IAPWS Collaborative Grant Proposal

An experimental study of viscosity of the binary ammonia + water system at high temperatures and pressures

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This proposal will have four principal outcomes: it will strengthen collaborations between the Department Theoretical Bases of the Thermal Engineering of the Kazan National Research Technological University (KNRTU) and the National Institute of Standards and Technology (NIST) in the US; it will enable a young scientist to travel from the KNRTU to NIST for training in best practices for calibrations, measurements and data evaluation; it will provide the IAPWS community with new measurements of viscosity for the aqueous system ammonia + water in wide ranges of temperature and pressure; and, it will initiate a broad program of measurements and models for the ammonia + water system.

An IAPWS Certified Research Need [1] indicated a need for properties for ammonia + water mixtures at temperatures to 866 K (593 °C) at pressures up to 35 MPa, covering the complete range of composition. In spite of research activity from 1997 to 2002 that was reported in the Closure Statement for this ICRN, viscosity data are still very limited for ammonia + water mixtures.

The primary reasons for the scarcity of data are experimental difficulties related to the fact that this system is corrosive, toxic, potentially flammable, and has a high relative volatility. Special materials, safety procedures, special equipment and knowledge of their proper use are all required. Only a handful of labs, including NIST, have been able to make sufficient investment in training and materials to make such measurements.

The $H_2O + NH_3$ mixture is receiving an increasing attention due to the potential use of the system as a working fluid in refrigeration and power plant cycles. The binary $H_2O + NH_3$ mixture has a large technical significance in the fields of absorption refrigeration machines, absorption heat pumps, and heat transformers. To prevent the destruction of environment, natural working fluids such as ammonia and water have been considered as alternative organic refrigerants to replace chlorofluorocarbons (CFC) in some refrigeration applications. Ammonia-water mixture does not affect the atmospheric ozone layer nor do they contribute to the green house effect. Therefore, the significance of this mixture in refrigeration technology is strongly increasing. Refrigerating cycle with $H_2O + NH_3$ mixtures as working fluids have been shown to reach higher coefficient of performance than traditional working fluids. Thermophysical modeling of a technological processes is requires information on the both transport properties (viscosity and thermal conductivity) of $H_2O + NH_3$ mixtures. The important properties as viscosity and thermal conductivity required for absorption cycle analysis and in design of heat exchanger. Power cycles with $H_2O + NH_3$ mixtures as working fluids also have been shown to reach higher thermal efficiencies than the traditional steam turbine (Rankine) cycle with water as the working fluid. The best $H_2O + NH_3$ cycle produced approximately 40-70 % more power than a single –pressure steam cycle and 20-25 % more power than a dual-pressure steam cycle. In calculating the performance of the power cycles, the accurate transport properties data of the $H_2O + NH_3$ mixture play an important role. The demand to decrease the consumption of primary energy is lead to optimization of technological processes. To improve the $H_2O + NH_3$ cycle efficiency and to operate apparatus at high temperatures and pressures, the need for pertinent data in regions beyond those covered by the available data becomes more urgent. For this aim, engineering design of absorption air-conditioning equipment utilizing the $H_2O + NH_3$ cycle requires accurate transport property data of $H_2O + NH_3$ mixtures over a wide range of T, P, x. However, reported transport property data cover limited range of T, P, x, and contain large uncertainties and inconsistency. Number of speeches about geothermal power cycle applications has been presented at the latest geothermal conference in Germany, 2010. Thermophysical Properties Division, TRC (M. Frenkel) and Modeling Group (E. Lemmon), was repeatedly requested from various Industrial Companies (Jim Tindill, Sr. Mechanical Engineer Southern Company Services; BR/Claes) for transport properties of ammonia + water mixture.

Accurate viscosity data are also essential to the development of a reference correlation equation. Experimental data for the dynamic viscosity of liquid ammonia + water mixtures are quite sparse. The currently available viscosity data (see Review [2] paper) cover only very limited temperature and concentration ranges. Pagliani & Battelli (1885) [3] made the first known measurements at 0 °C, 5.8 °C, and 13.4 °C. Kanitz (1897) [4] reports measured data at 25 °C, followed by a few other points, also at 25 °C, measured by Blanchard & Pushee (1904, 1912) [5,6]. Pleskov & Igamberdyev (1939) [7] made measurements at 20 °C, but the largest set of experimental data known is that published by Pinevic (1948) [8]. Frank et al. (1996) [9] carried out a few measurements in a limited range of temperatures and concentrations. Very low temperature measurements of the viscosity were reported by Kargel et al., (1991) [10]. A detailed analysis of the reported data is presented in the report [2]. As was mentioned in Ref. [2], the reported viscosity data show remarkable inconsistencies (large scattered data, large uncertainty). No data under pressure were published before for ammonia+water mixtures. A survey of the literature also reveals that most reported data at atmospheric pressure were published long times ago (between 1885 and 1948). Both the Thermophysical Properties Division of NIST and KNRTU have extensive experience and capabilities in accurate viscosity measurements covering wide ranges of temperature, pressure, and concentration and their modeling (Dr. M. Huber). In a previous IAPWS project we have reported *CvVTx* [11], *PVTx* [12], thermal-pressure coefficient [13], and thermal conductivity [14] data for the aqueous system (H_2O + ammonia) in the liquid phase and near-critical and supercritical regions. For the reasons mentioned earlier, the labs of KNRTU and NIST are among the few research facilities in the world with capabilities for H_2O + ammonia viscosity measurements at the high temperatures and high pressures.

Under other funding, Prof. Tarzimanov's team in the KNRTU Labs will investigate viscosity in a temperature range from 298 to 363 K and at pressures up to 20 MPa for the concentrations 25, 50, and 75 mass % of ammonia, with an uncertainty in viscosity of less than 2 %. This investigation will provide reliable viscosity data by using a falling-body technique [15-24].

Following the experiments, we plan to bring a younger KNRTU Labs scientist to the Boulder Labs of NIST for 6 months. Ph.D. Student Il'gis R. Gabitov will be our top choice, since his PhD dissertation is on thermophysical properties of aqueous systems. Mr. I. Gabitov will assist Dr. Huber and her team in the Boulder Labs with the following tasks: (1) analysis of the viscosity data for water+ammonia mixture; and, (2) comparison with published measurements and models; (3) develop new viscosity model for the mixture; (4) prepare MS of the paper for publication. As an additional educational component of his visit, we will conduct detailed discussions and comparisons of the experimental viscosity techniques used in the KNRTU Labs with those used in the Boulder Labs, methods for precise gravimetric mixture preparation, a propagation of uncertainties analysis, round-robin measurement comparisons, and establishing a chain of traceability to national and international standards.

Budget

We propose a total budget of $20,000 for this project and a period of performance of 6-7 months. This would pay for the travel expenses and visit for Mr. Il'giz Gabitov or other young KNRTU scientist for his work in Boulder with the US-based research team. A project report will be prepared and submitted to IAPWS by the next annual meeting.

Leveraging of the IAPWS Support

The research team has planned a comprehensive research project on the ammonia + water system, involving partnerships with university-based researchers. To leverage the support from IAPWS, we will seek additional support from other agencies. Toward the end of the proposed 6-7 months IAPWS project, one or more proposals will be prepared to support the following tasks: (1) additional measurements of transport properties (a) viscosity data for the ammonia + water system and (b) thermal diffusivity measurements at high temperatures and high pressures; (3) development of new models for viscosity.

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