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Japanese Research on Thermophysical Properties of Fluids

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Japanese research activities on thermophysical properties of gases and liquids, as well as some historical background, are outlined. The current situation is explained for industrially important substances, such as water and steam, high pressure gases and liquids, refrigerants, molten salts, and other fluids. Related activities are also briefly introduced. Although some of the Japanese studies can be traced back to more than 50 years ago, a systematic effort has been visible only in the last 20 years. However, quite recently, thermophysical properties research has begun to attract attention of more people in science and industry in Japan, probably as the natural sequence to the progress of technology.

KEY WORDS: fluids; gases; liquids; thermophysical properties.

1. INTRODUCTION

Historically, Japanese research on thermophysical properties of fluids can be traced back to the early years in the 20th century. However, before 1945, research efforts in this field were left to the interest of individual researchers and only sporadically exhibited. Therefore, there were no substantial contributions to global progress of science and technology. More systematic research programs started only after 1945, especially around 1960, when Japanese industry began its rapid advance. Although in recent years, Japan has been assuming a larger role in experimental study of thermophysical properties, she is still well behind the United States in collecting, evaluating, and disseminating thermophysical properties data.

In this short review, I shall try to briefly describe the present situation in thermophysical properties research in Japan and, to some extent, its historical background. The description is limited to the studies on industrially important fluids, more specifically, on energy related fluids. Studies on

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equilibrium properties data, such as phase equilibria, are not included, since there are so much available data and also since collective works are available. The focus of the present review is more on systematic or organizational activities and less on work done by individual efforts.

2. WATER AND STEAM

Since the first Japanese steam tables [1] were published in 1934 by the Japan Society of Mechanical Engineers (JSME), steam properties research has made steady progress with studies on formulating equations of state in the early stage and more experimental studies on thermodynamic and transport properties in later years. The equation of state by Sugawara was used for the first edition of the *JSME Steam Tables* while the equation by Tanishita was used for the revised edition [2] published in 1950. Experimental research was started about 1952 by a group of researchers in JSME led by Sugawara (Kyoto University), Tanishita (Keio University), and Yamada (Yamanashi University, later the Defence Academy) [3, 4]. For about 10 years, this project was financially supported by a fund from utility companies and heavy industry. In 1967, a number of reports were presented at the Seventh International Conference on the Properties of Steam (ICPS) held in Tokyo [5]. Steam research grew steadily, and a number of groups were active such as those of I. Tanishita (Keio University), T. Sato (Kyoto University), Y. Yamada and S. Nagai (Defence Academy), K. Tanaka (Resources Research Institute), and K. Miyabe and T. Fujii (Kyushu University).

In 1969, the national committee to the International Association for the Properties of Steam (IAPS) was established in the Japan Society for the Promotion of Science. Formerly, the steam committee was a part of JSME on a temporary basis. In the last ten years, research on the properties of water and steam have been carried out at the Central Research Institute of Power Industry, Komae; Ikutoku Technical University, Atsugi; Keio University, Yokoyhama; Kobe University, Kobe; Kyoto Institute of Technology, Kyoto; Kyushu University, Fukuoka; National Research Institute of Pollution and Resources, Tsukuba; National Reserach Laboratory of Metrology, Tsukuba; Nihon University, Koriyama; as well as at other institutions. Major accomplishments were presented at the Eighth and the Ninth International Conferences on the Properties of Steam [6, 7].

3. HIGH PRESSURE GASES AND LIQUIDS

Study of the thermophysical properties of gases and liquids under high pressure has advanced in Japan in accordance with the progress of high

pressure chemistry. After 1940, studies on thermodynamic and transport properties of hydrocarbons and other fluids were started by Kyoto University by a group of researchers including R. Kiyama, J. Osugi, and T. Makita. In the 1950s, at Tohoku University, H. Iwasaki and his coworkers started a research program of transport properties of high pressure gases. Then they, with other researchers in high pressure physics and chemistry, established in 1959 an annual symposium of high pressure science. This symposium has provided a good opportunity of communication among researchers of physical chemistry, chemical engineering, mechanical engineering, and other fields. The symposium acts as the national counterpart to the International High Pressure Conference (AIRAPT). In 1983, the 24th Symposium of High Pressure Science was held. At recent symposia, studies were reported, for example, by Iwasaki, Takahashi, Date, and coworkers (Tohoku University) on compressibility and viscosity of hydrocarbons and other fluids; by Saito (Tohoku University), on virial coefficients; by Kurase, Yoshida, and coworkers (National Research Laboratory of Metrology), on viscosity of gases and liquids; by Moriyoshi and coworkers (Tokushima University), on the dielectric constant and PVT relations of aqueous solutions; by Takagi and Teranishi (Kyoto Institute of Technology), on sonic velocity of high pressure liquids; by Makita, Kubota, and Tanaka (Kobe University), on viscosity, thermal conductivity, and the dielectric constant; by Watanabe, Uematsu, Sato, and coworkers (Keio University), on PVT relations and specific heat; by Nagashima, Nagasaka, and coworkers (Keio University), on thermal conductivity and viscosity; and by Oguchi and coworkers (Ikutoku Technical University), on thermodynamic properties. There were more papers on water substances and refrigerants which were referred to in other sections [8].

In 1970, the Physical Property Data Evaluation Committee was started to collect and critically evaluate the thermophysical properties data of fluids under high pressure. For the first seven years, this program was sponsored by the High Pressure Data Center of Japan (HPDCJ) and was supported by the Science and Technology Agency. The aim of the program was to study criteria and procedures of evaluating thermophysical properties data. Another objective was to look into the possibility of establishing a standard reference data system. Members of the committee were J. Osugi (Kyoto University, chairman), I. Tanishita (Ikutoku University), Y. Takezaki (Kyoto University), H. Iwasaki (Tohoku University), T. Makita (Kobe University), K. Date (Tohoku University), S. Takahashi (Tohoku University), K. Watanabe (Keio University), Y. Tanaka (Kobe University), A. Nagashima (Keio University), N. Sugita (Kyoto University), and K. Oguchi (Ikutoku University).

For the first several years, substances to be studied were limited to

hydrocarbons, and later the program was expanded to include some other fluids. All of the available data were collected and critically evaluated through group discussions. The properties included PVT relations, equation of state, vapor pressure, specific heat, viscosity, thermal conductivity, and the diffusion coefficient. As a result, tables and equations representing recommended data of each substance were formulated [9, 10]. In 1977, the committee was succeeded by the Japanese Research Committee on Thermophysical Properties with the same members and chaired by T. Makita. Unfortunately, at the present stage, activities of these two committees have not yet succeeded in creating a more influential project like NSRDS at NBS in the United States, but we believe that the accumulated experience will be valuable for future programs.

4. REFRIGERANTS (FLUORINATED HYDROCARBONS)

Properties of refrigerants were, in earlier years, studied for applications in refrigeration and air-conditioning engineering. But after the oil crisis, refrigerants, especially fluorinated hydrocarbons, have been proposed also as working fluids and heat carries for such wider applications as waste heat recovery, so-called freon turbines, and other new heat engines. Thus, research on thermophysical properties of refrigerants at higher temperatures and pressures exceeding the range needed for refrigeration was requested. The following studies are reported: Iwasaki and coworkers [11], viscosity of gaseous refrigerants; Makita and coworkers [12, 14] and Nagashima and coworkers [13, 15], viscosity and thermal conductivity; Minamiyama and Yata, thermal conductivity; Watanabe, Uematsu and coworkers [17] and Oguchi and coworkers [16], thermodynamic properties; and Hirata and coworkers, phase equilibria. Based also on these accomplishments, a project to publish data books on important individual refrigerants was started in 1973 at the Japanese Association of Refrigeration by a committee chaired by K. Watanabe. Two data books on R 22 [18] and R 12 [19] are available now.

In 1979, the Japan Society of Mechanical Engineers started a research committee on thermophysical properties of working fluids and heat carriers proposed for lower or moderate temperature applications. The committee was chaired by I. Tanishita. The aim was to supply an extensive and consistent set of thermodynamic, transport, and other necessary data for such fluids as freons, ammonia, etc. Collecting and analyzing available data on one hand and promoting experimental measurements on the other hand, the results of three years activity were accumulated into a single volume compilation [20].

5. MOLTEN SALTS

In recent years, molten salts have been used or proposed for use in science and industry much more extensively than even 20 years ago. In Japan, research on physical and chemical properties of molten salts was promoted at first by a committee in the Society of Electrochemical Technology. But driven by growing needs, especially after the oil crises, scientists and engineers in other fields set up the Society of Molten-Salt Thermal Energy in 1976. The Society has limited membership and has been chaired by T. Ishino (Professor emeritus, Osaka University); its intention is to study all aspects of molten salts relating to applications to high temperature technologies through discussions among its members, who include scientists and engineers of chemistry, nuclear engineering, chemical engineering, mechanical engineering, metallurgy, etc. A group in the society has been devoted to collecting and evaluating thermophysical properties data [21]. This aim was more towards applications to heat transfer and heat storage in energy technology, including a molten salt nuclear reactor, than on electrochemical applications. Some of the accomplishments were published [22].

Various properties have been studied by T. Ejima and his coworkers (Tohoku University) closely communicating with the Molten Salts Data Center in the United States headed by G. J. Janz (Rensselaer Polytechnic Institute). Viscosity and thermal conductivity were measured by M. Harada and his coworkers (Kyoto University), A. Nagashima and his coworkers (Keio University), K. Kobayasi and N. Araki (Shizuoka University), and K. Furukawa, Y. Kato, and their coworkers (Atomic Energy Research Institute).

6. OTHER FLUIDS

Researches on MHD power generation and high temperature gas turbines necessitated more extensive study on thermophysical properties of high temperature combustion gases. In Japan, only a few experimental studies are being undertaken. Efforts have been focused to date more on data survey and theoretical predictions. In the Gas Turbine Society of Japan, a committee was started in 1980 to collect information on thermophysical properties of combustion gases. The committee has been chaired by K. Sunobe (Tokyo Science University). The activity was mainly collecting and classifying the available information on data necessary for calculating gas turbine cycle performance and heat transfer characteristics [23].

Some studies on the properties of tritium and tritium oxide have been included in a research project supported by a Grant-in-Aid for Energy

Research of the Ministry of Education. The aim is to obtain basic information for handling these substances in nuclear fusion research. At present, the scheme on thermophysical properties is limited, and major concern includes the diffusion coefficient and solubility in addition to density, viscosity, and thermal conductivity.

In the field of medical science, some studies on the properties of biological fluids have been done. They include a study on the thermal conductivity of blood by Tanishita and coworkers [24] and studies on the effective diffusion coefficient of oxygen and carbon dioxide in blood by Tanasawa, Tanishita, and coworkers [25].

7. REFERENCE SUBSTANCES

Although the study on standard reference data has not yet matured in Japan, some precise measurements were done at the National Research Laboratory of Metrology. After M. Kawata initiated an extensive research program on the viscosity standard right after the World War II, K. Karuse, K. Yoshida, and their coworkers continued to determine the most precise values of reference liquids and nitrogen gas [26, 27]. Since 1968, they have also taken part in an international program to set the international standard for liquid viscosity [28].

The very accurate value of the density of water was determined by H. Watanabe and K. Iizuka at the same laboratory [29]. They employed a precision pycnometer and performed measurements in the temperature range 0–44°C. For the standardization of industrial calorimeters used for determining the calorific value of fuels, M. Sasaki (with Y. Kobayashi as his successor) at the National Research Institute for Pollution and Resources has done research to improve the instruments. On the thermal conductivity of liquids, Y. Nagasaka and A. Nagashima selected toluene as the candidate for a reference substance and made a recommendation after critically evaluating available data, including their own measurements [30].

8. OTHER ACTIVITIES

A database of thermophysical properties of fluids has been established at Kobe University by T. Makita and his coworkers. The program was started in 1978, and the database now contains 10 kinds of thermodynamic and transport properties for 343 substances [31]. Makita and coworkers have been closely associated with CINDAS at Purdue University for more than 20 years. A retrospective search service of bibliographies and a data information service are offered also by the Japan Information Center of Science and Technology.

A comprehensive data book of fluid properties was published in 1983

by JSME [32]. The volume contains such data as thermodynamic, transport, calorific, radiative, and other properties for industrially important substances in their fluid state. The editorial committee was headed by H. Uchida (Professor emeritus, Tokyo University). The book is the result of seven years of work by experts in Japan. Since 1963, a group at the Society of Chemical Engineers, Japan, headed by K. Sato, have edited and published an annual survey of thermophysical properties data. Some review articles were also included. This program has since been transferred to a commercial publisher [33].

Because of limited space, the author omits other items and would like to conclude this review by introducing one of the most important activities in Japan relating to thermophysical properties research. It is the start of the Japan Symposium on Thermophysical Properties in 1980 and also the start of the Japan Society of Thermophysical Properties. The society acts as the governing board of the annual symposium. At the symposium, researchers in properties of solids as well as those in liquid properties meet and discuss their work.[2] The symposium is held in collaboration with more than 20 scientific and engineering societies in Japan. The Society is also planning, as a future activity, the publication of data books and the organization of seminars. We hope these activities will contribute not only to the national but also to the global progress of science and technology.

9. CONCLUDING REMARKS

In order to write this article, the present author tried in vain to find reviews which explain the earlier history of thermophysical property research in Japan.[3] This fact shows that the research in this field in Japan is still in its early developmental stage. To meet the growing demand from industrial as well as scientific community, we hope that thermophysical properties research will become more active through not only US–Japan, but also broader international, cooperation.

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[2] Proceedings of annual symposium are obtainable from the Japan Society of Thermophysical Properties, c/o Prof. A. Nagashima, Dept. of Mechanical Engineering, Keio University, Hiyoshi, Yokohama 223, Japan.

[3] Historical background is found, to some extent, in articles such as refs. [3] and [4]. Also, the situation in Japan in the year 1976–1977 is compactly described with an explanation of geographical locations of research institutes in an article by K. Watanabe, *Proc. 7th Symp. Thermophys. Prop.* (ASME, 1977), p. 46.

REFERENCES

1. *The JSME Steam Tables* (Japan Society of Mechanical Engineers, 1934).
2. *The JSME Steam Tables*, rev. ed. (JSME, 1950).
3. I. Tanishita, an article in the commemorative volume of the 80th year of JSME (1977), p. 11 (in Japanese).
4. I. Tanishita, Karyoku Hatsuden, 15–9 (1964), p. 719 (in Japanese).
5. Proc. 7th ICPS, Tokyo (ASME, 1967).
6. Proc. 8th ICPS, Giens (1974).
7. Proc. 9th ICPS, Munich, *Water and Steam*, J. Straub and K. Scheffler, eds. (Pergamon Press, Elmsford, N.Y., 1979).
8. Koatsu-toronkai Koen-yoshishu (in Japanese), Proceedings of annual symposia. Chairman of the organizing committee of 24th symposium (1983) is Prof. M. Tanaka, Dept. of Chemistry, Fukuoka University, Fukuoka, Japan.
9. Report of the Physical and Chemical Property Data; Fluid Property Data, Vol. 5 (Promotion Bureau, Science and Technology Agency, Japan).
10. T. Makita, et al., Proc. 7th Int. CODATA Conf., Kyoto (Pergamon Press, Elmsford, N.Y., 1980).
11. For example, M. Takahashi and H. Iwasaki, Koatsu-toronkai Koen-yoshishu (1973), 57. This research program is now directed by S. Takahashi; see 23rd Koatsu-toronkai Koen-yoshishu (1982), 208 (in Japanese).
12. T. Makita, *Rev. Phys. Chem. Japan*, 24–2 (1955), 74.
13. A. Nagashima, et al., *Trans. JSME*, 342–655 (1975), 62.
14. T. Makita, et a., *Int. J. Thermophys.*, **2**–(3), (1981).
15. N. Kitazawa and A. Nagashima, *Bull. JSME* 24–188 (1981), 274.
16. K. Oguchi, et al., *Trans. JSME*, 41–344 (1975), 1234 (in Japanese).
17. K. Watanabe, et al., Proc. 7th Symp. Thermophys. Prop. (1977), p. 489.
18. Thermophysical Properties of Refrigerants (R 22, chlorodifluoromethane), Japanese Assoc. of Refrigeration (1975).
19. Thermophysical Properties of Refrigerants (R 12, dichlorodifluoromethane), Japanese Assoc. of Refrigeration (1981).
20. Thermophysical Properties of Fluids at Moderate and Lower Temperatures (in Japanese), Report of RC57 Research Committee (1983). This report is not open to the public for a certain period.
21. K. Furukawa and H. Ohno, Data-Book for Molten Materials: I Molten LiF–BeF2 (Flibe) System, Japan Nuclear-Energy Information Center (1980).
22. Fundamentals of Molten-Salt Thermal Technology: Status and Scope, The Society of Molten-Salt Thermal Technology, Japan (1979).
23. Report on Collecting Thermophysical Property Data of Gas Turbine Working Fluids, Nihon Gas Turbine Gakkaishi, 10–39 (1982), 68; 10–40 (1983), 61 (in Japanese).
24. K. Tanishita, et al., *Trans. JSME*, 47–421 (1981), 1784 (in Japanese).
25. K. Tanishita, et al., Kikai-Gakkai Koen-ronbunshu, No. 830–13 (1983), 20. Also, Hori et al., *Trans. JSME*, 46–409 (1980), 1854 (in Japanese).
26. M. Kawata, et al., Proc. 5th Int. Congr. Rheology (1969), p. 453.
27. K. Kurase, et al., Proc. 7th Int. Congr. Rheology, Gothenburg (1976), p. 480.
28. K. Yoshida, et al., Report Natl. Res. Lab. Metrology, Japan, 19–4 (1970), p. 175.
29. H. Watanabe and K. Iizuka, On the redetermination of the thermal expansivity of water, a report to the 139th Committee, Japan Soc. Promotion of Science (1981).
30. Y. Nagasaka and A. Nagashima, Proc. 1st Japan Symp. Thermophys. Properties (1980), p. 67.
31. Y. Takaoka, et al., Johoshori-Gakkai-Ronbun-shu, 23–4 (1982), p. 406 (in Japanese).
32. *JSME Data Book*: *Thermophysical Properties of Fluids* (JSME, 1983).
33. *Bussei-josu*, published annually by Maruzen Publ. Co. (in Japanese).