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Review

The Li_2CO_3–Na_2CO_3–K_2CO_3 Eutectic Revisited: Challenges and Gaps in Thermophysical Property Data

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Abstract

Molten salts are increasingly regarded as promising fluids for high-temperature heat transfer, thermal energy storage, and advanced reaction processes, including concentrated solar power (CSP), molten salt oxidation (MSO), and next-generation nuclear reactors. Among these materials, the ternary eutectic mixture Li_2CO_3–Na_2CO_3–K_2CO_3 (32.12–33.36–34.52 wt%) has emerged as a leading candidate due to its wide operating temperature range and favourable thermodynamic properties. Despite its relevance, substantial inconsistencies and gaps remain in the available thermophysical property data, posing challenges for reliable design, modelling, and industrial deployment. This work revisits the Li_2CO_3–Na_2CO_3–K_2CO_3 eutectic through a critical assessment of the literature from its reported melting point at 670 K (397 °C) up to approximately 1200 K (927 °C). Using a methodology inspired by IUPAC-supported strategies previously applied to common liquids such as water and hydrocarbons, we examine the quantity, quality, and coherence of existing measurements. Reference correlations are proposed only where the data are sufficiently robust to justify them. The analysis highlights a pressing need for more accurate and comprehensive measurements—particularly for heat capacity, thermal conductivity, and viscosity—to enable the development of reliable standard reference correlations. Brief recommendations are given on the measurement methods that should be used in high-temperature measurements, namely for heat capacity, viscosity, and thermal conductivity. Reliable thermophysical property data for $(LiNaK)_2CO_3$ remain limited and inconsistent, despite its relevance for high-temperature energy applications. Density data are comparatively robust, but heat capacity, thermal conductivity, and viscosity still require high-accuracy measurements at elevated temperatures. Addressing these data deficiencies is essential for advancing the safe and efficient use of molten carbonates in high-temperature energy technologies.

Keywords: molten carbonates; Li_2CO_3–Na_2CO_3–K_2CO_3 eutectic; thermophysical properties; concentrated solar power; high-temperature heat transfer; viscosity; thermal conductivity; heat capacity; reference correlations; critical review

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1. Introduction

Molten alkali carbonates—both pure and mixed—are regarded as highly promising fluids for high-temperature applications, including concentrated solar power (CSP), molten salt oxidation (MSO), and advanced nuclear reactor (ANR) technologies. An excellent review of energy storage technologies and their real-life applications, compares various storage approaches in terms of technical performance, deployment scale, number of operational projects, and technological maturity [1]. Their analysis concluded that molten salts (MS) will continue to dominate the thermal energy storage sector for large-scale applications.

In a comprehensive two-part review [2,3] the properties and applications of molten carbonates were examined in detail. Due to their unique physical and physicochemical characteristics, molten carbonates are highly attractive for a broad range of energy technologies operating under diverse conditions. The review highlighted several key advantages, including high thermal and moisture stability, reusability, elevated electrical conductivity, and relatively low corrosiveness toward metals in controlled atmospheres. Additionally, their eutectic mixtures exhibit reduced melting points, which minimizes the risk of freezing and congesting pipelines and equipment.

Among these materials, the ternary eutectic mixture Li_2CO_3–Na_2CO_3–K_2CO_3 has been selected as an alternative high-temperature heat transfer fluid (HTF) and thermal energy storage (TES) medium for a molten salt solar-thermal pilot plant [4]. Its adoption enabled an increase in operational temperatures from the conventional limit of 838 K (565 °C, typical of alkali nitrates) up to 973 K (700 °C). For proper equipment design and reliable process modelling, accurate thermophysical property data are essential. However, a survey of the literature reveals significant disparity among published measurements, as shown in a previous review by our group [5]. This situation has not improved substantially since then, despite the publication of some new datasets. Consequently, there remains a strong need for high-quality experimental measurements of the most relevant thermophysical properties for heat transfer and thermal storage—namely density, heat capacity, thermal conductivity, and viscosity—and for the establishment of recommended reference values for these properties.

Measuring thermophysical properties of molten carbonates presents several challenges. Some arise from their intrinsic behaviour at high temperatures, while others stem from limitations of the experimental techniques themselves, including high measurement uncertainties and material incompatibilities between molten samples and instrument components, which are often metallic. These factors contribute to inconsistencies and reduce confidence in the available data.

Reference correlations for the viscosity of 13 inorganic molten salts, reporting expected uncertainties between 2% and 7% have been proposed [6]. However, none of the carbonate salts or their eutectic mixtures were included due to the poor quality of the available viscosity measurements. More recently, the same group [7] proposed a viscosity correlation for the ternary carbonate eutectic, although it relied on Arrhenius modelling of experimental data that had not been reported by the original authors.

This paper aims to provide a critical assessment of the existing thermophysical property data for the ternary eutectic molten carbonate system. Our approach follows a strategy inspired by methodologies pioneered under IUPAC for common liquids, such as hydrocarbons and water [8–10]. Historical recommendations for the thermophysical properties of molten salts date back to the work of George Janz and co-workers in the 1960s and 1970s at NBS/NIST [11]. The present work does not replace the need for new, accurate measurements of the heat capacity, viscosity, and thermal conductivity of the Li_2CO_3–Na_2CO_3–K_2CO_3 eutectic—a task currently underway in our laboratory—but aims to clarify

the state of the literature, identify critical gaps, recommend methods of measurement and increase industrial and societal awareness of data quality requirements for optimal and safe design of industrial plants.

2. Ternary Eutectic of Molten Carbonates

The ternary mixture of lithium carbonate, sodium carbonate, and potassium carbonate (Li_2CO_3–Na_2CO_3–K_2CO_3) has a composition of 43.5–31.5–25.0 mol%, respectively (or 32.12–33.36–34.52 wt%), with a suggested melting point of T_m = 670 K (397 °C), as determined by DSC [12]. Throughout this text, it will be denoted as $(LiNaK)_2CO_3$ or LiNaK (in equations).

3. Data Analysis

3.1. Density

Table 1 summarizes the available works on the density of molten ternary eutectic $(LiNaK)_2CO_3$, including the NBS/NIST reference data published in 1979 [11].

Table 1. Existing literature data on the density of molten ternary eutectic $(LiNaK)_2CO_3$, at P = 0.1 MPa.

Measuring Method [a]	Declared Relative Uncertainty [b]	Temperature Range (K)	Purity of Sample [c] (%)	Number of Data Points (Equation)	Reference
A	0.01	680–860	NA	Equation	Janz et al. (1979) [11]
A	---	677–1081	NA	Equation	Araki et al. (1988) [13]
DBA	0.005	882–1158	NA	#4	Liu et al. (2003) [14]
MBP	0.003	770–1163	99.5	Equation	Kojima et al. (2008,1999) [15,16]
A	---	723–893	99.9	#4	An et al. (2016) [12]

[a] A—Archimedean; DBA—double-bob Archimedean; MBP—maximum bubble pressure. [b] Standard uncertainty. [c] As reported by the authors (typically manufacturer values). NA—not available.

Figure 1 shows the plotted data. For comparison purposes, to show the effect of composition on the density of the melt, data for a ternary carbonate mixture with a different composition (4–4–2 mass ratio) have also been included [17].

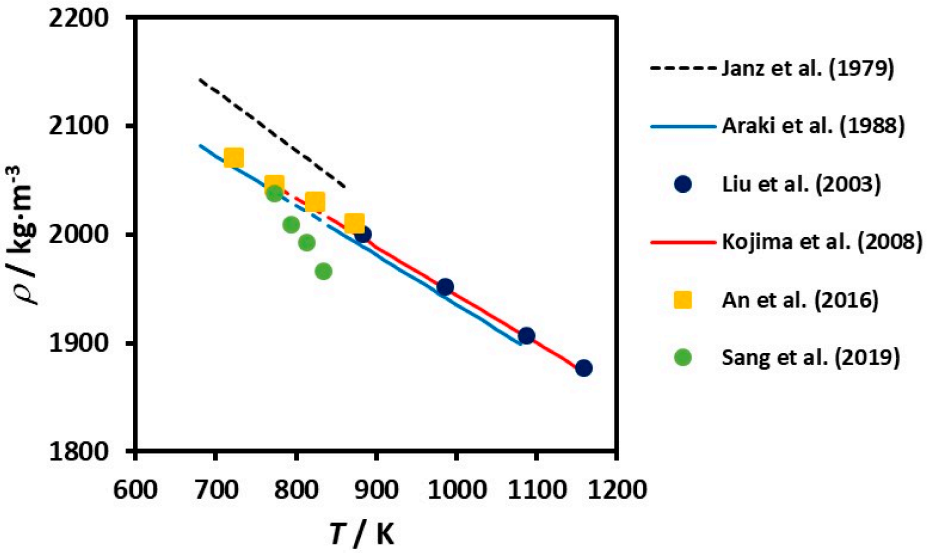


Figure 1. Density of the ternary eutectic $(LiNaK)_2CO_3$ as a function of temperature. Janz et al. (1979) [11]; Araki et al. (1988) [13]; Liu et al. (2003) [14]; Kojima et al. (2008) [15,16]; An et al. (2016) [12]; Sang et al. 2019 [17]. The lines represent equations reported by the authors.

Based on the plotted data, we have chosen the data reported in references [12–15] to establish a correlation for the density of the $(LiNaK)_2CO_3$ system. For datasets whereby only regression lines were available, a total of eight points were selected to cover the temperature range. The obtained equation is (1):

$$\rho\ (\mathrm{kg{\cdot}m^{-3}}) = (2387.52 \pm 7.39) - (0.44466 \pm 0.00802)(T/\mathrm{K}), \quad (1)$$

The correlation has a root mean square deviation of 5.29 $\mathrm{kg{\cdot}m^{-3}}$, fits the data within ± 0.3%, and can be applied in the temperature interval $650 < T/\mathrm{K} < 1150$. Figure 2 shows the deviation of the different datasets relative to this correlation. It can be seen that the older recommendations from 1979 [11] are significantly higher than this correlation.

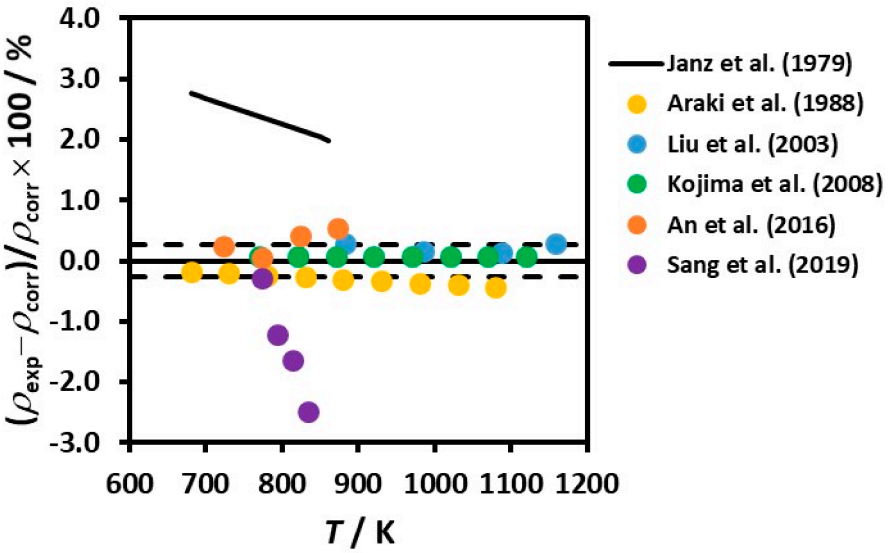


Figure 2. Deviation of different sets of data relative to the proposed correlation, Equation (1). Janz et al. (1979) [11]; Araki et al. (1988) [13]; Liu et al. (2003) [14]; Kojima et al. (2008) [15,16]; An et al. (2016) [12]; Sang et al. 2019 [17]. The dashed lines represent the estimated standard uncertainty of the correlation, 0.3%.

In Table 2, we propose recommended values for the density of molten ternary eutectic $(LiNaK)_2CO_3$, obtained from Equation (1), with an uncertainty of 0.5%.

Table 2. Recommended values for the density of molten ternary eutectic $(LiNaK)_2CO_3$, at P = 0.1 MPa.

T/K	ρ/kg·m^{-3}	T/K	ρ/kg·m^{-3}
680	2085.1	950	1965.1
710	2071.8	980	1951.8
740	2058.5	1010	1938.4
770	2045.1	1040	1925.1
800	2031.8	1070	1911.7
830	2018.5	1100	1898.4
860	2005.1	1130	1885.1
890	1991.8	1160	1871.7
920	1978.4		

It is interesting to note that the molar volume of the eutectic can be calculated to within 0.1 $\mathrm{cm^3{\cdot}mol^{-1}}$ from the pure-component molar volumes at the same temperature, using the molar additivity rule, at 1073 K [16]. This means that the excess volume on the formation of the eutectic is almost negligible. However, this is not a real physical situation, as pure salts

are solid at the temperatures of the eutectic, melting at temperatures above the eutectic (996 K for Li_2CO_3; 1124 K for Na_2CO_3, and 1164 K for K_2CO_3), and liquid metastable states of molten salts at temperatures 500 K below the melting point have not been reported until now. To verify if this result is valid at the full liquid temperature range of the eutectic, it was assumed that "virtual" liquid phases composed of pure liquid Li, Na, and K carbonates exist at a temperature well below their melting points, within the temperature range of the liquid eutectic LiNaK and with the same composition as the eutectic mixture.

From the available density data for pure liquid Li, Na, and K carbonates at high temperatures [16], we calculated the "virtual" molar volume of the pure components by extrapolating the pure salts' density data to the molten eutectic temperature. The molar volume of this "virtual" ideal eutectic mixture can be calculated using the additivity rule for the ideal solution (no differences in interionic interactions between the three cations and between these and the carbonate ions, at the same temperature and pressure of the mixture), as explained in Equations (2)–(4).

$$V_{m,\,LiNaK} = \frac{\overline{M}_{LiNaK}}{\rho_{LiNaK}}, \tag{2}$$

$$V_{m,\,Li_2CO_3} = \frac{M_{Li_2CO_3}}{\rho_{Li_2CO_3}},\ V_{m,\,Na_2CO_3} = \frac{M_{Li_2CO_3}}{\rho_{Li_2CO_3}},\ V_{m,\,K_2CO_3} = \frac{M_{Li_2CO_3}}{\rho_{Li_2CO_3}}, \tag{3}$$

$$V_m^{id} = x_{Li_2CO_3} \times V_{m,\,Li_2CO_3} + x_{Na_2CO_3} \times V_{m,\,Na_2CO_3} + x_{K_2CO_3} \times V_{m,\,K_2CO_3}\,, \tag{4}$$

where x_i (i = Li_2CO_3, Na_2CO_3, and K_2CO_3) is the mole fraction of each salt in the eutectic mixture, and $\overline{M}_{LiNaK}$ is the average molar molecular weight of the eutectic salt. The difference between the molar volume of the molten eutectic and that of a "virtual" ideal solution of the individual molten salts at the same temperature is the excess volume of the mixture, defined in Equation (5):

$$V_m^E = V_{m,\,LiNaK} - V_m^{id}, \tag{5}$$

Using the recommended values from Table 1 for the density of $(LiNaK)_2CO_3$ and the densities for the pure salts obtained from [16], it can be shown that the excess volume is negligible at all temperatures, smaller than 0.001 $cm^3 \cdot mol^{-1}$. Therefore, Equations (4) and (5) can also be used to calculate the density of LiNaK, with $V_m^E = 0$. This result also confirms the similarity of the interactions among alkali metal ions and between alkali metal ions and with carbonate ions. However, care must be taken not to make any conclusions from this result since, as mentioned above, the system is not an ideal solution in thermodynamic terms, where the components must be liquid at the same temperature as the mixture.

3.2. Heat Capacity

Available data on the heat capacity of the ternary eutectic is scarce, similar to density data. Table 3 summarizes the available data. Figure 3 shows the plotted data, including data for a different composition [17,18]. The scarcity of data, especially over extended temperature intervals, does not allow for the establishment of a heat capacity correlation, and further measurements are in progress in our laboratory. There are three sets of data within the temperature interval from 723 to 873 K, but unfortunately, with different temperature slopes. Four main reasons might explain the lack of data and the discrepancies between different laboratories. Firstly, possible variations in the molten salt structure (non-congruent melting, with floating solid aggregates lasting up to 50 K above the reported melting temperature) may lead to phase heterogeneities. Secondly, different temperature scanning rates are reported in the literature for DSC measurements, with heating or cooling

tests not performed carefully, leading to non-reproducible results. Thirdly, results were obtained mostly under a non-controlled atmosphere, and, at high temperatures, decomposition of the salt by releasing CO_2, especially for Li_2CO_3, is thermodynamically possible. Finally, the use of different crucibles, open, closed, or sealed, made from materials like platinum, alumina, and aluminium, might have introduced additional reactions with the carbonate samples.

An alternative for readers could be the use of estimation techniques based on chemical structure and properties of similar compounds. Heat capacities in the liquid state are very difficult to estimate at high temperatures [19,20]. Most available methods work for organic liquids and use group estimation or corresponding states methods, which require good heat capacity values for similar compounds. For molten inorganic salts, due to their corrosive nature, no reliable estimation method exists, namely for carbonates.

A constant value of C_p = 1.61 $J \cdot g^{-1} \cdot K^{-1}$ was suggested [12]. Figure 4 shows the deviations of other data from this reference value.

Table 3. Existing literature data on the heat capacity of molten ternary eutectic $(LiNaK)_2CO_3$, at P = 0.1 MPa.

Measuring Method [a]	Declared Relative Uncertainty [b]	Temperature Range (K)	Purity of Sample [c] (%)	Number of Data Points (Equation)	Reference
DC	0.01	680–1100	NA	Equation	Janz et al. (1979) [11]
DSC	NA	723–873	99.9	Equation	An et al. (2016) [12]
STA	NA	703–1023	NA	Equation	Liao et al. (2010) [21]
DSC	0.01	723–873	>99	Equation	Zhang et al. (2017) [22]
DSC	0.03	773–833	99.7	#4; #3	Sang et al. (2019a, 2019b) [17,18]

[a] DC—drop calorimetry; DSC—differential scanning calorimetry; STA—simultaneous thermal analysis. [b] Standard uncertainty. [c] As reported by the authors (typically manufacturer values). NA—not available.

The data reported in [21] is far higher than all the others, probably due to sample purity problems, which were not reported. Even for the other datasets, the percent deviation can only be accommodated within ± 20% of the chosen reference point. Improved heat capacity measurements are, therefore, vital to understanding LiNaK behaviour at these challenging temperatures.

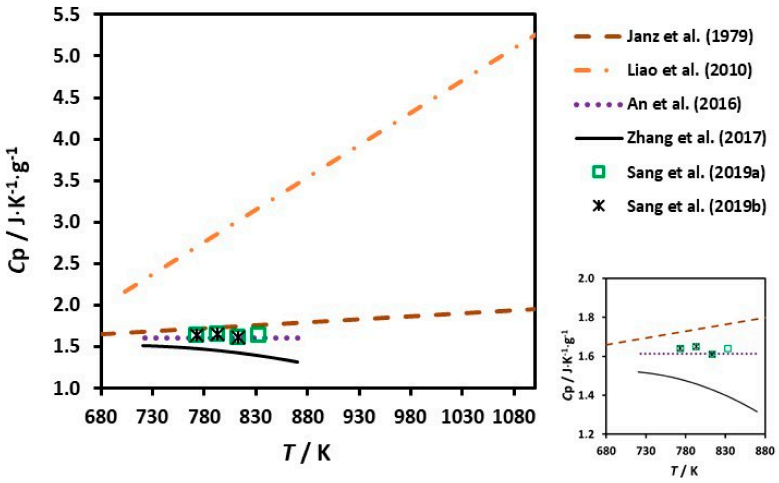


Figure 3. Heat capacity of the ternary eutectic $(LiNaK)_2CO_3$. Janz et al. (1979) [11]; An et al. (2016) [12]; Liao et al. (2010) [21]; Zhang et al. (2017) [22]; Sang et al. (2019a, 2019b) [17,18]. The lines are equations reported by the authors. The inset represents the data within a limited temperature range to enhance visibility.

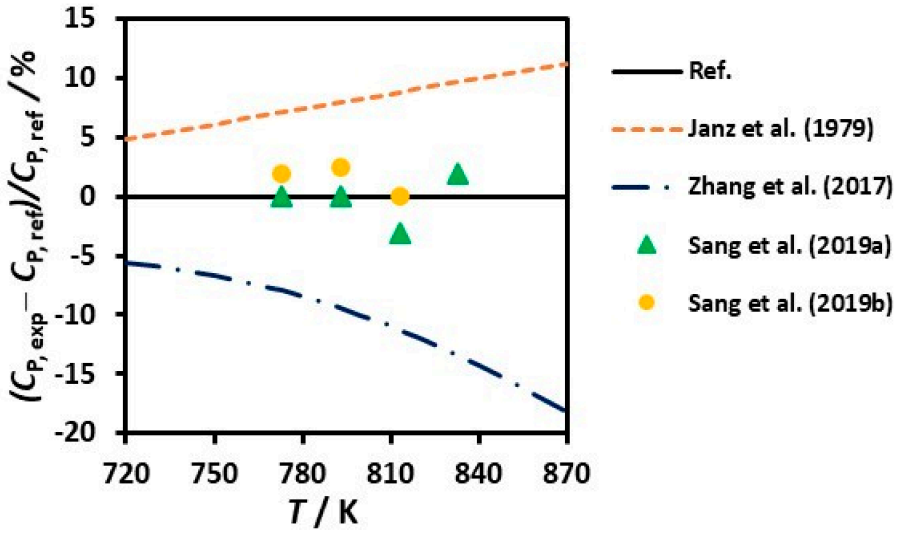


Figure 4. Deviation of different sets of data relative to the proposed reference value [12], Ref. Janz et al. (1979) [11]; Zhang et al. (2017) [22]; Sang et al. (2019a, 2019b) [17,18]. The lines are equations reported by the authors.

3.3. Thermal Conductivity

Contrary to other properties, Janz et al. (1979) [11] did not provide a reference correlation for the thermal conductivity of the $(LiNaK)_2CO_3$ system. Table 4 lists the available data.

Figure 5 shows the thermal conductivity as a function of temperature for the different data. As can be seen, the differences between datasets are very large, an obvious consequence of poorly designed experimental apparatus or not accounting for additional methods of heat transfer present in the measurements, namely, radiation. There are three sets of data with similar trends [13,17,23], all obtained with the laser flash technique. However, new data, preferably obtained with a direct method to measure the thermal conductivity, is necessary. This technique directly measures the thermal diffusivity, and if density, ρ, and specific heat capacity, C_p, are available, thermal conductivity, λ, can be obtained using Equation (6):

$$\lambda = \alpha \rho C_p, \quad (6)$$

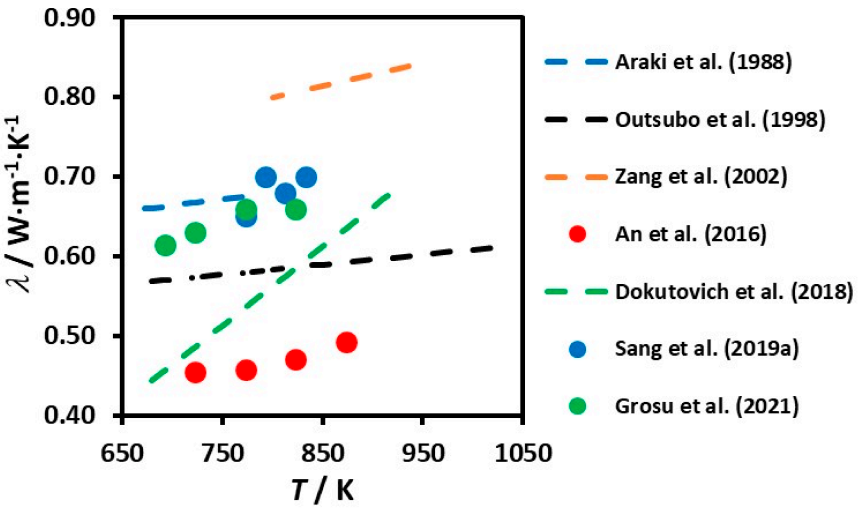


Figure 5. Thermal conductivity of the ternary eutectic $(LiNaK)_2CO_3$. Araki et al. (1988) [13]; Otsubo et al. (1998) [24]; Zhang et al. (2002) [25]; An et al. (2016) [12]; Dokutovich et al. (2018) [26]; Sang et al. (2019) [17]. The points from Grosu et al. (2021) [23] were estimated from the available plot. The lines are equations reported by the authors.

Table 4. Existing literature data for the thermal conductivity of molten ternary eutectic $(LiNaK)_2CO_3$, at P = 0.1 MPa.

Measuring Method [a]	Declared Relative Uncertainty [b]	Temperature Range (K)	Purity of Sample [c] (%)	Number of Data Points (Equation)	Reference
LF (Calc)	NA	673–764	NA	Equation	Araki et al. (1988) [13]
FRS (Calc)	NA	680–1030	NA	Equation	Otsubo et al. (1998) [24]
THW	0.03	803–943	NA	Plot	Zhang et al. (2002) [25]
LF (Calc)	NA	723–873	NA	#4	An et al. (2016) [12]
SSCC	0.03	670–930	pure	Equation	Dokutovich et al. (2018) [26]
LF (Calc)	0.03	773–833	>99	#4	Sang et al. (2019) [17]
LF (Calc)	0.05	693–823	NA	#4	Grosu et al. (2021) [23]

[a] LF(Calc)—laser flash, calculated from thermal diffusivity, heat capacity, and density; FRS (Calc)—forced Rayleigh scattering, calculated from thermal diffusivity, heat capacity, and density; THW—transient hot wire; SSCC—steady-state coaxial cylinders. [b] Standard uncertainty. [c] As reported by the authors (typically manufacturer values). NA—not available.

In our opinion, it is premature to suggest any reference correlation for this property at this time, as further measurements are necessary. Measurements based on the transient hot-strip method [27,28], using a specially designed platinum thin-film sensor, are underway in our laboratory, and we hope to present data soon.

3.4. Viscosity

Viscosity was first measured using an oscillating cylinder viscometer by Janz and Saegusa (1963) [29], and these measurements formed the basis for the first reference correlation proposed by Janz et al. (1979) [11]. However, these measurements were later revised using an improved instrument and were found to have serious shortcomings. Table 5 summarizes the available data for the viscosity of the ternary melt, and Figure 6 displays the variation in viscosity with temperature for all datasets.

Table 5. Existing literature data for the viscosity of molten ternary eutectic $(LiNaK)_2CO_3$, at P = 0.1 MPa.

Measuring Method [a]	Declared Relative Uncertainty [b]	Temperature Range/K	Purity of Sample [c]/%	Number of Data Points/Equation	Reference
OCY	0.25	760–870	NA	Equation	Janz et al. (1979) [11]
OCY	0.03	890–1175	98.4	#15	Ejima et al. (1987) [30,31]
RC	NA	700–970	NA	Diagram	Liao et al. (2010) [21]
RC	0.05	690–1120	99.8	#6	Kim et al. (2015) [32]
RC	NA	740–920	99.9	Equation	An et al. (2016) [12]
RC	NA	740–890	99.9	Equation	An et al. (2017) [33]
RPP	NA	673–773	99	Diagram	Grosu et al. (2021) [23]

[a] OCY—oscillating cylinder; RC—rotating cylinder; RPP—rheometer, parallel plate. [b] Standard uncertainty. [c] As reported by the authors (typically manufacturer values). NA—not available.

It is clear from Figure 6 that the datasets [11,22] deviate very much from the other data, namely in the lower temperatures of the melt. Recently, a reference correlation for the viscosity of the ternary melt for $740 < T/\mathrm{K} < 1140$ was proposed [7]. Three sets of data [30,31,33] were considered as primary data, although the data points used were taken from the correlation. The proposed reference, Equation (7), was:

$$\eta\ (\mathrm{mPa{\cdot}s}) = 0.1901 \exp\left(\frac{2660.0}{\mathrm{T(K)}} + \frac{726990}{\mathrm{T(K)}^2}\right), \quad (7)$$

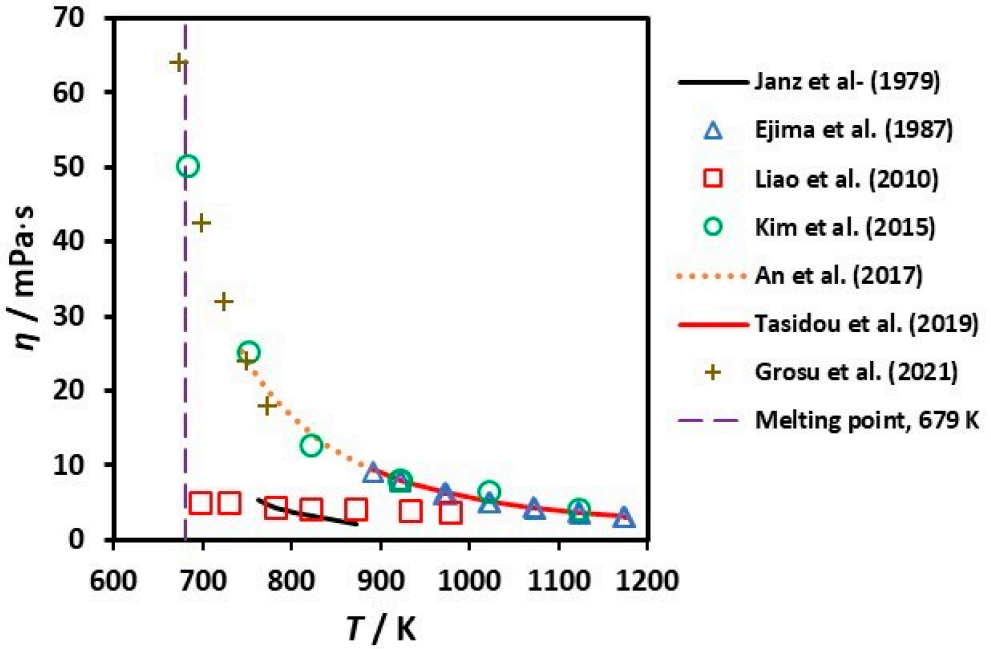


Figure 6. Viscosity of the ternary eutectic $(LiNaK)_2CO_3$. Janz et al. (1979) [11]; Ejima et al. (1987) [30,31]; Kim et al. (2015) [32]; An et al. (2017) [33]. The points from Liao et al. (2010) [21] and Grosu et al. (2021) [23] were estimated from the available plot. The lines are equations reported by the authors.

An uncertainty of 3% was reported. An earlier publication by the same authors of [33] also reported the viscosity of this melt [12], and a slightly different equation was presented, differing no more than 0.5% from the previous equation.

Figure 7 shows the percentage deviation of the other data from the previously proposed reference correlation [7] within the temperature interval considered. It includes the other existing experimental points. The deviations of the data used in the correlation never exceed 3%. However, the data from [11,21] deviate considerably from the proposed equation (−80 to −40%), likely due to flawed measurements. The data reported in [32] must have an uncertainty greater than that reported, even though they follow the temperature variation trend. The data from [23] also deviates significantly, showing a completely different slope with temperature (and consequently, an incorrect activation energy for flow). However, it should be noted that most of this data was obtained at temperatures below the correlation limit. New experimental data using an absolute viscometer are recommended and are currently underway in our laboratories, with an estimated expanded uncertainty of 1.2%, using an oscillating cup viscometer.

The equation presented in [30] has the form of the Arrhenius equation, which is normally obeyed by fluids with Newtonian behaviour (Equation (8)). It was obtained using a reagent and commercial-grade eutectic samples:

$$\eta\ (\text{mPa·s}) = 0.1038 \exp\frac{(33140)}{RT(\text{K})}, \tag{8}$$

The equation reported in [7] extends the applicability of Equation (4) to much lower temperatures, including the graphical data from [32]. Since the method used in [30,31] is an absolute method, and experimental data are available, it can be considered as the reference for the viscosity in the interval of temperatures from 890 to 1175 K. New data on the viscosity of molten ternary eutectic $(LiNaK)_2CO_3$ is necessary, namely for temperatures between the melting point and 920 K, obtained with an absolute method. These data are currently being obtained in our laboratory and will be published soon.

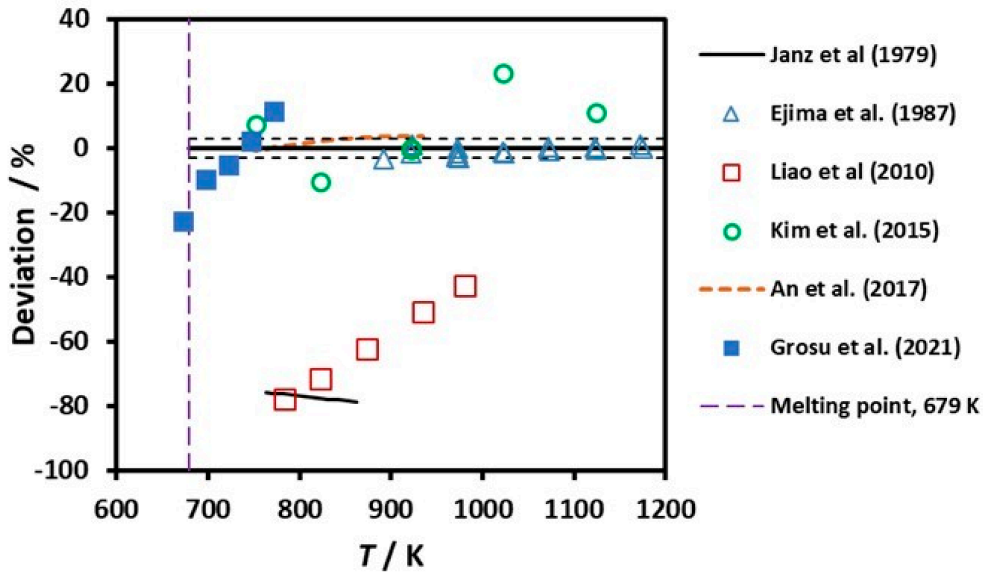


Figure 7. Deviation (in %) of different sets of data relative to the proposed reference data [7], for the temperature range 670 < T/K < 1200. Janz et al. (1979) [11]; Ejima et al. (1987) [30,31]; Kim et al. (2015) [32]; An et al. (2017) [33]. The points from Liao et al. (2010) [21] and Grosu et al. (2021) [23] were estimated from the available plot. The lines are equations reported by the authors. Dashed lines represent the reported standard uncertainty of this correlation.

4. Conclusions and Recommendations

This report critically assesses the available thermophysical property data for the ternary molten carbonate eutectic $(LiNaK)_2CO_3$, a material of growing relevance for high-temperature heat transfer and thermal energy storage in CSP, MSO, and advanced nuclear reactor applications. Despite its technological importance, data quality and consistency have not improved substantially since our previous review [5], although some new datasets have become available.

- Density remains the only property with a reliable reference correlation, as equilibrium measurements are sufficiently consistent, making Equation (1) suitable for estimating its temperature dependence. A constant value of C_p = 1.61 J·g^{-1}·K^{-1} is suggested for the specific heat capacity, in line with classical recommendations [11]. Thermal conductivity data remain contradictory, as most measurements are derived from thermal diffusivity experiments that yield contradictory temperature trends (dλ/dT either positive or negative), as observed previously for conductive liquids [5]. The 2019 viscosity correlation [7] is valid only within 890–1175 K (617–902 °C), based on oscillating-cylinder measurements [27,28]. Older recommendations are inconsistent with these reliable data.
- There is a clear need for new high-quality measurements of heat capacity, thermal conductivity, and viscosity up to at least 1100 K (827 °C) to enable robust reference correlations for accurate CSP, MSO, and ANR process design. However, economic constraints may limit CSP operation above 923 K (650 °C) [34]. Although higher temperatures improve the thermal efficiency of Rankine cycles, this gain is offset by the substantially higher cost of the required high-temperature materials, such as nickel-based superalloys (Inconel 625 or Haynes 230) used in receivers, piping, and storage tanks. Nevertheless, $(LiNaK)_2CO_3$ remains a strong candidate for advanced nuclear reactor TES systems due to its favourable thermal performance and low heat-loss probability [35].

Although it is not the purpose of this paper to discuss the best methods for measuring properties such as heat capacity, thermal conductivity, and viscosity at high temperatures, or for eutectic sample preparation, we would like to recommend some steps for high-quality measurements of thermophysical properties at high temperatures. These may serve as a guide for future works aimed at filling the existing data gaps in this and related systems:

(a) Prepare the salt samples from pure chemicals using one of the two methods, the dry or wet process. The latter is recommended because the dissolution of the different eutectic components in water guarantees a well-homogenized solid phase before melting.

(b) For heat capacity measurements, use differential scanning calorimetry (DSC) with correct calibration in temperature and enthalpy using reference materials like sapphire and molten metals (In, Pb, Sn, Zn, and Al) to enable a reliable uncertainty budget calculation. Scanning rates between 2 and 5 °C/min are recommended. A study of heating and cooling profiles must be performed to ensure that the melting point is well-defined (not a melting interval), and certified software for heat capacity determination should be used, including baseline stability assessment. Today, this is common on most commercial equipment, but a tendency to use "black boxes" should be avoided. Finally, the choice of crucible (open, covered, or sealed) and its material is critical, as chemical reactions with the atmosphere (air or inert gas) can occur. As an example, the decomposition of Li salts is possible above 500 °C. Thoughtful analyses of these problems can be found in references [36–38] for DSC and drop calorimetry.

(c) For thermal conductivity, a full discussion about the best direct methods for measurement at high temperatures can be found in references [27,39,40], namely in Table 1 of [27]. Reference must also be made to a method for the determination of thermal diffusivity, $\alpha = \frac{\lambda}{\rho C_p}$, namely the laser flash technique [40–43], from which thermal conductivity can be obtained, if accurate values of density (usually available) and heat capacity (more difficult to obtain, as explained above) are available. The transient hot-wire, transient hot-strip, and laser flash methods seem to be the most appropriate for high-accuracy thermal conductivity measurements at high temperatures. These methods are supported by complete working equations, including analytical or CFD solutions, deviations from idealized model, and well-defined uncertainty budgets. Care must be taken to avoid parallel modes of heat transfer in the samples, namely convection (which should be eliminated) or radiation (which should be corrected for).

(d) Regarding viscosity, a complete discussion on the best methods for its measurement can be found in references [39,44–46], including the assessment of uncertainty. For high temperature measurements, it is recommended to use either the oscillating body viscometers (cup or cylinder) or the vibrating wire [45,46]. Special attention should be given to the compatibility of the materials of the oscillating bodies/vibrating wires with the samples to be measured to avoid corrosion of metals at high temperatures (stainless steel, molybdenum, or tungsten). Ceramic bodies can also be used. Detection of the oscillating/vibrating frequency and temperature measurements are very important for the measurement's uncertainty.

Overall, this report highlights the critical importance of reliable thermophysical data for the carbonate eutectic $(LiNaK)_2CO_3$. It guides designers toward safer and more efficient operation of CSP and TES systems, encourages researchers to prioritize accurate data, and supports the establishment of standardized measurement protocols and safe material characterization, as well as improved measurement methods, optimized designs, and energy-saving solutions in renewable energy applications.

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Abbreviations

The following abbreviations are used in this manuscript:

CSP	Concentrated solar power
MSO	Molten salt oxidation
ANR	Advanced nuclear reactor
A	Archimedean
DBA	Double-bob Archimedean
MBP	Maximum bubble pressure
DC	Drop calorimetry
DSC	Differential scanning calorimetry
STA	Simultaneous thermal analysis
LF (Calc)	Laser flash, calculated from thermal diffusivity, heat capacity, and density
FRS (Calc)	Forced Rayleigh scattering, calculated from thermal diffusivity, heat capacity, and density
THW	Transient hot wire
SSCC	Steady-state coaxial cylinders
OCY	Oscillating cylinder
RC	Rotating cylinder
RPP	Rheometer, parallel plate
NA	Not available

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