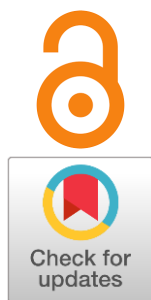


Thermal diffusivity of molten CeCl_3 - $M\text{Cl}$ ($M = \text{Li}, \text{Na}, \text{K}, \text{Rb}, \text{Cs}$) mixtures

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Thermal diffusivity is a key thermophysical parameter that characterizes the rate of heat propagation through a material under transient thermal conditions. For molten salts, including halide systems, this property is of particular importance for the design and optimization of high-temperature processes. Rare-earth metal halides, such as cerium(III) chloride, are of interest due to their specific structural features and their role as model systems in nuclear technology research. Owing to its electrochemical similarity to plutonium, CeCl_3 is widely employed in experimental studies simulating actinide behavior in pyrochemical processing of spent nuclear fuel. While the thermal diffusivity of pure alkali halides is relatively well studied, the introduction of trivalent cations such as Ce^{3+} leads to significant structural rearrangements in the melt, making direct extrapolation from pure salts unreliable. This work focuses on the thermal diffusivity of binary CeCl_3 - $M\text{Cl}$ ($M = \text{Li}, \text{Na}, \text{K}, \text{Rb}, \text{Cs}$) systems over a wide temperature range, using calculated values based on experimental data for thermal conductivity, density, and specific heat capacity. The results reveal a pronounced dependence of the thermal diffusivity on the cationic composition and temperature. The observed trends are interpreted in terms of changes in molar mass, ionic mobility, interionic interaction energies, and structural organization within the melts. The findings provide valuable input for validating molecular dynamics simulations, as well as for developing predictive models of heat and mass transfer in high-temperature applications, including pyrochemical nuclear fuel processing and thermal energy storage systems.

keywords: thermal diffusivity, cerium chloride, alkali chloride, heat transfer, pyrochemical processing, molten electrolytes, specific heat capacity

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1. Introduction

Thermal diffusivity is one of the key thermophysical parameters that determines the rate of heat propagation in a material under non-steady-state thermal conditions. Unlike thermal conductivity, which characterizes a material's ability to conduct heat under steady-state conditions, thermal diffusivity reflects how quickly a substance responds to changes in temperature over time. Thermal diffusivity is quantitatively related to thermal conductivity, specific heat capacity, and density. The study of thermal diffusivity is critically important for numerical modeling of heat transfer under significant temperature gradients, as well as for the calculation of thermal regimes in high-temperature technological and energy systems.

Molten salts, including halides, are widely used as heat transfer fluids and functional media in various high-temperature technological installations. For example, mixtures based on fluorides and chlorides of alkali and rare-earth metals are employed as electrolytes in systems for the production of rare-earth elements, as well as metals and their alloys [1–8], in reactive media for the pyrochemical processing of spent nuclear fuel [9–11], and serve as key materials in concentrating solar power plants and thermal energy storage systems [12–15]. In each of these cases, knowledge of thermal diffusivity is of practical importance: for the design of heat and mass transfer processes, the selection of materials with minimal thermal losses and maximum thermal stability, and the numerical modeling of such processes.

To estimate the thermal diffusivity of molten salts, computational methods are often used, based on data for thermal conductivity, density, and specific heat capacity.

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However, these properties strongly depend on temperature and composition, and experimental data are often contradictory. This is particularly true for molten halides of rare-earth elements, where the presence of multiply charged ions, such as Ce^{3+} , can significantly affect interionic interactions, melt structure, and the contributions of different heat transfer mechanisms.

Cerium, as one of the lanthanides, plays an important role in simulation studies of nuclear technologies. Due to its electrochemical properties being similar to those of plutonium [16–17], its compounds are used as model systems to study the behavior of radioactive components without the need to handle nuclear materials. Cerium(III) chloride is often employed as a model salt component in the development of pyrochemical processes, such as the electrodeposition of uranium and plutonium in molten chlorides [18–22]. Thus, knowledge of the thermal diffusivity of melts based on CeCl_3 and its mixtures with alkali metal chlorides is of interest not only for fundamental science but also for the development of specific technological solutions in non-aqueous electrochemistry, spent nuclear fuel processing, and high-temperature energy applications.

Data on the thermal diffusivity of pure alkali metal halides and their mixtures are relatively well studied [23–28]. However, when trivalent ions such as Ce^{3+} are added to the melt, the system's behavior becomes significantly more complex. It is therefore necessary to determine the thermal diffusivity of binary mixtures containing cerium(III) chloride, since simple extrapolation from the pure salts becomes impossible due to structural changes in the melt and the redistribution of contributions from different heat transfer mechanisms.

Nevertheless, the literature reports data on the electrochemical properties of molten chloride systems containing CeCl_3 [29–33], while information on their thermal diffusivity remains limited to only a few studies.

A systematic study of the thermal diffusivity of molten mixtures of cerium(III) chloride with alkali metal chlorides will help reveal the influence of cation radius, mass, and interionic interactions on heat diffusion in the melt. It is expected that as the radius and mass of the cation increase from Li^+ to Cs^+ , the thermal diffusivity decreases, owing to the reduced average kinetic energy and enhanced structural organization of the system. Moreover, knowledge of thermal diffusivity is essential for validating the results of numerical modeling (molecular dynamics, Monte Carlo methods), which use simplified interionic interaction potentials. Comparison of calculated and experimental values allows for the calibration of such models, enabling the prediction of

properties of new compositions without labor-intensive experiments.

The present work aims to evaluate the thermal diffusivity of molten binary systems $\text{CeCl}_3\text{-MCl}$, where $M = \text{Li, Na, K, Rb, Cs}$, over a wide temperature range, based on experimental data on thermal conductivity, isobaric specific heat capacity, and density. Temperature dependences are analyzed, the influence of the alkali metal cation nature is assessed, and possible heat transfer mechanisms are discussed. The obtained data will complement the existing database on the thermophysical properties of cerium(III) chloride-containing halide melts and may be used in the design and optimization of high-temperature processes in the chemical and energy industries.

2. Result and discussion

Thermal diffusivity (a , m^2/s) was calculated using formula (1):

$$a = \frac{\lambda}{c_p \cdot \rho}, \quad (1)$$

where λ – thermal conductivity, $\text{W}/(\text{m} \cdot \text{K})$, ρ – density, g/m^3 , c_p – isobaric specific heat capacity, $\text{J}/(\text{g} \cdot \text{K})$.

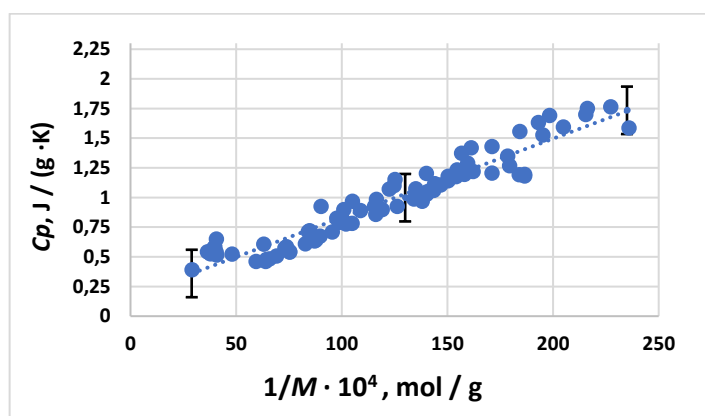
Thermal conductivity values used in the work were obtained by the authors using the stationary method of coaxial cylinders and published in the work [34]. There are no data in the literature on the density of molten mixtures of cerium(III) chloride with alkali metal chlorides; therefore, for these systems, its values were calculated using the software Data Organizer 1.0. The methodological part was described in the A.M. Potapov's work [35]. As an example, Table 1 shows the density values calculated at a temperature of 1023 K.

In the present study, it was not possible to achieve reproducible values of the specific heat capacity at constant pressure of molten chloride mixtures $\text{CeCl}_3\text{-MCl}$, where $M = \text{Li, Na, K, Rb, Cs}$ using the DSC method on the STA 449 C Jupiter instrument. There are no similar data in the literature, therefore, empirical Equation (2) was derived based on experimental data for isobaric specific heat capacity alkali chlorides (Li [36], Na , K , Cs [37], Rb [38] and their mixtures [39]), alkaline earth chlorides (Be , Sr [38], Mg , Ca , Ba [37]), rare-earth chlorides (La , Ce , Nd , Pr , Gd , Dy [40], Sm , Tm [41], Tb [42]) and (LiCl-KCl)- NdCl_3 - CeCl_3 - UCl_3 mixtures [43] (Figure 1).

$$c_p = \frac{66.47}{M} + 0.167 \pm 0.2. \quad (2)$$

Table 1 – Density values of molten salt mixtures of cerium(III) chloride with alkali-metal chlorides at 1023 K.

Composition of the salt melt	Density ($\rho \cdot 10^{-6}$), g/m ³
CeCl ₃	3.3110 ± 0.0662
0.75 LiCl-0.25 CeCl ₃	2.2753 ± 0.0455
0.50 LiCl-0.50 CeCl ₃	2.7583 ± 0.0552
0.25 LiCl-0.75 CeCl ₃	3.0803 ± 0.0616
0.75 NaCl-0.25 CeCl ₃	2.2417 ± 0.0448
0.50 NaCl-0.50 CeCl ₃	2.6986 ± 0.0540
0.25 NaCl-0.75 CeCl ₃	3.0438 ± 0.0609
0.75 KCl-0.25 CeCl ₃	2.0795 ± 0.0416
0.50 KCl-0.50 CeCl ₃	2.5464 ± 0.0509
0.25 KCl-0.75 CeCl ₃	2.9569 ± 0.0591
0.75 RbCl-0.25 CeCl ₃	2.4702 ± 0.0494
0.50 RbCl-0.50 CeCl ₃	2.7589 ± 0.0552
0.25 RbCl-0.75 CeCl ₃	3.0468 ± 0.0609
0.75 CsCl-0.25 CeCl ₃	2.7349 ± 0.0547
0.50 CsCl-0.50 CeCl ₃	2.9038 ± 0.0581
0.25 CsCl-0.75 CeCl ₃	3.1090 ± 0.0622

**Figure 1** Summary data on the values of specific heat capacity of chlorides of alkali, alkaline earth, rare earth metals and their mixtures from the reciprocal molar mass of the salt.

The basis of the equation is the empirical dependence of the experimental values of the heat capacity on the reciprocal molar mass using the example of fluorides from the work [44]. The resulting in this study Equation (2) can be used to estimate the specific isobaric heat capacity of chloride melts for which there are no data in the literature and experimental measurement may be difficult.

Table 2 shows the thermal diffusivity equations for all studied systems at various temperatures. The margin of error of the thermal diffusivity was calculated and amounted to 8.63 %.

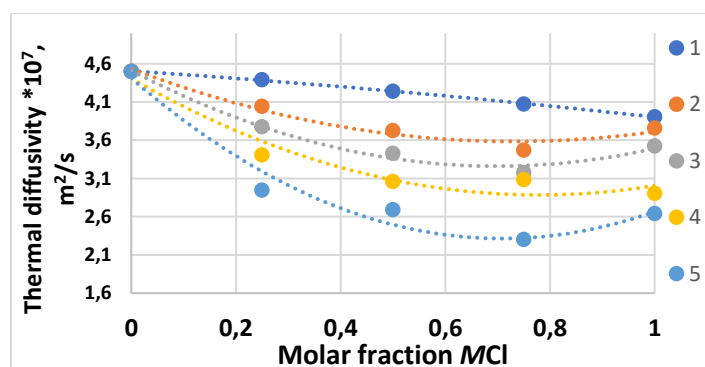
Figure 2 shows concentration dependences of molten mixtures of cerium chlorides and alkali-metal chlorides at 1023 K as an example.

The thermal diffusivity of molten mixtures decreases from lithium to cesium and negative relative deviations from additive values increases (Table 3).

The greatest deviations are observed in mixtures containing cerium chloride. Deviations in mixtures with lithium chloride lie within the limits of experimental error in measuring thermal diffusivity.

Table 2 – Equation of temperature dependence of thermal diffusivity of cerium(III) chloride and its mixtures with alkali-metal chlorides.

Composition of the salt melt	Equations ($a \cdot 10^{-7}$), m ² /s
CeCl ₃	$a = 0.006 T - 1.6776$
0.75 LiCl-0.25 CeCl ₃	$a = 0.0051 T - 1.1360$
0.50 LiCl-0.50 CeCl ₃	$a = 0.0054 T - 1.2664$
0.25 LiCl-0.75 CeCl ₃	$a = 0.0057 T - 1.4546$
0.75 NaCl-0.25 CeCl ₃	$a = 0.0056 T - 2.2368$
0.50 NaCl-0.50 CeCl ₃	$a = 0.0057 T - 2.0381$
0.25 NaCl-0.75 CeCl ₃	$a = 0.0058 T - 1.8502$
0.75 KCl-0.25 CeCl ₃	$a = 0.0056 T - 1.8573$
0.50 KCl-0.50 CeCl ₃	$a = 0.0055 T - 2.1541$
0.25 KCl-0.75 CeCl ₃	$a = 0.0057 T - 2.5224$
0.75 RbCl-0.25 CeCl ₃	$a = 0.0044 T - 2.4186$
0.50 RbCl-0.50 CeCl ₃	$a = 0.0056 T - 2.5841$
0.25 RbCl-0.75 CeCl ₃	$a = 0.0055 T - 2.1726$
0.75 CsCl-0.25 CeCl ₃	$a = 0.0034 T - 1.1023$
0.50 CsCl-0.50 CeCl ₃	$a = 0.0039 T - 1.1740$
0.25 CsCl-0.75 CeCl ₃	$a = 0.0041 T - 1.1871$

**Figure 2** Concentration dependence of the thermal diffusivity of chloride systems at a temperature of 1023 K, where 1. LiCl-CeCl₃ ($R^2 = 0.9992$), 2. NaCl-CeCl₃ ($R^2 = 0.9662$), 3. KCl-CeCl₃ ($R^2 = 0.9868$), 4. RbCl-CeCl₃ ($R^2 = 0.9456$), 5. CsCl-CeCl₃ ($R^2 = 0.9643$).

As an example, Figures 3 and 4 show the temperature dependences of the thermal diffusivity for mixtures LiCl-CeCl₃ and KCl-CeCl₃. Figure 3 shows a change in composition from pure lithium chloride to cerium(III) chloride.

This dependence seems surprising because cerium(III) chloride has a lower thermal conductivity (0.65 W/m · K) than lithium chloride (W/m · K) at 1023 K [34], but of cerium(III) chloride's thermal diffusivity is higher than that of lithium chloride. This is due to the significantly smaller isobaric heat capacity of CeCl₃, which, with comparable density, leads to a decrease in the value $\rho \cdot C_p$ in the Equation (1).

Table 3 – Relative deviations from additive values of thermal diffusivity for CeCl₃-MCl mixtures at 1023 K.

Composition	Relative deviations, %
0.75 LiCl-0.25 CeCl ₃	0.98
0.50 LiCl-0.50 CeCl ₃	0.91
0.25 LiCl-0.75 CeCl ₃	0.51
0.75 NaCl-0.25 CeCl ₃	-6.24
0.50 NaCl-0.50 CeCl ₃	-9.78
0.25 NaCl-0.75 CeCl ₃	-11.98
0.75 KCl-0.25 CeCl ₃	-11.23
0.50 KCl-0.50 CeCl ₃	-14.53
0.25 KCl-0.75 CeCl ₃	-15.64
0.75 RbCl-0.25 CeCl ₃	-16.82
0.50 RbCl-0.50 CeCl ₃	-17.35
0.25 RbCl-0.75 CeCl ₃	-6.56
0.75 CsCl-0.25 CeCl ₃	-26.88
0.50 CsCl-0.50 CeCl ₃	-24.65
0.25 CsCl-0.75 CeCl ₃	-25.87

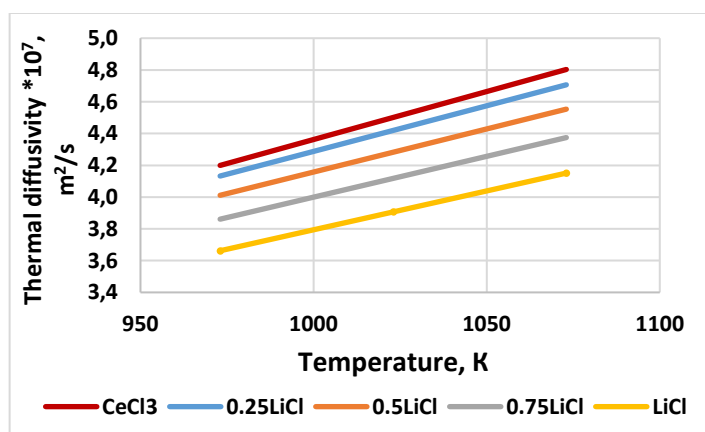


Figure 3 Temperature dependences of the thermal diffusivity for mixtures LiCl-CeCl₃.

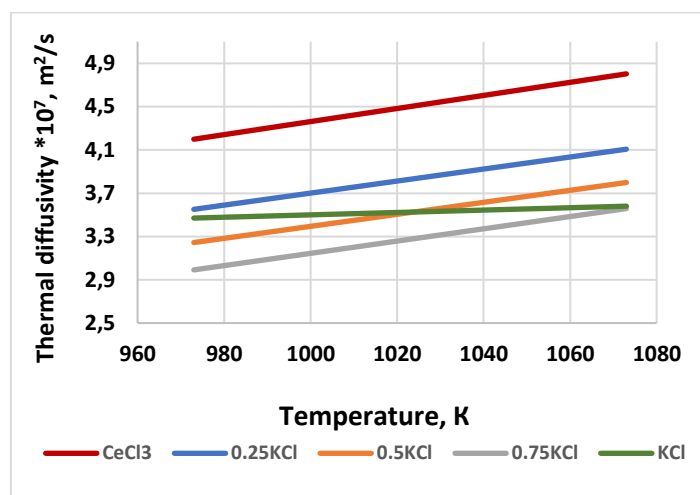


Figure 4 Temperature dependences of the thermal diffusivity for mixtures KCl-CeCl₃.

Moreover, the specific structural features of molten CeCl₃ – particularly the presence of a loose network structure characteristic of molten rare-earth metal halides – may contribute to a different heat transfer mechanism, in which a more ordered structure facilitates a more efficient leveling of temperature gradients.

At the same time, for mixtures containing other alkali metals, the dependence exhibits the same trend, as illustrated in the example KCl-CeCl₃ shown in Figure 4.

The thermal diffusivity of all studied mixtures increases with increasing temperature. This is consistent with general trends for ionic melts. The absolute values of thermal conductivity decrease with an increase in the proportion of KCl: the highest values are typical for pure CeCl₃, the lowest for mixtures with a composition of 0.75 KCl. The thermal diffusivity of pure potassium chloride, as measured, is found to be higher than that of a mixture containing 0.75 moles of KCl and 0.25 moles of CeCl₃. Additionally, the slope of the temperature dependence for pure KCl appears to be lower, which requires separate consideration.

Firstly, pure KCl is an ionic melt with a simple structure dominated by K⁺ and Cl⁻ ions. This accounts for its relatively high thermal diffusivity. In contrast, structural rearrangements may occur in mixtures with CeCl₃: Ce³⁺ ions tend to form stable coordination complexes ([CeCl₆]³⁻ and others), as confirmed by the data reported in [45], leading to a more pronounced temperature dependence of the system's thermal properties.

Secondly, thermal diffusivity is determined by the relationship between thermal conductivity, density, and heat capacity. Upon the introduction of CeCl₃, the density and heat capacity of the melt can decrease; however, the formation of complex ionic structures and

changes in interionic interactions can offset or even enhance the resistance to heat transfer. This explains why the thermal diffusivity of the mixture containing 0.75 mol. fraction KCl is lower than that of pure KCl.

Finally, the smaller slope of the temperature dependence of thermal diffusivity in pure KCl is due to the absence of structural rearrangements with increasing temperature. In mixtures, by contrast, rising temperature can cause the breakdown of coordination complexes, thereby increasing the mobility of heat carriers and enhancing thermal diffusivity.

Thus, the differences between the thermal diffusivity of pure KCl and its mixture with CeCl_3 are related not only to composition but also to the specific features of interionic interactions and the possible structural rearrangement upon heating. This highlights the importance of considering structural effects when interpreting the thermal characteristics of multicomponent melts.

3. Conclusions

The thermal diffusivity of CeCl_3 - $M\text{Cl}$ ($M = \text{Li, Na, K, Rb, Cs}$) depends on temperature and alkali cation type. It increases with increasing temperature for all studied mixtures in a wide temperature range (973–1073 K). This behavior correlates with the behavior of thermal conductivity of the studied systems. It is due to the increase in thermal conductivity and the decrease in density with increasing temperature, while the isobaric heat capacity changes to a lesser extent.

A comparison of mixtures with various alkaline cations shows that the thermal conductivity decreases in the series: CeCl_3 -LiCl > CeCl_3 -NaCl > CeCl_3 -KCl > CeCl_3 -RbCl > CeCl_3 -CsCl.

This is associated with an increase in the molar mass of M^+ ions and the corresponding increase in the density and heat capacity of the systems when moving from lighter to heavier cations, which collectively reduces the value of α . The influence of the alkali component on thermal diffusivity may also be related to differences in ionic mobility and the nature of interionic interactions in the presence of trivalent cerium.

Thus, the thermal diffusivity of CeCl_3 - $M\text{Cl}$ melts exhibits a pronounced dependence on both cationic composition and temperature, reflecting a complex interplay of mass, structural, and energetic factors such as interionic interaction energy and ion polarizability. The obtained correlations can be used to develop heat and mass transfer models for high-temperature processes, including pyrochemical technologies for handling nuclear materials in which cerium is employed as an actinide surrogate.

Supplementary materials

No supplementary materials are available.

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Author contributions

Kseniya Kesler: Formal analysis; Data curation; Visualization; Writing – Original draft; Writing – Review & Editing.

Vasiliy Dokutovich: Discussion of results; Writing – Review & Editing.

Conflict of interest

The authors declare no conflict of interest.

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References

- Habashi F. Handbook of extractive metallurgy. Wiley-VCH: Weinheim; 1997. 2426 p.
- Fang ZZ. Extractive metallurgy of titanium: Conventional and recent advances in extraction and production of titanium metal. Elsevier: Amsterdam, Netherlands; 2019. 436 p. <https://doi.org/10.1016/C2018-0-00468-5>
- Abbasalizadeh A, Malfliet A, Seetharaman S, Sietsma J, Yang Y, Electrochemical extraction of rare earth metals in molten fluorides: conversion of rare earth oxides into rare earth fluorides using fluoride additives, Journal of Sustainable Metallurgy, **3** (2017) 627–637. <https://doi.org/10.1007/s40831-017-0120-x>
- Smolenskiy VV, Novoselova AV, Bovet AL. Production of high purity metallic cerium by electrolysis of LiCl-KCl-CeCl₃. In: Prospects for the development of metallurgy and mechanical engineering using completed fundamental research and R&D; 2020; Ekaterinburg, Russia. p. 142–145. Russian.
- Jiang K, Shao Y, Smolenski V, Novoselova A, et al., Electrochemical study of reduction Ce(III) ions and production of high purity metallic cerium by electrorefining in fused LiCl-KCl eutectic, Journal of Electroanalytical Chemistry, **878** (2020) 114691. <https://doi.org/10.1016/j.jelechem.2020.114691>

6. Kaplan GE, Splina GF, Ostroynshko YI. *Elektroliz v metallurgii regkih metallov* [Electrolysis in metallurgy of rare metals]. Moscow: Metallurgizdat; 1963. 360 p. Russian.
7. Baimakov YV, Bitykov MM. *Electroliz rasplavlennykh soley* [Electrolysis of molten salts]. Moscow: Metallurgiya; 1966. 560 p. Russian.
8. Zalikmai AN, Krein OE, Samsonov GV. *Metallurgiya redkih metallov* [Metallurgy of rare metals]. Moscow: Metallurgiya; 1978. 560 p. Russian.
9. Locatelli G, Mancini M, Todeschini N, Generation IV nuclear reactors: Current status and future prospects, *Energy Policy*, **61** (2013) 1503–1520. <https://doi.org/10.1016/j.enpol.2013.06.101>
10. Sorbom BN, Ball J, Palmer TR, Mangiarotti FJ, et al., ARC: A compact, high-field, fusion nuclear science facility and demonstration power plant with demountable magnets, *Fusion Engineering and Design*, **100** (2015) 378–405. <https://doi.org/10.1016/j.fusengdes.2015.07.008>
11. Degtyarev A, Myasnikov A, Ponomarev L, Molten salt fast reactor with U–Pu fuel cycle, *Progress in Nuclear Energy*, **82** (2015) 33–36. <https://doi.org/10.1016/j.pnucene.2014.07.014>
12. Vignarooban K, Xu X, Arvay A, Hsu K, Kannan AM, Heat transfer fluids for concentrating solar power systems – A review, *Applied Energy*, **146** (2015) 383–396. <https://doi.org/10.1016/j.apenergy.2015.01.125>
13. Prieto K, Tagle-Salazar PD, Patino D, Schallenberg Rodrigues HC, et al., Use of molten salt tanks for seasonal thermal energy storage with high renewable share in the energy system, *Journal of Energy Storage*, **86(Part A)** (2024) 111203. <https://doi.org/10.1016/j.est.2024.111203>
14. Tian Y, Zhao CY, A review of solar collectors and thermal energy storage in solar thermal applications, *Applied Energy*, **104** (2013) 538–553. <https://doi.org/10.1016/j.apenergy.2012.11.051>
15. Halliday C, Hatton TA, The potential of molten metal oxide sorbents for carbon capture at high temperature: conceptual design, *Applied Energy*, **280** (2020) 116016. <https://doi.org/10.1016/j.apenergy.2020.116016>
16. Marsden KC, Pestic B, Evaluation of the electrochemical behavior of CeCl_3 in molten LiCl–KCl eutectic utilizing metallic Ce as an anode, *J. Electrochem. Soc.*, **159(6)** (2011) F111. <https://doi.org/10.1149/1.3575637>
17. Shannon RD, Revised effective ionic radii and systematic studies of interatomic distances in halides and chalcogenides, *Acta Crystallographica Section A*, **32** (1976) 751–767.
18. Smirnov MV, Komarov VE, Alekseev VN. *Ravnesnye potentsialy yrana d rasplavlennykh hloridah shelochnykh metallov* [Equilibrium potentials of uranium in molten alkali metal chlorides]. Moscow: Nauka; 1970. 201 p. Russian.
19. Skiba OV, Smirnov MV, Ravnesnye potentsialy yrana v rasplave NaCl–KCl [Equilibrium potentials of uranium in the NaCl–KCl melt], *Trydi instityta elektrokhimii* [Proceedings of the Institute of Electrochemistry], **2** (1961) 3–8. Russian.
20. Kuznetsov SA, Hayashi H, Minato K, Gaune-Escard M, Electrochemical transient techniques for determination of uranium and rare-earth metal separation coefficients in molten salts, *Electrochimica Acta*, **51(12)** (2006) 2463–2470. <https://doi.org/10.1016/j.electacta.2005.07.028>
21. Serrano K, Taxil P, Electrochemical reduction of trivalent uranium ions in molten chlorides, *Journal of Applied Electrochemistry*, **29** (1999) 497–503. <https://doi.org/10.1023/A:1003402029895>
22. Strepetov KE, Maltsev DS, Volkovich VA, Uranium reduction from chloride melts on solid and liquid metal cathodes, *AIP Conference Proceedings*, **2174(1)** (2019) 2174. <https://doi.org/10.1063/1.5134218>
23. Bystraj GP, Desyatnik VN, Metod tonkoj peremychki dlya opredeleniya teploprovodnosti rasplavlennykh soley [Thin bridge method for determining thermal conductivity of molten salts], *Fizicheskaya himiya i elektrokhimiya rasplavlennykh i tverdyh elektrolitov* [Physical chemistry and electrochemistry of molten and solid electrolytes], **1** (1973) 56–57. Russian.
24. Kato Y, Furukawa K, Araki N, Kobayasi K, Thermal diffusivity measurement of molten salts by use of a simple ceramic cell, *High Temperatures - High Pressures*, **15** (1983) 191–198.
25. Filatov ES, Hohlov VA, Nechkin GV. *Teplofizicheskie svoystva rasplavlennykh smesey hloridov litiya i cезiya* [Thermophysical properties of molten mixtures of lithium and cesium chlorides]. In: 4-ya Ural'skaya konferentsiya po vysokotemperaturnoy fizicheskoy khimii i elektrokhimii [4th Ural Conference on High-Temperature Physical Chemistry and Electrochemistry]; 1985 October 30–31; Perm, Russia. p. 10. Russian.
26. Baranov VL, Hohlov VA, Filatov ES, *Teplo- i temperaturoprovodnost' kristallicheskih i rasplavlennykh evtekticheskikh smesey hloridov shchelochnykh metallov vblizi ih temperatury plavleniya* [Thermal conductivity and diffusivity of crystalline and molten eutectic mixtures of alkali metal chlorides near their melting point], *Rasplavy* [Melts], **4** (1998) 52–55. Russian.
27. Nagasaka Y, Nakazawa N, Nagashima A, Experimental determination of the thermal diffusivity of molten alkali halides by the forced Rayleigh scattering method. I. Molten LiCl, NaCl, KCl, RbCl, and CsCl, *International Journal of Thermophysics*, **13** (1992) 555–574. <https://doi.org/10.1007/BF00501941>
28. Cockrell C, Withington M, Devereux HL, et al., Thermal conductivity and thermal diffusivity of molten salts: Insights from molecular dynamics simulations and fundamental bounds, *J. Phys. Chem. B*, **129(8)** (2024) 2271–2279. <https://doi.org/10.48550/arXiv.2409.03775>
29. Kim S, Lee S-H, Electrochemical properties of NdCl_3 and CeCl_3 in molten LiCl–KCl eutectic salt, *Applied Sciences*, **10(20)** (2020) 7252. <https://doi.org/10.3390/app10207252>
30. Misra M, Raja KS, Jaques A, Baral S, Effect of addition of multi-component lanthanides to LiCl–KCl eutectic on thermal and electrochemical properties, *ECS Transactions*, **33(7)** (2010) 351–360. <https://doi.org/10.1149/1.3484793>
31. Novoselova AV, Smolenskiy BB, Electrochemical and thermodynamic properties of lanthanides (Nd, Sm, Eu, Tm, Yb) in alkali metal chloride melts, *Radiochemistry*, **3(55)** (2013) 243–256. <https://doi.org/10.1134/S1066362213030016>
32. Yamamura T, Mehmood M, Maekawa H, Sato Y, Electrochemical processing of rare-earth and rare metals by using molten salts, *Chemistry for Sustainable Development*, **12** (2004) 105–111.
33. Yoon D, Phongikaroon S, Electrochemical properties and analyses of CeCl_3 in LiCl–KCl eutectic salt, *J. Electrochem.*

- Soc., **162(10)** (2015) E237–E243.
<https://doi.org/10.1149/2.0401510jes>
34. Bobrova KO, Teploprovodnost' rasplavlennykh smesey sistemy CeCl₃-MCl (M = Li, Na, K, Cs) [Thermal conductivity of molten mixtures of the CeCl₃-MCl (M = Li, Na, K, Cs) system], Rasplavy [Melts], **3** (2023) 287–297. Russian.
<https://doi.org/10.31857/S0235010623030027>
35. Potapov AM. Transportnye svoystva rasplavlennykh hloridov lantanidov i ih binarnykh smesey s hloridami shchelochnykh metallov [Transport properties of molten lanthanide chlorides and their binary mixtures with alkali metal chlorides] [dissertation]. Ekaterinburg; 2009. 467 p. Russian.
36. Minchenko V, Filatov E, Khokhlov V, Korzun I, Temperature and concentration changes of the isobaric and isochoric heat capacity of some halide melts, Rasplavy [Melts], **6** (1999) 22–30. Russian.
37. Chase MW], NIST-JANAF Thermochemical Tables, J. Phys. Chem. Ref. Data, **9** (1998) 1–1951.
38. Glushko VP, Gurvich LV, et al. Termodinamicheskie svoystva individual'nykh veshchestv: Sprav. izd. [Thermodynamic properties of individual things: reference publication] Nauka: Moscow; 1982. Russian.
39. Minchenko VI, Stepanov VP. Ionnye rasplavy. Uprugie i kaloricheskie svoystva [Ionic Melts. Elastic and Caloric Properties]. RAS, Ural Branch, Institute of High-Temperature Electrochemistry:Ekaterinburg; 2008. 366 p. Russian.
40. Gaune-Escard M, Bogacz A, Rycerz L, Szczepaniak W, Heat capacity of LaCl₃, CeCl₃, PrCl₃, NdCl₃, GdCl₃, DyCl₃, Journal of Alloys and Compounds, **235(2)** (1996) 176–181.
[https://doi.org/10.1016/0925-8388\(95\)02071-3](https://doi.org/10.1016/0925-8388(95)02071-3)
41. Rycerz L, Gaune-Escard M, Thermodynamics of SmCl₃ and TmCl₃: Experimental enthalpy of fusion and heat capacity. estimation of thermodynamic functions up to 1300 K, Z. Naturforsch., **57a** (2002) 79–84. <https://doi.org/10.1515/zna-2002-1-212>
42. Rycerz L, Gaune-Escard M, Enthalpies of phase transitions and heat capacity of TbCl₃ and compounds formed in TbCl₃-MCl systems (M = K, Rb, Cs), Journal of Thermal Analysis and Calorimetry, **68** (2002) 973–981.
<https://doi.org/10.1023/A:1016102925181>
43. Korzun IV, Dokutovich VN, Khokhlov VA. Thermal properties of quasi-binary mixtures of eutectic (LiCl-KCl) with uranium and lanthanide trichlorides. In: International Conference on Thermal Analysis and Calorimetry in Russia (RTAC-2016); Vol I; 2016 September 16–23; St. Petersburg, Russia. pp 80-85.
44. Khokhlov V, Ignatiev V, Afonichkin V, Evaluating physical properties of molten salt reactor fluoride mixtures, Journal of Fluorine Chemistry, **130(1)** (2009) 30–37.
<https://doi.org/10.1016/j.jfluchem.2008.07.018>
45. Zakiryanova ID, Zakiryarov DO, Zakiryarov PO, Local structure and dynamics of ions in LiCl-GdCl₃, KCl-GdCl₃ and LiCl-GdCl₃-Gd₂O₃ melts: Ab initio molecular dynamics simulations and Raman spectroscopy, Journal of Molecular Liquids, **376** (2023) 121485.
<https://doi.org/10.1016/j.molliq.2023.121485>