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Review

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Activity Report on Information-Gathering of Database Literatures for Molten Salts

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ABSTRACT

The authors worked as working group members in the Molten Salt Committee of the Electrochemical Society of Japan in FY 2015–2016 to collect and summarize information on books and literatures devoted to molten salts. They covered a wide range of aspects of molten salts such as handling/measurement techniques, thermophysical properties, phase diagrams, thermodynamic data, electrochemical data, and structures. A total of 89 books and database literature sources were organized by content. The group also carried out an activity to archive the technical data of the electrolytic smelting of Al metal in the Hall-Héroult process that has operated in Japan. We hope this activity report will allow molten salt researchers to access trustworthy information conveniently.

Keywords : Molten Salt, Database Literature, Gathering Activity, Archive Activity

1. Introduction

Half a century ago, the activities of academic societies in Japan were small in both the frequency and scale of international collaboration, with few opportunities to interact with researchers from other countries. Systematic studies on molten salt chemistry had started at this time, and subsequently a great deal of information on the characteristics and experimental methods of molten salts was published from the 1960s to the 1980s. The difficult access to the literatures in that time period made the consolidation of the information on these books the most significant contribution. After the 1st International Conference on Molten Salt Chemistry and Technology (MS1) in 1983, the globalization and growth of research in science and engineering introduced an active international exchange of information and a vast number of scientific papers on molten salts. The recent growth of the internet has facilitated access to individual data, but the immense volume of information makes the compilation into databases more difficult.

Under these circumstances, one of the authors worked as a lecturer at the experimental workshop of the Molten Salt Committee (MSC) in 2014 and noticed many participants had little experience in handling molten salts. From the discussion, it was clear that they had the impression that molten salts are substances with many interests but with high hurdles. In other words, dealing with molten salts is difficult owing to the lack of basic information such as the thermophysical properties and experimental techniques. This was a new aspect for the MSC members, who had been specializing in molten salts for a long time, and simultaneously, highlights the challenges of the field. For example, an experienced person in the molten salt field can easily get various information for a specific molten salt. On the other hand, a less experienced person would have difficulty getting access to the information. Accordingly, the molten salt community might have lost not only opportunities to expand the scope of molten salt chemistry but also the introduction of new researchers into the field.

The working group for the collection of the database literatures devoted to molten salts was set up after board approval in MSC of The Electrochemical Society of Japan (ECSJ) in FY 2015. The objective of the working group is to enable people involved in the research field of molten salts to easily search and access information, e.g., physicochemical and electrochemical properties of molten salts. The activity of the working group plays an essential role in efficient research and development of new technologies using molten salts in various fields such as electronics and energy. The working group is also involved in an activity to archive valuable technical data of the electrolytic smelting of Al metal in the Hall-Héroult process operated in Japan. These kinds of information-gathering activities on various aspects of molten salts significantly improve the service to the MSC members and the attractiveness of the committee. This article summarizes the reports on "collection of books and the database literatures" and "archive activity of the electrolytic smelting of Al metal" of the working group for two years with additional information published after the end of the activity in 2016.

2. Course of Action of the Working Group

The most significant feature of the working group activities performed over the two years was that writing books or database documents had not been conducted because of the enormous labor involved. Instead, the works by utilization of the great pioneers in the molten salt field gave a more efficient method. The working group's policy was to introduce information and numerical data about molten salts and related fields from books and database literatures. It was expected that this policy could satisfy the purpose

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Table 1. General books and literatures on molten salts.

General		
Year	Author	Literature
1971	J. Braunstein, G. Mamantov, and G. P. Smith (Eds.)	Advances in Molten Salt Chemistry, Volume 1, Plenum Press, New York and London (1971)
1973	J. Braunstein, G. Mamantov, and G. P. Smith (Eds.)	Advances in Molten Salt Chemistry, Volume 2, Plenum Press, New York and London (1973)
1975	J. Braunstein, G. Mamantov, and G. P. Smith (Eds.)	Advances in Molten Salt Chemistry, Volume 3, Plenum Press, New York and London (1975)
1981	G. Mamantov and J. Braunstein (Eds.)	Advances in Molten Salt Chemistry, Volume 4, Plenum Press, New York and London (1981)
1983	G. Mamantov and J. Braunstein (Eds.)	Advances in Molten Salt Chemistry, Volume 5, Elsevier Science, Amsterdam (1983)
1987	G. Mamantov, C. B. Mamantov, and J. Braunstein (Eds.)	Advances in Molten Salt Chemistry, Volume 6, Elsevier Science, Amsterdam (1987)
1993	Yoyuen Netsu Gijutsu Kenkyu-kai	Yoyuen Netsu Gijutsu no Kiso, AGNE Gijutsu Center Inc., Tokyo (1993)
1998	D. H. Kerridge and E. G. Polyakov (Eds.)	Refractory Metals in Molten Salts, Their Chemistry Electrochemistry and Technology, Kluwer Academic Publishers, Dordrecht (1998)
2002	M. Gaune-Escard	Molten Salts: From Fundamentals to Applications (Nato Science Series II), Springer, Heidelberg (2002)
2003	Y. Ito (Ed.)	Yoyuen no Ohyo -Energy Kankyo Gijutsu eno Tenkai-, Industrial Publishing & Consulting, Inc., Tokyo (2003)
2004	Y. Ito and T. Nohira	Jikken Kagaku Kouza, 5th Edition, (Ed. The Chemical Society of Japan), Vol. 27, Functional Materials, Section 5.2.1 Molten Salt, Maruzen Publishing Co., Ltd., Tokyo, pp. 408–421 (2004)
2005	Y. Ito (Ed.)	Yoyuen no Kagaku, Industrial Publishing & Consulting, Inc., Tokyo (2005)
2011	G. Adachi (Ed.)	Rare Metal Binran, Maruzen Publishing Co., Ltd., Tokyo (2011)
2013	The Electrochemical Society of Japan (Ed.)	Denki Kagaku Binran, 6th Edition, Maruzen Publishing Co., Ltd., Tokyo (2013)
2013	S. Tamaki	Yoyuen no Bussei, Ion-sei Muki-ekitai no Kouzo, Netsurikigaku, Yuso Gensho no Bishiteki Sokumen, AGNE Gijutsu Center Inc., Tokyo (2013)
2013	F. Lantelme and H. Groult (Eds.)	Molten Salts Chemistry: From Lab to Applications, 1st Edition, Elsevier, Amsterdam (2013)
2014	M. Gaune-Escard and G. M. Haarberg (Eds.)	Molten Salts Chemistry and Technology, Wiley, Chichester (2014)
2018	N. Sato and Y. Waseda (Eds.)	Shisshiki Process, Yoeki, Yobai, Haisui Shori, Uchida Rokakuho Publishing Co., Ltd., Tokyo (2018)

of the activity to improve the ability for the MSC members to get easy access to information.

The working group members were selected from young MSC members with different specialties as molten salts possess various properties. The group members shared their following properties; for electrochemistry by KY, thermodynamics by KY and HS, magnetic resonance, molecular dynamics calculations, and first principle calculations by TO, thermophysical properties by OT, transport phenomenon analysis by SN, and phase diagrams by HS. Information-gathering was carried out in the form of a shared editorial. Everyone had access rights to an exclusive site created on the server of Chiba University and uploaded information of books and literatures that were frequently used in each specialized field.

3. Books and Database Literatures Devoted to Molten Salts

3.1 General

Table 1 summarizes the general books on molten salts.[1–18] In the 1970s and 1980s, researchers from Europe and the United States published "Advances in Molten Salt Chemistry" in six volumes, and introduced thermodynamics, physical chemistry properties, and spectroscopic aspects in each chapter.[1–6] Later, several books have been published in Europe and Japan. Recently, molten salts have been compiled in some handbooks, such as electrochemistry and rare metals in Japan, as well as specialized books on molten salts.

3.2 Handling and measurement techniques

The books and literatures summarizing the handling and various experimental methods of molten salts are listed in Table 2.[19–34] "Molten Salt Techniques" published in the 1980s summarize the experimental techniques used in the early days of molten salt research.[20–23] For example, research on thermophysical properties was active at that time, but rare earth halide salts were available only as hydrates. As purification was a critical process to eliminate as much as possible the effects of impurities, the purification methods by each research group were described in the books. Even today, with various equipments and analyzers available, high purity is required for optical measurements. Accordingly, the books present noteworthy information sources introducing useful methods for removing impurities, particularly oxide ions and moisture. In

Table 2. Books and literatures on handling and measurement techniques on molten salts.

Handling and measurement techniques		
Year	Author	Literature
1982	D. G. Lovering (Ed.)	Molten Salt Technology, Plenum Press, New York (1982)
1983	D. G. Lovering and R. J. Gale (Eds.)	Molten Salt Techniques, Volume 1, Plenum Press, New York and London (1983)
1984	R. J. Gale and D. G. Lovering (Eds.)	Molten Salt Techniques, Volume 2, Plenum Press, New York and London (1984)
1987	D. G. Lovering and R. J. Gale (Eds.)	Molten Salt Techniques, Volume 3, Plenum Press, New York and London (1987)
1991	R. J. Gale and D. G. Lovering (Eds.)	Molten Salt Techniques, Volume 4, Plenum Press, New York and London (1991)
1998	Y. Sato	"Purification and Handling Technique of Molten Salts", J. Surf. Finish. Soc. Jpn., 49(4), 331–335 (1998)
2000	T. Yamamura and Y. Sato	"Handmade Laboratory, Molten Salt (1) Purification of Salt", Kinzoku, 70(3), 208–212 (2000)
2003	T. Nohira	"Know-how of Measurements in Molten Salt Systems", Electrochemistry, 71(11), 966–968 (2003)
2010	T. Nohira and T. Tsuda	"Polarization Curve and Cyclic Voltammetry (14) Ionic Liquid and Molten Salt", Electrochemistry, 78(6), 549–555 (2010)
2011	Y. Shiraishi and T. Azakami (Eds.)	Tokashite Hakaru, Kouon Bussei no Tezukuri Jikken Shitsu -Zatsugaku Mansai no Sokutei Shinan-, AGNE Gijutsu Center Inc., Tokyo (2011)
2014	Molten Salt Committee	"Electrochemical Measurements in High-temperature Molten Salts and Room-temperature Ionic Liquid (Experimental Workshop)" Textbook of 44th Workshop of Molten Salt Chemistry (2014)
2016	H. Tsujimura and Y. Ito	"Fundamentals and Measurement Methods of Molten Salts and Ionic Liquid (1) Electrochemical Measurement in Molten Salt System ～Fundamental of Experimental Technique～", Electrochemistry, 84(4), 263–268 (2016)
2016	T. Nishikiori and Y. Ito	"Fundamentals and Measurement Methods of Molten Salts and Ionic Liquid (2) Electrochemical Measurement in Molten Salt System ～Concrete Example (1)～", Electrochemistry, 84(6), 460–468 (2016)
2016	T. Nishikiori, H. Tsujimura, and Y. Ito	"Fundamentals and Measurements Method of Molten Salts and Ionic Liquid (3) Electrochemical Measurement in Molten Salt System ～Concrete Example (2)～", Electrochemistry, 84(7), 540–549 (2016)
2016	Molten Salt Committee	"Handling of Active Metals and Electrochemical Measurements in High-temperature Molten Salts (Experimental Workshop)" Textbook of 46th Workshop of Molten Salt Chemistry (2016)
2018	Molten Salt Committee	"Measurements of Physical Properties of Molten Salts (Experimental Workshop)" Textbook of 47th Workshop of Molten Salt Chemistry (2018)

addition, "Electrochemistry"[26,27,30–32] published by ECSJ and the textbooks of the experimental workshops of molten salt chemistry[29,33,34] published by MSC have also become valuable references in recent years.

3.3 Thermophysical properties

Table 3 lists the books and literatures summarizing the thermophysical properties of molten salts.[28,35–56] MSC compiled the data from 1959 to 1961 as a book "Yoyuen Kousu Hyo (Tables for Constant Data of Molten Salts),"[35] which was subsequently released as "Yoyuen Bussei Hyo (Molten Salt Property Tables)"[36] by Kagaku-Dojin Publishing Company, Inc. This demonstrates the world-leading and pioneering activities of MSC, which attempted to create databases of various thermophysical properties. Although the book "Yoyuen Bussei Hyo", exceeding 650 pages, is out of print at present, the sale of print-on-demand and electronic versions is agreed between MSC and Kagaku-Dojin Publishing Company, Inc.

Following the work in Japan, the pioneering activities of Janz et al. in the United States compiled for various thermophysical properties over 15 years.[37–39,41–49] These data are open to the public as PDF files on the webpages of the National Institute of Standards and Technology (NIST). The hyperlinks in Table 3 can be used to access the URL of each database. In Japan, the National Institute of Advanced Industrial Science and Technology (AIST) has recently published web databases that allow online search of various thermophysical properties.[53]

3.4 Phase diagrams

Phase diagrams are summarized in the books and software, as shown in Table 4.[48,57–71] Various phase diagrams of molten salts for binary, ternary, and multi-component systems have been summarized in "Phase Diagrams for Ceramists".[57–62] Although the number is not as high as before, phase diagrams for molten salts have been reported recently and can be easily searched by software. Some software have a function to create calculated phase diagrams based on the equipped thermodynamic data such as Gibbs energy and activity of the solution. In the research of high-temperature molten salts, alloying reactions should be considered for not only the reaction targets but also the reaction vessels etc., which require checking phase diagrams for metals as well. Since phase diagrams

Table 3. Books and literatures on thermophysical properties of molten salts.

Thermophysical properties			
Year	Author	Literature	Note
1959	Molten Salt Committee	Yoyuen Kousu Hyo, No. 1–5 (1959–1961)	Single-electrode potential, Decomposition voltage, Electric conductivity, Thermal conductivity, Viscosity, Density, Surface tension, Vapor pressure, Phase diagram, Diffusion coefficient, Corrosion
1963	Molten Salt Committee	Yoyuen Bussei Hyo, Kagaku-Dojin Publishing Company, Inc., Kyoto (1963)	Single-electrode potential, Decomposition voltage, Electric conductivity, Thermal conductivity, Viscosity, Density, Surface tension, Vapor pressure, Phase diagram, Diffusion coefficient, Corrosion, Measurement technique
1967	G. J. Janz	Molten Salts Handbook, Academic Press, New York and London (1967)	Wide range data including electrical conductivity, density, viscosity, and vapor pressure
1968	G. J. Janz, F. W. Dampier, G. R. Lakshminarayanan, P. K. Lorenz, and R. P. T. Tomkins	Molten Salts: Volume 1, Electrical Conductance, Density, and Viscosity Data, NSRDS-NBS 15, National Bureau of Standards, Washington D.C. (1968)	https://nvlpubs.nist.gov/nistpubs/Legacy/NSRDS/nbsnsrds15.pdf
1969	G. J. Janz, C. G. M. Dijkhuis, G. R. Lakshminarayanan, R. P. T. Tomkins, and J. Wong	Molten Salts: Volume 2, Section 1. Electrochemistry of Molten Salts: Gibbs Free Energies and Excess Free Energies from Equilibrium-Type Cells; Section 2. Surface Tension Data, NSRDS-NBS 28, National Bureau of Standards, Washington D.C. (1969)	https://nvlpubs.nist.gov/nistpubs/Legacy/NSRDS/nbsnsrds28.pdf
1971	The Iron and Steel Institute of Japan	Yo-tetsu Yo-sai no Busseichi Binran (1971)	
1972	G. J. Janz, U. Krebs, H. F. Siegenthaler, and R. P. T. Tomkins	Molten Salts: Volume 3, Nitrates, Nitrites, and Mixtures: Electrical Conductance, Density, Viscosity, and Surface Tension Data, J. Phys. Chem. Ref. Data, 1(3), 581–746 (1972)	https://srd.nist.gov/jpcrdreprint/1.3253103.pdf
1974	G. J. Janz, G. L. Gardner, U. Krebs, and R. P. T. Tomkins	Molten Salts: Volume 4, Part 1, Fluorides and Mixtures; Electrical Conductance, Density, Viscosity, and Surface Tension Data, J. Phys. Chem. Ref. Data, 3(1), 1–115 (1974)	https://srd.nist.gov/jpcrdreprint/1.3253134.pdf
1975	G. J. Janz, R. P. T. Tomkins, C. B. Allen, J. R. Downey, G. L. Garner, U. Krebs, and S. K. Singer	Molten Salts: Volume 4, Part 2, Chlorides and Mixtures; Electrical Conductance, Density, Viscosity, and Surface Tension Data, J. Phys. Chem. Ref. Data, 4(4), 871–1178 (1975)	https://srd.nist.gov/jpcrdreprint/1.555527.pdf
1977	G. J. Janz, R. P. T. Tomkins, C. B. Allen, J. R. Downey, and S. K. Singer	Molten Salts: Volume 4, Part 3, Bromides and Mixtures; Iodides and Mixtures- Electrical Conductance, Density, Viscosity, and Surface Tension Data, J. Phys. Chem. Ref. Data, 6(2), 409–596 (1977)	https://srd.nist.gov/jpcrdreprint/1.555552.pdf
1979	G. J. Janz, R. P. T. Tomkins, and C. B. Allen	Molten Salts: Volume 4, Part 4, Mixed Halide Melts; Electrical Conductance, Density, Viscosity, and Surface Tension Data, J. Phys. Chem. Ref. Data, 8(1), 125–302 (1979)	https://srd.nist.gov/jpcrdreprint/1.555590.pdf
1980	G. J. Janz	Molten Salts Data as Reference Standards for Density, Surface Tension, Viscosity, and Electrical Conductance: KNO_3 and NaCl, J. Phys. Chem. Ref. Data, 9(4), 791–829 (1980)	https://srd.nist.gov/jpcrdreprint/1.555634.pdf

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Thermophysical properties			
Year	Author	Literature	Note
1980	G. J. Janz and R. P. T. Tomkins	Molten Salts: Volume 5, Part 1, Additional Single and Multi-Component Salt Systems. Electrical Conductance, Density, Viscosity, and Surface Tension Data, J. Phys. Chem. Ref. Data, 9(4), 831–1021 (1980)	https://srd.nist.gov/jpcrdreprint/1.555635.pdf
1983	G. J. Janz and R. P. T. Tomkins	Molten Salts: Volume 5, Part 2, Additional Single and Multi-Component Salt Systems. Electrical Conductance, Density, Viscosity and Surface Tension Data, J. Phys. Chem. Ref. Data, 12(3), 591–815 (1983)	https://srd.nist.gov/jpcrdreprint/1.555693.pdf
1988	G. J. Janz	Thermodynamic and Transport Properties for Molten Salts: Correlation Equations for Critically Evaluated Density, Surface Tension, Electrical Conductance, and Viscosity Data, J. Phys. Chem. Ref. Data, 17, Supplement 2, 1–309 (1988)	https://srd.nist.gov/JPCRD/jpcrdS2Vol17.pdf
1988	Y. Kawai and Y. Shiraishi	Handbook of Physico-Chemical Properties at High Temperatures, The Iron and Steel Institute of Japan, Tokyo (1988)	
2004	The Japan Institute of Metals and Materials (Ed.)	Kinzoku Databook, 4th Edition, Maruzen Publishing Co., Ltd., Tokyo, 74–78 (2004)	Density, Electric conductivity, Surface tension, Viscosity, Sound velocity, Diffusion coefficient, Thermal conductivity
2006	V. Danek	Physico-Chemical Analysis of Molten Electrolytes, Elsevier, Amsterdam (2006)	Phase diagram, Density, Surface tension, Electric conductivity, Viscosity
2006	National Institute of Advanced Industrial Science and Technology	Network Database System for Thermophysical Property Data (2006–)	Web database, http://tpds.db.aist.go.jp/index.html
2008	Japan Society of Thermophysical Properties (Ed.)	Shin-pen Netsu Bussei Handbook, Yokendo Ltd. Publishers (2008)	General thermophysical properties
2008	K. Ogino	Kouon Kaimen Kagaku, AGNE Gijutsu Center Inc., Tokyo (2008)	
2011	Y. Shiraishi and T. Azakami (Eds.)	Tokashite Hakaru, Kouon Bussei no Tezukuri Jikken Shitsu -Zatsugaku Mansai no Sokutei Shinan-, AGNE Gijutsu Center Inc., Tokyo (2011)	Electric conductivity, Thermal conductivity, Viscosity, density, Surface tension, Vapor pressure, Diffusion coefficient
2016	R. P. T. Tomkins and N. P. Bansal (Eds.)	Gases in Molten Salts (IUPAC Solubility Data Series), Pergamon, Oxford (2016)	Solubility, https://srdata.nist.gov/solubility/IUPAC/SDS-45-46/SDS-45-46.pdf

for metals can be easily searched even on the internet, searching for individual papers would be effective.

3.5 Thermodynamic data

Table 5 lists the books, web databases and software of thermodynamic data for various substances including molten salts.[72–82] Data for major compounds are mostly reported in books before "NIST-JANAF Thermochemical Table"[77] published in 1998. However, reliability of the data for metastable phases needs to be verified by checking and evaluating the original papers. Besides, careful attention should be focused on the different publication formats, such as the units, e.g., cal instead of J, and $\Delta G°_f$ instead of $G°$. There are many software options on the market, and some can calculate the predicted thermophysical properties of slags at any compositions. The choice of software to suit each purpose is possible.

3.6 Electrochemical data

The books and literatures summarizing the electrochemical data in molten salts are listed in Table 6.[12,14,83–85] Although thermophysical properties like conductivity and density are related to electrochemistry, they are abundantly listed in the books shown in Table 3. Standard electrode potentials are summarized for common molten salts such as LiCl–KCl eutectic salts, NaCl–KCl equimolar salts, and LiF–NaF–KF eutectic salts. However, their temperature dependence is not summarized, and hence, the search for individual papers is necessary.

3.7 Structure

Table 7 summarizes the books related to the structure of molten salts.[13,86–89] They also show the force field database for molecular dynamics calculations of ionic crystals and molten salts. Since molten salt, slag, and liquid metal have common features as high-temperature melt, similar techniques are used for their measurement, analysis, and simulation. X-ray and neutron diffraction, X-ray absorption fine structure (XAFS) analysis, and Raman spectroscopy are utilized for experimental analysis. These books summarize the information for interatomic distances, coordination numbers etc.

Table 4. Books and literatures on phase diagrams of molten salts.

Phase diagrams			
Year	Author	Literature	Note
1964	E. M. Levin, C. R. Robbins, H. F. McMurdie, and M. K. Reser (Eds.)	Phase Diagrams for Ceramists, The American Ceramic Society, Columbus (1964).	Molten salt
1969	E. M. Levin, C. R. Robbins, H. F. McMurdie, and M. K. Reser (Eds.)	Phase Diagrams for Ceramists, 1969 Supplement, The American Ceramic Society, Columbus (1969)	Molten salt
1975	E. M. Levin, H. F. McMurdie, and M. K. Reser (Eds.)	Phase Diagrams for Ceramists, 1975 Supplement, The American Ceramic Society, Columbus (1975)	Molten salt
1981	R. S. Roth, T. Negas, L. P. Cook, and G. Smith (Eds.)	Phase Diagrams for Ceramists, Volume IV, The American Ceramic Society, Columbus (1981)	Molten salt
1983	R. S. Roth, T. Negas, L. P. Cook, G. Smith, and M. A. Clevinger	Phase Diagrams for Ceramists, Volume V, The American Ceramic Society, Columbus (1983)	Molten salt
1983	G. J. Janz and R. P. T. Tomkins	Molten Salts 2: Volume 5, Part. 2, Additional Single and Multi-Component Salt Systems. Electrical Conductance, Density, Viscosity and Surface Tension Data, J. Phys. Chem. Ref. Data, 12(3), 591–815 (1983)	Molten salt, https://srd.nist.gov/jpcrdreprint/1.555693.pdf
1986	E. M. Levin, C. R. Robbins, and H. F. McMurdie (Eds.)	Phase Diagram for Ceramists, Volume I: Oxides and Salts, The American Ceramic Society, Columbus (1986)	Molten salt
1986	T. B. Massalski, J. L. Murray, L. H. Bennett, and H. Baker (Eds.)	Binary Alloy Phase Diagrams, American Society for Metals, Metals Park (1986)	Metal
1987	J. Sangster and A. D. Pelton	Phase Diagrams and Thermodynamic Properties of the 70 Binary Alkali Halide Systems Having Common Ions, J. Phys. Chem. Ref. Data, 16(3), 509–561 (1987)	Molten salt
1988	G. Petzow and G. Effenberg	Ternary Alloys: A Comprehensive Compendium of Evaluated Constitutional Data and Phase Diagrams, VCH, Weinheim (1988)	Metal
1990	T. B. Massalski, H. Okamoto, P. R. Subramanian, and L. Kacprzak (Eds.)	Binary Alloy Phase Diagrams, 2nd Edition, ASM International, Materials Park (1990)	Metal
1995	P. Villars, A. Prince, and H. Okamoto (Eds.)	Handbook of Ternary Alloy Phase Diagrams, ASM International, Materials Park (1995)	Metal
1995	B. J. Keene	Slag Atlas, 2nd Edition, Verlag Stahleisen GmbH, Dusseldorf (1995)	Oxide
2006	H. Okamoto and K. Cenzual (Eds.)	ASM Alloy Phase Diagram Database, ASM International, Materials Park (2006–)	Metal, inorganic compound, Web database, login required, https://matdata.asminternational.org/matinfo/?_ga=2.202472209.1653483845.1575885784-127698090.1573176980
2007	National Institute for Materials Science	NIMS Thermodynamic Database (2007)	Metal, Web database http://www.gotrawama.eu/NIMSMIRROR/www.nims.go.jp/cmsc/pst/database/periodic.html
2014	National Institute of Standards and Technology	ACerS-NIST Phase Equilibria Diagrams Database, Ver. 4, NIST Standard Reference Database 31, National Institute of Standards and Technology Standard Reference Data Program (2014)	Software

4. Archive Activity of the Electrolytic Smelting of Al Metal

Electrolytic smelting of Al metal in the Hall-Héroult process is a significant process in the molten salt industry. Many aluminum electrolysis plants have operated in Japan in the past, but many of them stopped operation due to the oil shock. In March 2014, the last aluminum electrolytic plant in Japan at the Kambara Complex of Nippon Light Metal Co., Ltd. stopped the operation. The working group conducted an archive activity to store the operation records, photos of the furnaces and related equipments for aluminum electrolysis, and the experiences of the operation staff, which are valuable technical information of the molten salt industry in Japan.

The materials donated by courtesy of Nippon Light Metal Co., Ltd. are (1) movies of work processes such as a crust break, feeding, and tapping out, (2) photos of the factory and workers (Fig. 1), (3) typical operation records, logs, and equipment drawings, and (4) PowerPoint materials used in the training of new members of the Japan Institute of Light Metals. Nippon Light Metal Co., Ltd. gave a

Table 5. Books and literatures on thermodynamic data of molten salts.

Thermodynamic data			
Year	Author	Literature	Note
1966	J. Lumsden (Ed.)	Thermodynamics of Molten Salt Mixture, Academic Press, New York and London (1966)	
1973	I. Barin and O. Knacke	Thermochemical Properties of Inorganic Substances, Springer-Verlag, Berlin, Heidelberg, and New York (1973)	
1977	I. Barin, O. Knacke, and O. Kubaschewski	Thermochemical Properties of Inorganic Substances: Supplement, Springer-Verlag, Berlin, Heidelberg, and New York (1977)	
1986	M. W. Chase, C. A. Davies, and J. R. Downey	JANAF Thermochemical Tables, American Chemical Society and American Institute of Physics for the National Bureau of Standards, New York (1986)	Published in J. Phys. Chem. Ref. Data. Vol. 14, Supp. 1 (1985), https://srd.nist.gov/JPCRD/jpcrdS1V14.pdf
1993	I. Barin	Thermochemical Data of Pure Substances, 2nd Edition, VCH, Weinheim (1993)	
1998	M. W. Chase	NIST-JANAF Thermochemical Tables, American Chemical Society and American Institute of Physics for the National Bureau of Standards, New York (1998)	https://srd.nist.gov/JPCRD/jpcrdM9.pdf
2013	National Institute of Standards and Technology	NIST-JANAF Thermochemical Tables, National Institute of Standards and Technology Standard Reference Data Program (2013)	Web database, http://kinetics.nist.gov/janaf/
—	MALT Group	Thermodynamic Database, MALT for Windows, Ver. 1.0	Software
—	Outotec Research Oy.	HSC Chemistry Ver. 9, Outotec Research Oy.	Software
—	Centre for Research in Computational Thermochemistry (CRCT) and GTT-Technologies	FactSage Ver. 7.3, Centre for Research in Computational Thermochemistry (CRCT) and GTT-Technologies	Software
—	Thermo-Calc Software	Thermo-Calc, SGTE Molten Salts Database, Ver. 1.2, Thermo-Calc Software	Software

Table 6. Books and literatures on electrochemical data of molten salts.

Electrochemical data			
Year	Author	Literature	Note
1976	J. A. Plambeck and A. J. Bard (Eds.)	Encyclopedia of Electrochemistry of the Elements, Vol. X, Fused Salt Systems, Marcel Dekker Inc., New York (1976)	Single-electrode potential
1994	M. Takahashi	"Atlas of Electrochemical Equilibria in the Molten Alkali Chlorides Solutions. -E-pO^{2-} Diagrams of the Molten LiCl-KCl and NaCl-KCl Solutions-", Molten Salts, 37(3), 215–308 (1994)	Potential-pO^{2-} diagram
2005	Y. Ito (Ed.)	Yoyuen no Kagaku, Industrial Publishing & Consulting, Inc., Tokyo (2005)	
2005	M. Takahashi and N. Masuko	Denkai Hyaku-wa, Vol. 3, Story 62–74, The Committee of the Electrolytic Science and Technology, pp. 42–131 (2005)	Single-electrode potential, Potential-pO^{2-} diagram
2013	The Electrochemical Society of Japan (Ed.)	Denki Kagaku Binran, 6th Edition, Maruzen Publishing Co., Ltd., Tokyo (2013)	Single-electrode potential

special consideration that the videos, images, and slides can be freely modified, and allowed to freely use them for educational activities within MSC and at universities. Only public release requires the approval of Nippon Light Metal Co., Ltd. An MSC member who wishes to use the archived materials needs an application to the committee office and the submission of a pledge.

5. Future Prospect

Although the information-gathering activities conducted from

Table 7. Books and literatures on structures of molten salts.

Structure			
Year	Author	Literature	Note
1978	S. Takeuchi (Ed.)	Kinzoku Ekitai no Kouzo to Bussei, Kinzoku Bussei Kiso Kouza, The Japan Institute of Metals and Materials, Maruzen Publishing Co., Ltd., Tokyo (1978)	Structure analysis method of liquid metal
1981	A. M. Stoneham	Handbook of Interatomic Potentials I. Ionic Crystals, AERE-R 9598, Harwell (1981)	Collection of force field parameters for molecular dynamics calculation of molten salt
1998	T. Yokokawa (Ed.)	Kouon Yutai no Kagaku, Yoyu Sanka-butsu no San Enki to Kagaku Kouzo, AGNE Gijutsu Center Inc., Tokyo (1998)	Data other than slag is also listed.
2011	G. Adachi (Ed.)	Rare Metal Binran, Maruzen Publishing Co., Ltd., Tokyo (2011)	Structure of molten salts in Chap. 15
2014	J.-C. G. Bünzli and V. K. Pecharsky (Eds.)	Handbook on the Physics and Chemistry of Rare Earths, Vol. 44, Elsevier, Amsterdam (2014)	Structure of molten salts in Chapter 260

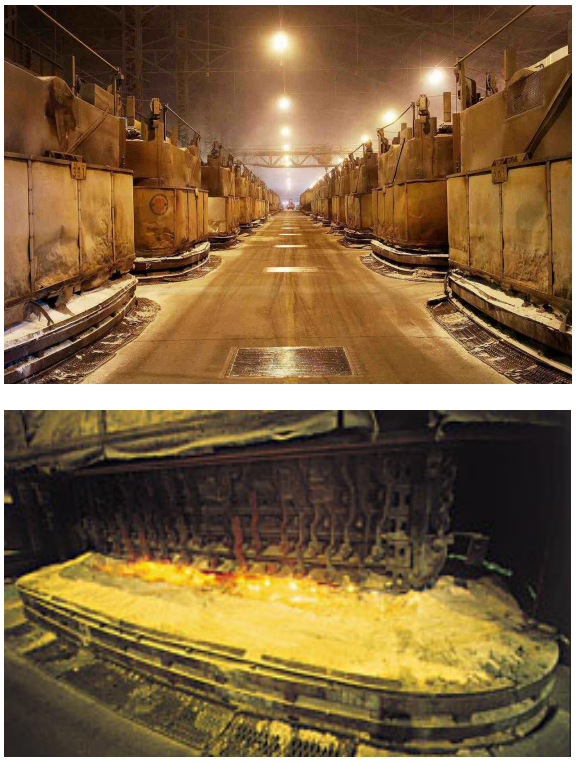

Figure 1. Representative photographs of the electrolytic smelting of Al metal in the Hall-Héroult process operated in Nippon Light Metal Co., Ltd. (Reprint permission by Nippon Light Metal Co., Ltd. and MSC).

2015 to 2016 have paused, further activities must continue. Further activities will be planned as follows;

1. Service provision to MSC members
   - Open at the webpage of MSC
   - Classification of the papers published in "Molten Salts"
2. Periodical update
   - Addition of new information
   - Checking the changes of URLs
   - Adding information on other aspects
3. Preservation of books
   - Avoiding lost and discard of out-of-print books
4. Creation of new databases
   - Systematization of the data that have not been centralized

The most recent necessary activity is to provide services to the MSC members, which was the original purpose of the working group. We provide the literature data in Tables 1–7 as Supporting Information (Tables S1–S7). The same data will be uploaded to the webpage of MSC. These data are provided in Excel files to improve the convenience of the MSC members and readers. One of the advantages of the distribution of Excel files is the capability to modify and add the information on the MSC member's and reader's side. Additionally, the files include several additional information such as ISBN numbers of the books and hyperlinks to internet bookstores and library sites for easy access. Another service provision is the information of the journal "Molten Salts" published by MSC. There is no doubt that this journal is one of the world's leading collections of molten salt information, although it was excluded from the tables in this paper. Since the electronic version of "Molten Salts" has been recently prepared from the first issue to the latest issue, the access to each paper has been greatly facilitated. Classifying items like this article will make it a precious information source.

Next, update work such as adding and updating information is required periodically. The first working group collected and accumulated information on books and database literatures from the dawn of molten salt chemistry to approximately 2015. As new books and database literatures are published in the future, the addition of new information is necessary. Over the past ten years advances in analysis technology using synchrotron radiation and new knowledge on structures have been obtained, new updates are desirable about once every ten years. The updates are necessary not only for the content but also for checking the changes in the URLs of the published documents and web databases. In fact, while we were writing this article, URLs were changed on multiple sites in the three years after the activity. Based on the above situations, the authors hope that young MSC members in their thirties, like in our first activity, will mainly do the next update. Hopefully, members with different specializations, such as glass and slag, will also join the present working group and gather information on books and other materials.

Additionally, since many books introduced in this article have already been out of print, prevention of the loss of these books is necessary. Activities to hand over these valuable books among molten salt researchers are required at and after each retirement of them.

Finally, in the future, it may be necessary to collect information in the fields not yet included in the databases created in this activity. Electrochemical data, for example, were poorly collected, except for

the molten salt systems described above, which are still based on the literature book published in 1976.

6. Conclusion

The transfer of valuable information and knowledge obtained by the past researchers to later generations is essential. One of the major missions of MSC is to collect all the data on molten salt without missing any information. We would like to continue promoting the activity to contribute to the development of molten salt chemistry.

Supporting Information

The references and tables are given in the supporting information. The Supporting Information is available on the website at DOI: https://doi.org/10.5796/electrochemistry.20-00058.

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