouse gas emissions in accordance with the Kyoto Protocol is more familiarized to meet the new outcomes of next-generation refrigerants. Refrigerants belong to the hydrofluoroolefins (HFOs), hydrochloro-fluoroolefins (HCFOs) and hydrofluoroether (HFEs) families are promising candidates for designing high-temperature heat pumps and organic Rankine cycles owing to their favorable properties especially for low-GWP. The viscosity and thermal conductivity are the important transport properties of working fluids that are used as the key tools to design and implement the optimum energy systems, efficient processes, selection of the refrigerant for the practical appliances, and simulations. Therefore, the motivations of this research are to measure the viscosity and thermal conductivity of next-generation potential low GWP refrigerants. In this research work, the viscosities and thermal conductivities of R1336mzz(E), 3,3,4,4,5,5-HFCPE, R1132(E), and a mixture of R1123+R32 were measured over a wide range of temperature and pressure by using the tandem capillary tubes method and transient hot-wire method, respectively.

In the tandem capillary tubes method, the pressure drop of a laminar flow was determined to measure the viscosity of test fluids. This is an improved technique of the Hagen-Poiseuille theory-based capillary tube method by considering pipe end and kinetic energy correction coefficients. In this method, the measuring cell known as viscometer was constructed using almost the same diameter but different lengths of two capillary tubes that are horizontally installed in series connection to minimize the end effects of capillary tubes. For R1336mzz(E), the viscosity measurements were performed over the pressures from 0.5 to 4.0 MPa and temperatures from 314 to 394 K for the liquid phase, 353 to 453 K for the vapor phase, and 413 to 453 K for the supercritical region, respectively. The measured liquid, vapor, and supercritical viscosity data were reported at a range of 79.6 to 251.3 μPa s, 10.8 to 16.2 μPa s, and 18.1 to 53.6 μPa s corresponding to the above pressure and temperature. The expanded uncertainties for this measurement are calculated at 2.26 % for liquid, 2.30 % for vapor, and 2.32 % for supercritical phase using k=2 and the 95 % confidence level. For 3,3,4,4,5,5-HFCPE, the kinematic viscosities were measured by using this method at the range of temperatures from 332 to 494 K over the pressure up to 4.0 MPa in the liquid phase, while in the vapor phase from 413 to 514 K at pressures up to 2.0 MPa. The measured liquid and vapor kinematic viscosities were reported at a range of 0.0009 to 0.0041 $cm^2\,s^{-1}$, and 0.0014 to 0.0065 $cm^2\,s^{-1}$ for the above pressure and temperature. The expanded uncertainties of

博 士 論 文 の 要 旨

専攻名 Department of Science and Advanced Technology (システム創成科学専攻)
氏 名（本籍）Dipayan Mondal

the measurements for both liquid and vapor phases were 2.24 % and 2.94 % with k=2 and a 95% confidence level, respectively. For R1132(E), the viscosity measurements were performed over the pressure up to 4.0 MPa at a temperature range from 302 to 335 K for liquid and 323 to 345 K for vapor phases, respectively. Corresponding to the above pressure and temperature, the measured liquid and vapor viscosities of R1132(E) were reported at a range of 63.8 to 114.5 μPa s, and 12.5 to 15.2 μPa s, respectively. For the binary mixture of R1123+R32, the viscosities of the mixture refrigerant were measured by this method over the pressure up to 4.5 MPa and a temperature range from 251 to 313 K for the liquid phase and from 323 K to 383 K in the vapor phase, respectively. Mass fractions of measured R1123/R32 refrigerant mixture were 0.428/0.572 in the liquid phase and 0.425/0.575 in the vapor phase. The measured liquid, and vapor viscosity data were reported at a range of 84.2 to 200.4 μPa s, and 14.6 to 19.1 μPa s, respectively. The expanded uncertainties of viscosity measurements for R1123+R32 were estimated at 2.21 % and 2.60 % of the liquid and vapor phases, respectively. Therefore, the measured viscosity data for each refrigerant are compared and correlated with the predicted or calculated data from the existing correlations and models, REFPROP, and/or other research data. Moreover, the simplified correlations in terms of saturation temperature for the above-mentioned refrigerants are developed to predict the saturated viscosities for liquid and vapor phases, respectively.

On the other hand, the well-known transient hot-wire method was used to measure the thermal conductivity of fluids. Two thin (diameter 15 μm) platinum wires in parallel connection had been used in this hot wire apparatus as short and long wire, which is worked as both electrical heat source and resistance thermometer to measure the temperature rise during experiments. In addition, the two wires compensating system was considered to eliminate the axial heat conduction. The temperature ranges were considered for the measurements from around room temperature to the high temperature for pure working fluids in this study. For R1336mzz(E), the thermal conductivity data were reported in the temperature from 313 to 393 K over the pressure until 4.0 MPa for liquid state and temperature from 313 to 453 K at pressure up to 2.5 MPa for vapor state. Also, the thermal conductivity in a supercritical region was recorded from temperature range 413 to 453 K and pressures at 3.0 to 4.0 MPa. Corresponding to the above pressure and temperature, the measured liquid, vapor, and supercritical thermal conductivities were reported as 52.0 to 70.2 mW m^{-1} K^{-1}, 12.6 to 21.6 mW m^{-1} K^{-1}, and 21.5 to 45.5 mW m^{-1} K^{-1}, respectively. The expanded uncertainties for the thermal conductivity measurements of R1336mzz(E) were reported as 3.06 %, 3.16 %, and 3.23 % at the liquid, vapor, and supercritical regions, respectively. For 3,3,4,4,5,5-HFCPE, the measurements of the thermal conductivity were performed over temperatures from 333 to 473 K and pressure up to 4.0 MPa. This measured liquid and vapor thermal conductivity data were found in the range of 51.0 to 85.1 mW m^{-1} K^{-1} and 15.7 to 23.0 mW m^{-1} K^{-1}, respectively. The combined standard uncertainties were calculated as 1.54 % and 1.76 % for liquid and vapor phases, respectively, where the expanded uncertainties were found as 3.08 % and 3.52 % with k=2 and a confidence level of 95 % for the liquid and vapor thermal

博　士　論　文　の　要　旨

専攻名 Department of Science and Advanced Technology (システム創成科学専攻)
氏　名（本籍）Dipayan Mondal

conductivity measurements. Therefore, the measured thermal conductivities of the above-mentioned refrigerants are compared and correlated with the predicted or calculated data from the existing correlations and models, REFPROP, and/or other research data. Moreover, the simplified correlations in terms of saturation temperature for each refrigerant are developed to predict the saturated thermal conductivities for liquid and vapor phases by extrapolating the experimental data until the saturation conditions, respectively.