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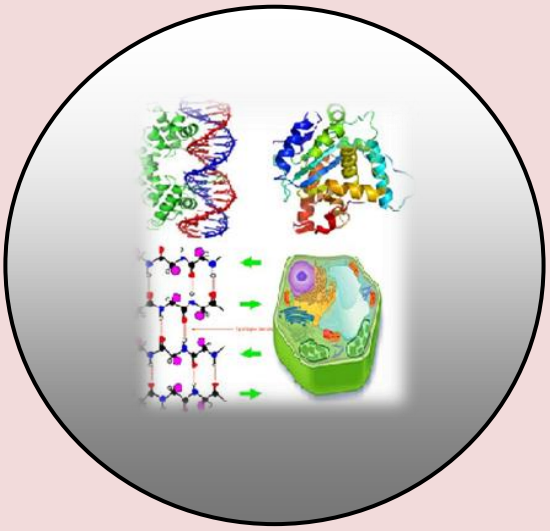

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# Computation of Thermodynamic and Thermoacoustical Properties of Liquid Metal-Alloys Using Density and Ultrasonic Speed Data

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## ABSTRACT
***Density and ultrasonic speed data have been employed to compute a number of important and useful thermophysical, thermodynamic and thermoacoustical properties of K-Rb, Na-Cs and Sn-Pb liquid metal alloys over a wide range of temperatures 343.15K-518K, 373.15K - 520.15K and 673K -973K respectively. Density-ultrasonic speed-thermodynamic properties correlations have been used to deduce the aforesaid properties over a wide range of compositions of two alloys. The deduced properties are thermal expansion coefficient (α), isothermal compressibility ($\beta_T$), specific heat ratio (γ), internal pressure ($P_{int}$), pseudo-Grüneisen parameter (Γ), non-linearity parameter (B/A) and surface tension (σ). The agreement between the calculated and experimentally known properties is found to be quite satisfactory.***
***Keywords: Empirical relations, Sonic speed, Density, Thermodynamic properties, Thermoacoustical properties and Liquid metal Alloys.***

## INTRODUCTION
Liquid metal alloys have some unique characteristics such as low vapor pressure, high boiling points high thermal expansivities and good thermal and reaction stability. Due to this reason liquid metal alloys have industrial importance particularly in the nuclear- power application. After an exhaustive literature survey we find that quite limited experimental and theoretical work has been done. Particularly experimental data on density, surface tension, viscosity, ultrasonic speed, thermal expansivity etc are very rare. Since, in the present work, we are using density and ultrasonic speed as a tool for the estimation of important and useful thermodynamic and thermoacoustical properties of liquid metal-alloys. In the year 1972 Konyudhenb (Konyudnenb, 1972) reported the experimental values of density and sound speed of Sn-Pb alloys at different temperatures. His data were employed by Pandey et al (Pandey, *et al.,* 1984; Pandey, *et al.,* 2004) and others (Pandey, *et al.,* 2005) to compute several thermoacoustic and thermodynamic properties of the alloy.

After this Kim and Letcher (Kim *et al.,* 1971) measured ultrasonic absorption, density and ultrasonic speed in K-Rb, Na-Cs and Sn-Pb alloys.

The objective of the present work is to apply density-ultrasonic speed-thermodynamic properties and density-ultrasonic speed- tension correlations to compute several thermodynamic and thermoacoustic properties of K-Rb, Na-Cs and Sn-Pb alloys using density and ultrasonic speed data of Kim and Letcher. Density-ultrasonic speed-thermodynamic properties (Pandey, *et al.,* 2013, Pandey, *et al.,* 1997; Pandey, *et al.,* 2006; Pandey, *et al.,* 2000) density-ultrasonic speed-surface tension (Pandey, *et al.,* 2013, Pandey, *et al.,* 2016) correlations have been obtained on the basis of dimensional analysis. These correlations have been applied and tested by several useful (Pandey, *et al.,* 1997, Sanguri, *et al.,* 2015, Pandey, *et al.,* 2008, Pandey, *et al.,* 2001, Marcus, 2013, Sanguri, *et al.,* 2018) during recent past for pure liquids, binary and higher order liquids. As far as our knowledge is concerned these correlations have never been applied to liquid metal alloys. In addition to this we have also calculated some important and useful thermoacoustic properties of these alloys.

**FORMULATION**

According to empirical correlations the expressions for thermodynamic properties in terms of ρ and u are given as;

Thermal expansion coefficient

$$\alpha = \frac{1}{V}\left(\frac{\partial V}{\partial T}\right)_P = \frac{75.6\times10^{-3}}{T^{1/9}u^{1/2}\rho^{1/3}} \quad \ldots (1)$$

Isothermal compressibility

$$\beta_T = -\frac{1}{V}\left(\frac{\partial V}{\partial P}\right)_T = \frac{1.71\times10^{-3}}{T^{4/9}\rho^{4/3}u^2} \quad \ldots (2)$$

Internal pressure

$$P_{\text{int}} = \alpha.T \Big/ \beta_T = 44.2\times10^{4/3}u^{3/2}\rho.T^{4/3} \quad \ldots (3)$$

The ρ-u-σ correlation yields

Specific heat ratio

$$\gamma = C_P \Big/ C_V = \beta_T \Big/ \beta_S = \frac{17.1}{T^{4/9}\rho^{1/3}} \quad \ldots (4)$$

pseudo-Grüneisen parameter

$$\Gamma = \frac{\gamma - 1}{\alpha.T} \quad \ldots (5)$$

Surface tension

$$\sigma = u^{3/2}\rho.T^{4/3}\times10^{-4} \quad \ldots (6)$$

Thermoacoustic parameters are;

Non-linearity parameter (B/A)

Hartmann (Hartmann, *et al.,* 1987)

$$\frac{B}{A} = 2 + \left[ \frac{0.98 \times 10^4}{u} \right] \quad \ldots (7)$$

Ballou (Hartmann, 1979)

$$\frac{B}{A} = -0.5 + \left[ \frac{1.2 \times 10^4}{u} \right] \quad \ldots (8)$$

Internal pressure

$$P_{\text{int}} = \frac{\rho u^2}{1 + B/A} \quad \ldots (9)$$

Density of alloys

$$\rho^{-1} = \left[ W / \rho^{(K)} \right] + \left[ (1-W) / \rho^{(Rb)} \right] \quad \ldots (10)$$

or

$$\rho^{-1} = \left[ W / \rho^{(Na)} \right] + \left[ (1-W) / \rho^{(Cs)} \right]$$

or

$$\rho^{-1} = \left[ W / \rho^{(Sn)} \right] + \left[ (1-W) / \rho^{(Pb)} \right]$$

## RESULTS AND DISCUSSION

Density (ρ) and sonic speed (u) data for K-Rb, Na-Cs (Kim *et al.,* 1971) and Sn-Pb (Konyudnenb, 1972) alloys are employed to compute the values of thermal expansion coefficient (α), isothermal compressibility ($\beta_T$), internal pressure ($P_{int}$), specific heat ratio (ϒ) and pseudo-Grüneisen parameter (Γ) using ρ-u-thermodynamic correlations with eqs (1) to (5). The surface tension (σ) is obtained from eq. (6). Further, the thermoacoustic parameter B/A and $P_{int}$ are obtained from eqs (7) to (9). The experimental densities of alloys were deduced from eq. (10).

**Table 1. Calculated values of thermal expansion coefficient (α), isothermal compressibility ($\beta_T$), internal pressure ($P_{int}$), specific heat ratio (ϒ) and pseudo-Grüneisen parameter (Γ) for K-Rb alloy at different compositions and varying temperatures by equations (1) to (5).**

| % of K in Rb | α x $10^{-4}$ | $\beta_T$ x $10^{-5}$ | $P_{int}$ x $10^3$ | ϒ | Γ |
|---|---|---|---|---|---|
| | $K^{-1}$ | $atm^{-1}$ | atm | | |
| T = 343.15 K | | | | | |
| 0 | 9.88 | 5.06 | 144.30 | 1.12 | 0.37 |
| 10.08 | 9.97 | 5.25 | 140.46 | 1.15 | 0.45 |
| 19.04 | 10.06 | 5.43 | 136.98 | 1.18 | 0.51 |
| 32.29 | 10.12 | 5.56 | 134.54 | 1.21 | 0.61 |
| 40.11 | 10.14 | 5.61 | 133.53 | 1.23 | 0.66 |
| 52.78 | 10.14 | 5.60 | 133.82 | 1.26 | 0.75 |
| 67.71 | 10.07 | 5.45 | 136.61 | 1.29 | 0.85 |
| 74.02 | 10.12 | 5.56 | 134.48 | 1.31 | 0.88 |
| 89.72 | 10.09 | 5.50 | 135.56 | 1.34 | 0.98 |
| 100 | 9.73 | 4.76 | 151.14 | 1.36 | 1.08 |
| T = 357.15 K | | | | | |
| 0 | 9.87 | 5.04 | 150.63 | 1.11 | 0.30 |

| | | | | | |
|---|---|---|---|---|---|
| 10.08 | 9.96 | 5.22 | 146.74 | 1.13 | 0.38 |
| 19.04 | 10.05 | 5.40 | 143.07 | 1.16 | 0.44 |
| 32.29 | 10.11 | 5.53 | 140.49 | 1.19 | 0.53 |
| 40.11 | 10.13 | 5.59 | 139.47 | 1.21 | 0.58 |
| 52.78 | 10.12 | 5.57 | 139.81 | 1.24 | 0.66 |
| 67.71 | 10.06 | 5.42 | 142.66 | 1.27 | 0.76 |
| 74.02 | 10.11 | 5.54 | 140.46 | 1.29 | 0.79 |
| 89.72 | 10.08 | 5.47 | 141.74 | 1.32 | 0.88 |
| 100 | 9.72 | 4.74 | 157.87 | 1.34 | 0.97 |
| T = 386.15 K | | | | | |
| 0 | 9.86 | 5.01 | 163.57 | 1.07 | 0.19 |
| 10.08 | 9.94 | 5.18 | 159.61 | 1.10 | 0.26 |
| 19.04 | 10.03 | 5.36 | 155.53 | 1.12 | 0.31 |
| 32.29 | 10.09 | 5.50 | 152.64 | 1.15 | 0.39 |
| 40.11 | 10.11 | 5.55 | 151.64 | 1.17 | 0.44 |
| 52.78 | 10.10 | 5.53 | 152.08 | 1.20 | 0.51 |
| 67.71 | 10.04 | 5.39 | 155.03 | 1.23 | 0.60 |
| 74.02 | 10.09 | 5.50 | 152.70 | 1.25 | 0.63 |
| 89.72 | 10.05 | 5.41 | 154.45 | 1.28 | 0.71 |
| 100 | 9.70 | 4.70 | 171.65 | 1.30 | 0.79 |
| T = 393.15 K | | | | | |
| 0 | 9.86 | 5.01 | 166.66 | 1.06 | 0.16 |
| 10.08 | 9.94 | 5.17 | 162.68 | 1.09 | 0.23 |
| 19.04 | 10.02 | 5.36 | 158.51 | 1.11 | 0.29 |
| 32.29 | 10.09 | 5.49 | 155.54 | 1.15 | 0.37 |
| 40.11 | 10.11 | 5.54 | 154.55 | 1.16 | 0.41 |
| 52.78 | 10.10 | 5.52 | 155.02 | 1.19 | 0.48 |
| 67.71 | 10.03 | 5.38 | 157.99 | 1.22 | 0.57 |
| 74.02 | 10.09 | 5.49 | 155.63 | 1.24 | 0.60 |
| 89.72 | 10.05 | 5.40 | 157.50 | 1.27 | 0.68 |
| 100 | 9.70 | 4.69 | 174.95 | 1.29 | 0.75 |
| T = 436.15 K | | | | | |
| 0 | 9.85 | 5.00 | 185.25 | 1.02 | 0.05 |
| 10.08 | 9.92 | 5.14 | 181.28 | 1.05 | 0.10 |
| 19.04 | 10.01 | 5.33 | 176.49 | 1.07 | 0.15 |
| 32.29 | 10.08 | 5.47 | 173.03 | 1.10 | 0.22 |
| 40.11 | 10.10 | 5.51 | 172.12 | 1.12 | 0.26 |
| 52.78 | 10.08 | 5.48 | 172.76 | 1.14 | 0.32 |
| 67.71 | 10.02 | 5.36 | 175.80 | 1.17 | 0.40 |
| 74.02 | 10.07 | 5.46 | 173.29 | 1.19 | 0.42 |
| 89.72 | 10.02 | 5.35 | 175.99 | 1.21 | 0.49 |
| 100 | 9.69 | 4.67 | 194.84 | 1.23 | 0.55 |
| T = 452.15 K | | | | | |
| 0 | 9.85 | 5.00 | 191.99 | 1.00 | 0.01 |
| 10.08 | 9.92 | 5.14 | 188.06 | 1.03 | 0.07 |
| 19.04 | 10.01 | 5.33 | 183.03 | 1.05 | 0.11 |
| 32.29 | 10.08 | 5.47 | 179.39 | 1.08 | 0.18 |
| 40.11 | 10.09 | 5.51 | 178.51 | 1.10 | 0.22 |
| 52.78 | 10.08 | 5.48 | 179.22 | 1.13 | 0.28 |
| 67.71 | 10.02 | 5.36 | 182.28 | 1.16 | 0.34 |
| 74.02 | 10.07 | 5.46 | 179.72 | 1.17 | 0.37 |
| 89.72 | 10.02 | 5.34 | 182.76 | 1.20 | 0.44 |
| 100 | 9.69 | 4.67 | 202.08 | 1.22 | 0.49 |

| T = 464.15 K | | | | | |
|---|---|---|---|---|---|
| 0 | 9.85 | 5.00 | 196.98 | 0.99 | -0.01 |
| 10.08 | 9.92 | 5.14 | 193.09 | 1.02 | 0.04 |
| 19.04 | 10.01 | 5.33 | 187.87 | 1.04 | 0.09 |
| 32.29 | 10.08 | 5.47 | 184.09 | 1.07 | 0.15 |
| 40.11 | 10.09 | 5.51 | 183.25 | 1.09 | 0.19 |
| 52.78 | 10.08 | 5.48 | 184.01 | 1.11 | 0.24 |
| 67.71 | 10.02 | 5.36 | 187.08 | 1.14 | 0.31 |
| 74.02 | 10.07 | 5.46 | 184.48 | 1.16 | 0.33 |
| 89.72 | 10.01 | 5.33 | 187.79 | 1.18 | 0.40 |
| 100 | 9.69 | 4.67 | 207.45 | 1.20 | 0.45 |
| T = 481.15 K | | | | | |
| 0 | 9.86 | 5.01 | 203.95 | 0.98 | -0.04 |
| 10.08 | 9.92 | 5.14 | 200.12 | 1.00 | 0.01 |
| 19.04 | 10.01 | 5.33 | 194.65 | 1.03 | 0.05 |
| 32.29 | 10.08 | 5.48 | 190.67 | 1.06 | 0.11 |
| 40.11 | 10.10 | 5.51 | 189.88 | 1.07 | 0.15 |
| 52.78 | 10.08 | 5.48 | 190.73 | 1.10 | 0.20 |
| 67.71 | 10.03 | 5.36 | 193.78 | 1.13 | 0.26 |
| 74.02 | 10.07 | 5.46 | 191.14 | 1.14 | 0.29 |
| 89.72 | 10.01 | 5.32 | 194.85 | 1.17 | 0.35 |
| 100 | 9.69 | 4.67 | 214.96 | 1.19 | 0.40 |
| T = 502.15 K | | | | | |
| 0 | 9.87 | 5.02 | 212.38 | 0.96 | -0.07 |
| 10.08 | 9.92 | 5.14 | 208.66 | 0.99 | -0.02 |
| 19.04 | 10.02 | 5.34 | 202.88 | 1.01 | 0.02 |
| 32.29 | 10.09 | 5.49 | 198.64 | 1.04 | 0.07 |
| 40.11 | 10.10 | 5.52 | 197.93 | 1.05 | 0.11 |
| 52.78 | 10.08 | 5.48 | 198.88 | 1.08 | 0.16 |
| 67.71 | 10.03 | 5.37 | 201.91 | 1.11 | 0.22 |
| 74.02 | 10.08 | 5.47 | 199.23 | 1.12 | 0.24 |
| 89.72 | 10.01 | 5.32 | 203.45 | 1.15 | 0.30 |
| 100 | 9.69 | 4.68 | 224.08 | 1.17 | 0.34 |
| T = 518.15 K | | | | | |
| 0 | 9.87 | 5.04 | 218.67 | 0.95 | -0.09 |
| 10.08 | 9.93 | 5.15 | 215.06 | 0.98 | -0.05 |
| 19.04 | 10.02 | 5.35 | 209.03 | 1.00 | -0.01 |
| 32.29 | 10.09 | 5.51 | 204.59 | 1.03 | 0.05 |
| 40.11 | 10.10 | 5.53 | 203.95 | 1.04 | 0.08 |
| 52.78 | 10.09 | 5.49 | 204.98 | 1.07 | 0.13 |
| 67.71 | 10.04 | 5.39 | 207.99 | 1.09 | 0.18 |
| 74.02 | 10.08 | 5.48 | 205.28 | 1.11 | 0.20 |
| 89.72 | 10.01 | 5.32 | 209.91 | 1.13 | 0.26 |
| 100 | 9.69 | 4.69 | 230.9 | 1.15 | 0.30 |

In table 1 the values of thermal expansion coefficient (α) and isothermal compressibility ($\beta_T$) decrease with temperature till 436.15 K then becomes constant till 481.15 K and starts to increase constantly showing that in the alloy of K-Rb the density and ultrasonic speed increase with temperature which invariably decrease the expansion and isothermal compressibility of the alloy owing to stronger metallic bonding prevalent between the two metals as they belong to the same group in s-block of the periodic table with only increase in atomic number.

The internal pressure and the surface tension data show a constant increase with temperature supporting the fact that stronger metallic bond leads to stronger forces between the two liquid metals which will now have a prolonged effect when it is beaten into sheets (malleability) and when drawn into wires (ductility) as an alloy. The specific heat ratio (ϒ) and pseudo-Grüneisen parameter (Γ) values decreases constantly with temperature as it is inversely proportional to the density which is increasing constantly. The pseudo-Grüneisen parameter (Γ) values also become negative at higher temperature indicating that the liquid metals has now started behaving like a solid.

As the mole fraction (in %) of potassium increases in the alloy slowly and steadily till 40.11% of potassium the thermal expansion coefficient (α) and isothermal compressibility ($\beta_T$) increase but when the percentage of potassium is maximum (100%) an abrupt fall is seen in the value which is always less when the percent of K is 0% thereby indicating that on increasing the % of potassium the possibility of thermal expansion increases thus increasing the softness of the liquid metal alloy on exposure to heat.

Internal pressure ($P_{int}$) is the fundamental property of liquid which provides an excellent basis for examining the solution phenomenon and studying the various properties of the liquid state. It is a measure of change in internal energy of liquid solution and it undergoes a very small isothermal change. It is a measure of cohesive or binding forces between the solute and solvent interaction. The trend of internal pressure and surface tension is just the reverse till 40.11% that is decrease and later increase. Since $P_{int}$ is decreasing with temperature indicates less binding forces between molecules of liquid metals thus less interaction.

The values of specific heat ratio (ϒ) and pseudo-Grüneisen parameter (Γ) increase constantly with increasing mole ratio of potassium in the alloy indicates that the two liquid metals now are behaving as one and solidifying to have entirely new set of properties.

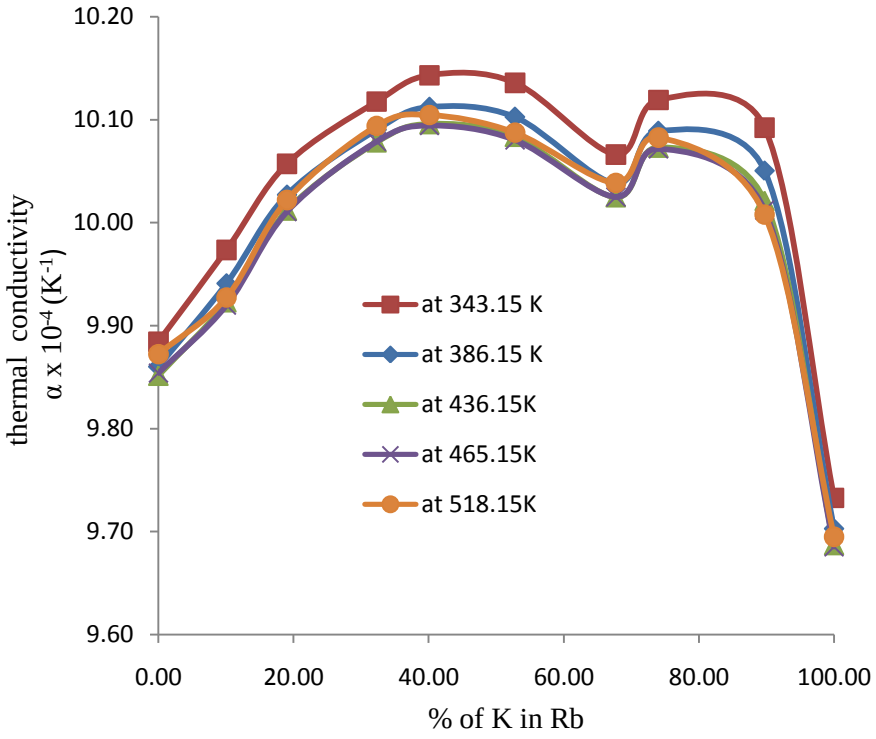


**Figure 1. Variation of thermal expansivity (α) with temperature ( in K) and percentage of potassium in the K-Rb alloy.**

Figure 1 supports the fact that as the % of potassium is increased the values of thermal expansivity is increasing showing a sharp dip at one point, but with temperature rise its value is decreasing showing a marked fall between 60 to 80% ratio which is a transition stage of the two metals. Here each curve is indicating its specific temperatures. The initial start of the graph is at higher value of thermal expansivity when % of potassium is zero but during the end the value is very low below the start point showing that when potassium is 100% thermal expansivity is less.

Table 2 shows calculated values of thermal expansion coefficient (α), isothermal compressibility ($\beta_T$), internal pressure ($P_{int}$), surface tension (σ), specific heat ratio (γ) and pseudo-Grüneisen parameter (Γ) of Na-Cs using empirical relations (1) to (5) at different temperatures.

**Table 2. Calculated values of thermal expansivity (α), isothermal compressibility ($\beta_T$), internal pressure ($P_{int}$), specific heat ratio (ϒ) and pseudo-Grüneisen parameter (Γ) of Na-Cs alloy at different compositions and varying temperatures by equations (1) to (5).**

| % of Na in Cs | $\alpha \times 10^{-4}$ | $\beta_T \times 10^{-5}$ | $P_{int} \times 10^{3}$ | ϒ | Γ |
|---|---|---|---|---|---|
| | $K^{-1}$ | $atm^{-1}$ | atm | | |
| T = 373.15 K | | | | | |
| 0 | 10.38 | 6.16 | 135.48 | 1.01 | 0.03 |
| 4.73 | 10.48 | 6.39 | 131.71 | 1.03 | 0.07 |
| 22.25 | 10.69 | 6.94 | 123.87 | 1.08 | 0.19 |
| 29 | 10.70 | 6.96 | 123.62 | 1.10 | 0.24 |
| 35.98 | 10.77 | 7.13 | 121.40 | 1.11 | 0.28 |
| 53.61 | 10.63 | 6.78 | 126.10 | 1.16 | 0.40 |
| 62.9 | 10.77 | 7.15 | 121.18 | 1.18 | 0.45 |
| 68.76 | 10.36 | 6.10 | 136.37 | 1.19 | 0.50 |
| 75.13 | 10.06 | 5.42 | 149.02 | 1.21 | 0.56 |
| 79.96 | 9.57 | 4.45 | 172.94 | 1.22 | 0.61 |
| 89.84 | 9.02 | 3.51 | 206.61 | 1.24 | 0.72 |
| 100 | 8.00 | 2.17 | 295.89 | 1.26 | 0.88 |
| T = 395.15 K | | | | | |
| 0 | 10.37 | 6.14 | 143.74 | 0.99 | -0.03 |
| 4.73 | 10.47 | 6.38 | 139.67 | 1.00 | 0.00 |
| 22.25 | 10.68 | 6.90 | 131.78 | 1.05 | 0.12 |
| 29 | 10.68 | 6.91 | 131.58 | 1.07 | 0.17 |
| 35.98 | 10.75 | 7.07 | 129.31 | 1.09 | 0.21 |
| 53.61 | 10.60 | 6.70 | 134.74 | 1.13 | 0.31 |
| 62.9 | 10.74 | 7.06 | 129.42 | 1.15 | 0.36 |
| 68.76 | 10.27 | 5.90 | 148.10 | 1.17 | 0.41 |
| 75.13 | 9.99 | 5.28 | 160.96 | 1.18 | 0.46 |
| 79.96 | 9.59 | 4.49 | 181.75 | 1.19 | 0.50 |
| 89.84 | 8.90 | 3.33 | 227.64 | 1.21 | 0.60 |
| 100 | 7.98 | 2.15 | 315.42 | 1.23 | 0.74 |
| T = 423.15 K | | | | | |
| 0 | 10.37 | 6.14 | 154.04 | 0.96 | -0.09 |
| 4.73 | 10.47 | 6.38 | 149.59 | 0.97 | -0.06 |
| 22.25 | 10.66 | 6.86 | 141.73 | 1.02 | 0.05 |
| 29 | 10.67 | 6.87 | 141.61 | 1.04 | 0.09 |
| 35.98 | 10.73 | 7.02 | 139.27 | 1.06 | 0.13 |
| 53.61 | 10.56 | 6.61 | 145.73 | 1.10 | 0.22 |
| 62.9 | 10.71 | 6.98 | 139.88 | 1.12 | 0.27 |
| 68.76 | 10.23 | 5.81 | 160.45 | 1.13 | 0.31 |
| 75.13 | 9.95 | 5.19 | 174.54 | 1.15 | 0.35 |
| 79.96 | 9.57 | 4.44 | 196.20 | 1.16 | 0.39 |
| 89.84 | 8.97 | 3.43 | 238.24 | 1.18 | 0.47 |
| 100 | 7.96 | 2.13 | 340.09 | 1.20 | 0.59 |

| T = 442.65 K | | | | | |
|---|---|---|---|---|---|
| 0 | 10.37 | 6.14 | 161.06 | 0.94 | -0.12 |
| 4.73 | 10.48 | 6.39 | 156.34 | 0.96 | -0.09 |
| 22.25 | 10.66 | 6.84 | 148.56 | 1.00 | 0.01 |
| 29 | 10.66 | 6.84 | 148.50 | 1.02 | 0.05 |
| 35.98 | 10.71 | 6.99 | 146.13 | 1.04 | 0.08 |
| 53.61 | 10.54 | 6.56 | 153.35 | 1.08 | 0.17 |
| 62.9 | 10.69 | 6.93 | 147.12 | 1.10 | 0.21 |
| 68.76 | 10.21 | 5.76 | 169.05 | 1.11 | 0.25 |
| 75.13 | 9.92 | 5.14 | 184.02 | 1.13 | 0.29 |
| 79.96 | 9.55 | 4.42 | 206.20 | 1.14 | 0.32 |
| 89.84 | 8.95 | 3.41 | 250.48 | 1.16 | 0.40 |
| 100 | 7.95 | 2.12 | 357.11 | 1.18 | 0.50 |
| T = 473.15 K | | | | | |
| 0 | 10.38 | 6.16 | 171.77 | 0.92 | -0.17 |
| 4.73 | 10.49 | 6.41 | 166.62 | 0.93 | -0.14 |
| 22.25 | 10.65 | 6.82 | 159.07 | 0.98 | -0.04 |
| 29 | 10.65 | 6.82 | 159.12 | 1.00 | -0.01 |
| 35.98 | 10.70 | 6.96 | 156.72 | 1.01 | 0.02 |
| 53.61 | 10.52 | 6.49 | 165.21 | 1.05 | 0.10 |
| 62.9 | 10.66 | 6.86 | 158.39 | 1.07 | 0.14 |
| 68.76 | 10.17 | 5.68 | 182.49 | 1.08 | 0.17 |
| 75.13 | 9.89 | 5.07 | 198.84 | 1.10 | 0.21 |
| 79.96 | 9.53 | 4.38 | 221.70 | 1.11 | 0.24 |
| 89.84 | 8.93 | 3.38 | 269.49 | 1.13 | 0.30 |
| 100 | 7.94 | 2.11 | 383.43 | 1.14 | 0.39 |
| T = 480.65 K | | | | | |
| 0 | 10.38 | 6.17 | 174.35 | 0.91 | -0.17 |
| 4.73 | 10.49 | 6.42 | 169.09 | 0.93 | -0.15 |
| 22.25 | 10.65 | 6.82 | 161.62 | 0.97 | -0.05 |
| 29 | 10.65 | 6.82 | 161.69 | 0.99 | -0.02 |
| 35.98 | 10.70 | 6.95 | 159.29 | 1.01 | 0.01 |
| 53.61 | 10.51 | 6.47 | 168.12 | 1.05 | 0.09 |
| 62.9 | 10.66 | 6.85 | 161.15 | 1.07 | 0.13 |
| 68.76 | 10.17 | 5.66 | 185.78 | 1.08 | 0.16 |
| 75.13 | 9.91 | 5.11 | 200.75 | 1.09 | 0.19 |
| 79.96 | 9.53 | 4.38 | 225.48 | 1.10 | 0.22 |
| 89.84 | 8.93 | 3.37 | 274.13 | 1.12 | 0.28 |
| 100 | 7.94 | 2.11 | 389.84 | 1.14 | 0.36 |
| T = 495.15 K | | | | | |
| 0 | 10.39 | 6.18 | 178.94 | 0.90 | -0.19 |
| 4.73 | 10.50 | 6.44 | 173.49 | 0.92 | -0.16 |
| 22.25 | 10.65 | 6.82 | 166.17 | 0.96 | -0.07 |
| 29 | 10.65 | 6.81 | 166.30 | 0.98 | -0.04 |
| 35.98 | 10.70 | 6.95 | 163.90 | 0.99 | -0.01 |
| 53.61 | 10.50 | 6.45 | 173.33 | 1.03 | 0.06 |
| 62.9 | 10.65 | 6.83 | 166.09 | 1.05 | 0.10 |
| 68.76 | 10.15 | 5.64 | 191.71 | 1.07 | 0.13 |
| 75.13 | 9.86 | 5.02 | 209.03 | 1.08 | 0.16 |
| 79.96 | 9.52 | 4.36 | 232.26 | 1.09 | 0.19 |
| 89.84 | 8.92 | 3.36 | 282.45 | 1.11 | 0.24 |
| 100 | 7.94 | 2.11 | 401.32 | 1.12 | 0.32 |
| T = 518.15 K | | | | | |

| | | | | | |
|---|---|---|---|---|---|
| 0 | 10.40 | 6.21 | 186.93 | 0.89 | -0.21 |
| 4.73 | 10.51 | 6.48 | 181.13 | 0.90 | -0.19 |
| 22.25 | 10.65 | 6.83 | 174.14 | 0.94 | -0.10 |
| 29 | 10.65 | 6.81 | 174.38 | 0.96 | -0.07 |
| 35.98 | 10.70 | 6.94 | 171.98 | 0.98 | -0.04 |
| 53.61 | 10.48 | 6.41 | 182.54 | 1.01 | 0.03 |
| 62.9 | 10.64 | 6.79 | 174.81 | 1.03 | 0.06 |
| 68.76 | 10.13 | 5.59 | 202.21 | 1.05 | 0.09 |
| 75.13 | 9.84 | 4.98 | 220.65 | 1.06 | 0.11 |
| 79.96 | 9.52 | 4.35 | 244.20 | 1.07 | 0.14 |
| 89.84 | 11.17 | 8.26 | 150.94 | 1.09 | 0.15 |
| 100 | 7.93 | 2.10 | 421.49 | 1.10 | 0.25 |
| T = 520.15 K | | | | | |
| 0 | 10.40 | 6.21 | 187.58 | 0.88 | -0.21 |
| 4.73 | 10.51 | 6.48 | 181.76 | 0.90 | -0.19 |
| 22.25 | 10.65 | 6.83 | 174.80 | 0.94 | -0.10 |
| 29 | 10.65 | 6.81 | 175.04 | 0.96 | -0.08 |
| 35.98 | 10.70 | 6.94 | 172.65 | 0.97 | -0.05 |
| 53.61 | 10.48 | 6.41 | 183.31 | 1.01 | 0.02 |
| 62.9 | 10.64 | 6.79 | 175.54 | 1.03 | 0.06 |
| 68.76 | 10.13 | 5.59 | 203.08 | 1.04 | 0.08 |
| 75.13 | 9.84 | 4.98 | 221.62 | 1.06 | 0.11 |
| 79.96 | 9.52 | 4.35 | 245.19 | 1.07 | 0.13 |
| 89.84 | 8.91 | 3.35 | 298.34 | 1.08 | 0.18 |
| 100 | 7.93 | 2.10 | 423.16 | 1.10 | 0.25 |

Table 2 shows a similar trend in thermal expansion coefficient (α), isothermal compressibility ($\beta_T$), internal pressure ($P_{int}$), specific heat ratio (Ɣ) and pseudo-Grüneisen parameter (Γ) with the only difference that the variation is at 35.98% mole fraction of sodium in Na-Cs alloy. This is due to the fact that they belong to the same group in the periodic table.

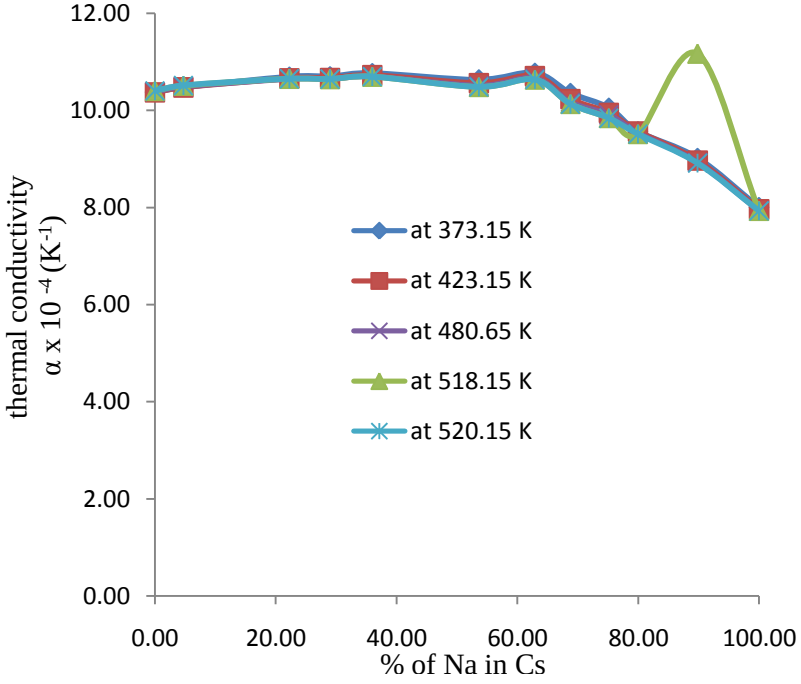


**Figure 2. Variation of thermal expansivity (α) with temperature (in K) and percentage of sodium in the Na-Cs alloy.**

Figure 2 supports the fact that as the % of sodium is increased the values of thermal expansivity is increasing showing a sharp rise at one point but with temperature rise its value is decreasing showing a marked fall between 60 to 80% ratio which is a transition stage of the two metals. Here each curve is indicating its specific temperatures. The initial start of the graph is at higher value of thermal expansivity when % of sodium is zero but during the end the value is low below the start point showing that when potassium is 100% thermal expansivity is less.

Table 3 enlists the calculated values of thermal expansivity (α), isothermal compressibility ($\beta_T$), internal pressure ($P_{int}$), specific heat ratio (ϒ) and pseudo-Grüneisen parameter (Γ) of Sn-Pb alloy using empirical relations (1-6) at three different temperatures.

**Table 3. Calculated values of thermal expansion coefficient (α), isothermal compressibility ($\beta_T$), internal pressure ($P_{int}$), specific heat ratio (ϒ) and pseudo-Grüneisen parameter (Γ) of Sn-Pb alloy at different compositions and varying temperatures by equations (1) to (5).**

| % of Sn in Pb | α x $10^{-4}$ | β x $10^{-5}$ | $P_{int}$ x $10^3$ | ϒ | Γ |
|---|---|---|---|---|---|
| | $K^{-1}$ | $atm^{-1}$ | atm | | |
| T = 673 K | | | | | |
| 10 | 39.12 | 1241.79 | 4.57 | 4.90 | 4.52 |
| 20 | 39.58 | 1301.63 | 4.41 | 4.92 | 4.54 |
| 30 | 40.09 | 1370.49 | 4.24 | 4.89 | 4.52 |
| 45 | 40.29 | 1397.48 | 4.18 | 4.85 | 4.48 |
| 60 | 40.72 | 1458.57 | 4.05 | 4.79 | 4.43 |
| T = 873 K | | | | | |
| 10 | 38.30 | 1141.23 | 6.31 | 4.37 | 4.07 |
| 20 | 38.55 | 1171.95 | 6.19 | 4.35 | 4.05 |
| 30 | 39.06 | 1234.47 | 5.95 | 4.33 | 4.03 |
| 45 | 39.36 | 1273.39 | 5.81 | 4.29 | 4.00 |
| 60 | 39.82 | 1333.97 | 5.61 | 4.25 | 3.96 |
| T = 973 K | | | | | |
| 10 | 37.97 | 1101.99 | 7.22 | 4.16 | 3.89 |
| 20 | 38.14 | 1122.82 | 7.12 | 4.13 | 3.86 |
| 30 | 38.64 | 1182.97 | 6.85 | 4.11 | 3.84 |
| 45 | 39.00 | 1227.46 | 6.66 | 4.07 | 3.81 |
| 60 | 39.46 | 1286.39 | 6.43 | 4.03 | 3.77 |

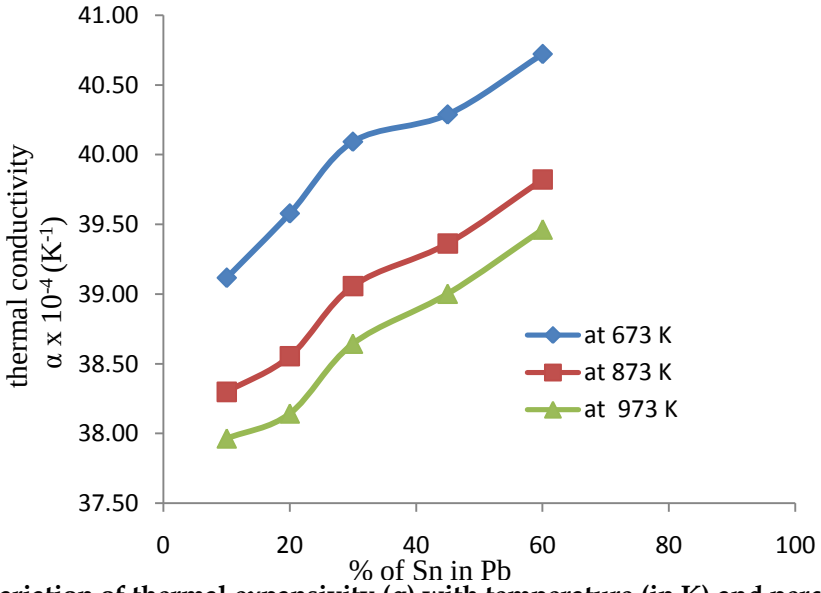


**Figure 3. Variation of thermal expansivity (α) with temperature (in K) and percentage of tin in the Sn-Pb alloy.**

In table 3 the values of thermal expansivity, isothermal compressibility, heat capacity ratio and pseudo-Grüneisen parameter show marked decrease with temperature and internal pressure along with surface tension shows increases with temperature. The values show a similar trend with mole fraction as when the ratio of tin increases the trend is very similar as reported earlier for other alloys. The specific change is that the changes are large and prominent as then two metals constituting the alloy are from p-block of the periodic table therefore show the effects with only few variations in temperature only.
Figure 3 shows that as the temperature is increased thermal expansivity decreases sharply and prominently. The trend of the graph with percentage increase in tin is showing an upward increase and is maximum at 60% only. This is a very characteristic feature as the alloy formation takes place at 60% Sn and 40% Pb ratio so more interactions at lesser ratio.

In table 4 the non-linearity parameter (B/A) increases and internal pressure decreases by Hartmann and Ballou relations showing less interaction between the atoms of metals in the alloy making it more strong in interaction intensity.

**Table 4. Calculated values of non-linearity parameter B/A and $P_{int}$ by using Hartmann and Ballou relations of K-Rb liquid metal alloy at different compositions and varying temperatures.**

| | Hartmann | | Ballou | |
|---|---|---|---|---|
| % of K in Rb | B/A | $P_{int}$ atm | B/A | $P_{int}$ atm |
| T = 343.15 K | | | | |
| 0 | 9.91 | 0.20 | 9.18 | 0.22 |
| 10.08 | 9.66 | 0.21 | 8.88 | 0.22 |
| 19.04 | 9.47 | 0.21 | 8.65 | 0.22 |
| 32.29 | 9.14 | 0.21 | 8.24 | 0.24 |
| 40.11 | 8.95 | 0.22 | 8.02 | 0.24 |
| 52.78 | 8.62 | 0.23 | 7.60 | 0.26 |
| 67.71 | 8.19 | 0.26 | 7.08 | 0.29 |
| 74.02 | 8.13 | 0.26 | 7.01 | 0.29 |
| 89.72 | 7.80 | 0.28 | 6.60 | 0.32 |
| 100 | 7.23 | 0.35 | 5.91 | 0.41 |
| T = 357.15 K | | | | |
| 0 | 9.94 | 0.20 | 9.23 | 0.21 |
| 10.08 | 9.69 | 0.20 | 8.91 | 0.22 |
| 19.04 | 9.50 | 0.20 | 8.68 | 0.22 |
| 32.29 | 9.17 | 0.21 | 8.28 | 0.23 |
| 40.11 | 8.98 | 0.22 | 8.05 | 0.24 |
| 52.78 | 8.64 | 0.23 | 7.64 | 0.26 |
| 67.71 | 8.22 | 0.25 | 7.12 | 0.29 |
| 74.02 | 8.15 | 0.25 | 7.04 | 0.29 |
| 89.72 | 7.82 | 0.27 | 6.63 | 0.32 |
| 100 | 7.25 | 0.34 | 5.93 | 0.41 |
| T = 386.15 K | | | | |
| 0 | 10.01 | 0.19 | 9.31 | 0.21 |
| 10.08 | 9.75 | 0.20 | 8.99 | 0.21 |
| 19.04 | 9.56 | 0.20 | 8.76 | 0.21 |
| 32.29 | 9.23 | 0.21 | 8.36 | 0.22 |
| 40.11 | 9.04 | 0.21 | 8.12 | 0.23 |
| 52.78 | 8.70 | 0.22 | 7.70 | 0.25 |
| 67.71 | 8.27 | 0.25 | 7.18 | 0.28 |
| 74.02 | 8.21 | 0.25 | 7.10 | 0.28 |
| 89.72 | 7.86 | 0.27 | 6.68 | 0.31 |
| 100 | 7.30 | 0.33 | 5.99 | 0.39 |

| T = 393.15 K | | | | |
|---|---|---|---|---|
| 0 | 10.03 | 0.19 | 9.33 | 0.21 |
| 10.08 | 9.76 | 0.20 | 9.01 | 0.21 |
| 19.04 | 9.58 | 0.20 | 8.78 | 0.21 |
| 32.29 | 9.25 | 0.20 | 8.38 | 0.22 |
| 40.11 | 9.05 | 0.21 | 8.14 | 0.23 |
| 52.78 | 8.71 | 0.22 | 7.72 | 0.25 |
| 67.71 | 8.29 | 0.24 | 7.20 | 0.28 |
| 74.02 | 8.22 | 0.24 | 7.11 | 0.28 |
| 89.72 | 7.87 | 0.26 | 6.69 | 0.31 |
| 100 | 7.31 | 0.33 | 6.00 | 0.39 |
| T = 436.15 K | | | | |
| 0 | 10.14 | 0.18 | 9.47 | 0.19 |
| 10.08 | 9.86 | 0.19 | 9.12 | 0.20 |
| 19.04 | 9.67 | 0.19 | 8.90 | 0.20 |
| 32.29 | 9.35 | 0.19 | 8.49 | 0.21 |
| 40.11 | 9.14 | 0.20 | 8.25 | 0.22 |
| 52.78 | 8.79 | 0.21 | 7.82 | 0.24 |
| 67.71 | 8.37 | 0.23 | 7.30 | 0.26 |
| 74.02 | 8.30 | 0.23 | 7.21 | 0.26 |
| 89.72 | 7.93 | 0.25 | 6.76 | 0.29 |
| 100 | 7.38 | 0.32 | 6.08 | 0.37 |
| T = 452.15 K | | | | |
| 0 | 10.18 | 0.18 | 9.52 | 0.19 |
| 10.08 | 9.89 | 0.18 | 9.16 | 0.20 |
| 19.04 | 9.71 | 0.18 | 8.94 | 0.20 |
| 32.29 | 9.38 | 0.19 | 8.54 | 0.21 |
| 40.11 | 9.18 | 0.20 | 8.29 | 0.21 |
| 52.78 | 8.82 | 0.21 | 7.85 | 0.23 |
| 67.71 | 8.40 | 0.23 | 7.34 | 0.26 |
| 74.02 | 8.33 | 0.23 | 7.25 | 0.26 |
| 89.72 | 7.95 | 0.25 | 6.79 | 0.29 |
| 100 | 7.40 | 0.31 | 6.11 | 0.37 |
| T = 464.15 K | | | | |
| 0 | 10.21 | 0.18 | 9.56 | 0.19 |
| 10.08 | 9.92 | 0.18 | 9.20 | 0.19 |
| 19.04 | 9.74 | 0.18 | 8.97 | 0.20 |
| 32.29 | 9.41 | 0.19 | 8.57 | 0.20 |
| 40.11 | 9.20 | 0.19 | 8.32 | 0.21 |
| 52.78 | 8.85 | 0.21 | 7.88 | 0.23 |
| 67.71 | 8.42 | 0.23 | 7.37 | 0.26 |
| 74.02 | 8.35 | 0.23 | 7.28 | 0.26 |
| 89.72 | 7.97 | 0.25 | 6.81 | 0.28 |
| 100 | 7.42 | 0.31 | 6.14 | 0.36 |
| T = 481.15 K | | | | |
| 0 | 10.26 | 0.17 | 9.61 | 0.18 |
| 10.08 | 9.96 | 0.18 | 9.24 | 0.19 |
| 19.04 | 9.78 | 0.18 | 9.02 | 0.19 |
| 32.29 | 9.45 | 0.18 | 8.62 | 0.20 |
| 40.11 | 9.24 | 0.19 | 8.36 | 0.21 |
| 52.78 | 8.88 | 0.20 | 7.92 | 0.22 |
| 67.71 | 8.46 | 0.22 | 7.41 | 0.25 |
| 74.02 | 8.38 | 0.22 | 7.31 | 0.25 |

| | | | | |
|---|---|---|---|---|
| 89.72 | 8 | 0.24 | 6.84 | 0.28 |
| 100 | 7.45 | 0.30 | 6.17 | 0.35 |
| T = 502.15 K | | | | |
| 0 | 10.32 | 0.17 | 9.68 | 0.18 |
| 10.08 | 10.00 | 0.17 | 9.30 | 0.19 |
| 19.04 | 9.83 | 0.17 | 9.08 | 0.19 |
| 32.29 | 9.5 | 0.18 | 8.68 | 0.20 |
| 40.11 | 9.28 | 0.19 | 8.42 | 0.20 |
| 52.78 | 8.92 | 0.20 | 7.97 | 0.22 |
| 67.71 | 8.50 | 0.22 | 7.46 | 0.24 |
| 74.02 | 8.42 | 0.22 | 7.36 | 0.24 |
| 89.72 | 8.03 | 0.24 | 6.88 | 0.27 |
| 100 | 7.48 | 0.29 | 6.21 | 0.35 |
| T = 518.15 K | | | | |
| 0 | 10.36 | 0.17 | 9.74 | 0.18 |
| 10.08 | 10.04 | 0.17 | 9.35 | 0.18 |
| 19.04 | 9.86 | 0.17 | 9.13 | 0.18 |
| 32.29 | 9.54 | 0.18 | 8.73 | 0.19 |
| 40.11 | 9.32 | 0.18 | 8.46 | 0.20 |
| 52.78 | 8.95 | 0.20 | 8.01 | 0.22 |
| 67.71 | 8.53 | 0.21 | 7.50 | 0.24 |
| 74.02 | 8.45 | 0.21 | 7.40 | 0.24 |
| 89.72 | 8.05 | 0.24 | 6.91 | 0.27 |
| 100 | 7.51 | 0.29 | 6.24 | 0.34 |

Table 5 highlights on the calculated values of thermoacoustic non-linearity parameter (B/A) and internal pressure ($P_{int}$) of high purity liquid alkali metal alloy Na-Cs as calculated from formulation (7), (8) and (9) consecutively at the different temperature.

**Table 5. Calculated values of non-linearity parameter B/A and $P_{int}$ by using Hartmann and Ballou relation of Na-Cs liquid metal alloy at different compositions and varying temperatures.**

| | **Hartmann** | | **Ballou** | |
|---|---|---|---|---|
| **% of Na in Cs** | **B/A** | **$P_{int}$ atm** | **B/A** | **$P_{int}$ atm** |
| T = 373.15 K | | | | |
| 0 | 12.20 | 0.12 | 11.99 | 0.13 |
| 4.73 | 12.10 | 0.12 | 11.86 | 0.12 |
| 22.25 | 11.53 | 0.12 | 11.18 | 0.13 |
| 29 | 11.23 | 0.13 | 10.80 | 0.13 |
| 35.98 | 11.03 | 0.13 | 10.56 | 0.14 |
| 53.61 | 10.14 | 0.15 | 9.47 | 0.16 |
| 62.9 | 10.05 | 0.15 | 9.36 | 0.16 |
| 68.76 | 9.27 | 0.19 | 8.41 | 0.21 |
| 75.13 | 8.69 | 0.23 | 7.70 | 0.26 |
| 79.96 | 7.96 | 0.31 | 6.79 | 0.35 |
| 89.84 | 7.11 | 0.44 | 5.76 | 0.52 |
| 100 | 5.89 | 0.84 | 4.26 | 1.10 |
| T = 395.15 K | | | | |
| 0 | 12.27 | 0.12 | 12.08 | 0.12 |
| 4.73 | 12.17 | 0.12 | 11.96 | 0.12 |
| 22.25 | 11.59 | 0.12 | 11.24 | 0.12 |
| 29 | 11.28 | 0.13 | 10.86 | 0.13 |
| 35.98 | 11.07 | 0.13 | 10.61 | 0.13 |
| 53.61 | 10.17 | 0.15 | 9.50 | 0.16 |

| | | | | |
|---|---|---|---|---|
| 62.9 | 10.08 | 0.15 | 9.39 | 0.16 |
| 68.76 | 9.22 | 0.19 | 8.34 | 0.21 |
| 75.13 | 8.67 | 0.23 | 7.66 | 0.26 |
| 79.96 | 8.04 | 0.29 | 6.90 | 0.34 |
| 89.84 | 7.02 | 0.45 | 5.65 | 0.55 |
| 100 | 5.91 | 0.83 | 4.28 | 1.08 |
| T = 423.15 K | | | | |
| 0 | 12.37 | 0.12 | 12.2 | 0.12 |
| 4.73 | 12.27 | 0.12 | 12.08 | 0.12 |
| 22.25 | 11.66 | 0.12 | 11.33 | 0.12 |
| 29 | 11.34 | 0.12 | 10.94 | 0.13 |
| 35.98 | 11.13 | 0.12 | 10.68 | 0.13 |
| 53.61 | 10.20 | 0.15 | 9.54 | 0.16 |
| 62.9 | 10.11 | 0.14 | 9.43 | 0.15 |
| 68.76 | 9.24 | 0.19 | 8.36 | 0.21 |
| 75.13 | 8.68 | 0.23 | 7.68 | 0.25 |
| 79.96 | 8.07 | 0.29 | 6.94 | 0.33 |
| 89.84 | 7.16 | 0.42 | 5.81 | 0.50 |
| 100 | 5.93 | 0.81 | 4.31 | 1.06 |
| T = 442.65 K | | | | |
| 0 | 12.44 | 0.11 | 12.28 | 0.12 |
| 4.73 | 12.34 | 0.11 | 12.16 | 0.11 |
| 22.25 | 11.71 | 0.12 | 11.39 | 0.12 |
| 29 | 11.38 | 0.12 | 10.99 | 0.12 |
| 35.98 | 11.17 | 0.12 | 10.73 | 0.13 |
| 53.61 | 10.22 | 0.15 | 9.56 | 0.16 |
| 62.9 | 10.14 | 0.14 | 9.46 | 0.15 |
| 68.76 | 9.25 | 0.19 | 8.38 | 0.21 |
| 75.13 | 8.69 | 0.23 | 7.69 | 0.25 |
| 79.96 | 8.10 | 0.28 | 6.96 | 0.32 |
| 89.84 | 7.17 | 0.42 | 5.83 | 0.50 |
| 100 | 5.95 | 0.80 | 4.33 | 1.04 |
| T = 473.15 K | | | | |
| 0 | 12.54 | 0.11 | 12.41 | 0.11 |
| 4.73 | 12.45 | 0.11 | 12.3 | 0.11 |
| 22.25 | 11.78 | 0.11 | 11.48 | 0.11 |
| 29 | 11.46 | 0.12 | 11.08 | 0.12 |
| 35.98 | 11.24 | 0.12 | 10.81 | 0.12 |
| 53.61 | 10.25 | 0.14 | 9.61 | 0.15 |
| 62.9 | 10.18 | 0.14 | 9.51 | 0.15 |
| 68.76 | 9.27 | 0.19 | 8.41 | 0.20 |
| 75.13 | 8.71 | 0.22 | 7.71 | 0.25 |
| 79.96 | 8.13 | 0.28 | 7.01 | 0.32 |
| 89.84 | 7.20 | 0.41 | 5.87 | 0.49 |
| 100 | 5.98 | 0.78 | 4.37 | 1.01 |
| T = 480.65 K | | | | |
| 0 | 12.57 | 0.11 | 12.44 | 0.11 |
| 4.73 | 12.48 | 0.11 | 12.34 | 0.11 |
| 22.25 | 11.80 | 0.11 | 11.50 | 0.11 |
| 29 | 11.47 | 0.12 | 11.10 | 0.12 |
| 35.98 | 11.25 | 0.12 | 10.83 | 0.12 |
| 53.61 | 10.26 | 0.14 | 9.62 | 0.15 |
| 62.9 | 10.19 | 0.14 | 9.52 | 0.15 |

| | | | | |
|---|---|---|---|---|
| 68.76 | 9.28 | 0.18 | 8.41 | 0.20 |
| 75.13 | 8.75 | 0.22 | 7.77 | 0.24 |
| 79.96 | 8.14 | 0.27 | 7.02 | 0.31 |
| 89.84 | 7.21 | 0.40 | 5.88 | 0.48 |
| 100 | 5.98 | 0.77 | 4.38 | 1.00 |
| T = 495.15 K | | | | |
| 0 | 12.62 | 0.11 | 12.50 | 0.11 |
| 4.73 | 12.53 | 0.11 | 12.40 | 0.11 |
| 22.25 | 11.84 | 0.11 | 11.55 | 0.11 |
| 29 | 11.51 | 0.11 | 11.14 | 0.12 |
| 35.98 | 11.28 | 0.12 | 10.87 | 0.12 |
| 53.61 | 10.28 | 0.14 | 9.64 | 0.15 |
| 62.9 | 10.20 | 0.14 | 9.54 | 0.15 |
| 68.76 | 9.29 | 0.18 | 8.42 | 0.20 |
| 75.13 | 8.72 | 0.22 | 7.73 | 0.25 |
| 79.96 | 8.15 | 0.27 | 7.04 | 0.31 |
| 89.84 | 7.22 | 0.40 | 5.89 | 0.48 |
| 100 | 5.99 | 0.76 | 4.39 | 0.99 |
| T = 518.15 K | | | | |
| 0 | 12.71 | 0.10 | 12.61 | 0.10 |
| 4.73 | 12.62 | 0.10 | 12.51 | 0.10 |
| 22.25 | 11.90 | 0.11 | 11.62 | 0.11 |
| 29 | 11.56 | 0.11 | 11.21 | 0.12 |
| 35.98 | 11.34 | 0.11 | 10.93 | 0.12 |
| 53.61 | 10.30 | 0.14 | 9.67 | 0.15 |
| 62.9 | 10.23 | 0.14 | 9.58 | 0.14 |
| 68.76 | 9.31 | 0.18 | 8.45 | 0.20 |
| 75.13 | 8.73 | 0.22 | 7.74 | 0.24 |
| 79.96 | 8.18 | 0.27 | 7.07 | 0.30 |
| 89.84 | 10.23 | 0.12 | 9.58 | 0.12 |
| 100 | 6.02 | 0.75 | 4.42 | 0.97 |
| T = 520.15 K | | | | |
| 0 | 12.71 | 0.10 | 12.62 | 0.10 |
| 4.73 | 12.63 | 0.10 | 12.52 | 0.10 |
| 22.25 | 11.91 | 0.11 | 11.63 | 0.11 |
| 29 | 11.57 | 0.11 | 11.22 | 0.12 |
| 35.98 | 11.34 | 0.11 | 10.94 | 0.12 |
| 53.61 | 10.31 | 0.14 | 9.67 | 0.15 |
| 62.9 | 10.24 | 0.14 | 9.59 | 0.14 |
| 68.76 | 9.31 | 0.18 | 8.45 | 0.20 |
| 75.13 | 8.73 | 0.22 | 7.74 | 0.24 |
| 79.96 | 8.19 | 0.27 | 7.07 | 0.30 |
| 89.84 | 7.24 | 0.39 | 5.92 | 0.47 |
| 100 | 6.02 | 0.75 | 4.42 | 0.97 |

Similar trend is observed as in Table 4 with constant increase in B/A values and decrease in $P_{int}$ values owing to interaction between metal and metallic bonding playing a strong role.

Table 6 shows the details of the calculated values of thermoacoustic non-linearity parameter (B/A) and internal pressure ($P_{int}$) of high purity liquid alkali metal alloy Sn-Pb as calculated from formulation (7), (8) and (9) consecutively at the three different temperatures.

**Table 6. Calculated values of B/A and $P_{int}$ by using Hartmann and Ballou relations of Sn-Pb alloy at different compositions and varying temperatures.**

| % of Sn in Pb | Hartmann | | Ballou | |
|---|---|---|---|---|
| | B/A | $P_{int}$ atm | B/A | $P_{int}$ atm |
| T = 673 K | | | | |
| 10 | 6.15 | 0.0055 | 4.58 | 0.0071 |
| 20 | 6.23 | 0.0052 | 4.68 | 0.0066 |
| 30 | 6.38 | 0.0048 | 4.87 | 0.0061 |
| 45 | 6.51 | 0.0046 | 5.02 | 0.0058 |
| 60 | 6.71 | 0.0043 | 5.27 | 0.0052 |
| T = 873 K | | | | |
| 10 | 6.22 | 0.0053 | 4.67 | 0.0067 |
| 20 | 6.32 | 0.0051 | 4.79 | 0.0064 |
| 30 | 6.47 | 0.0047 | 4.98 | 0.0059 |
| 45 | 6.62 | 0.0044 | 5.16 | 0.0055 |
| 60 | 6.83 | 0.0041 | 5.41 | 0.0050 |
| T = 973 K | | | | |
| 10 | 6.25 | 0.0052 | 4.71 | 0.0066 |
| 20 | 6.36 | 0.0050 | 4.83 | 0.0063 |
| 30 | 6.52 | 0.0046 | 5.03 | 0.0058 |
| 45 | 6.68 | 0.0043 | 5.23 | 0.0053 |
| 60 | 6.89 | 0.0040 | 5.49 | 0.0048 |

Table 6 shows that as temperature is increased in case of Sn-Pb liquid metal alloy the results are remarkable and holds good for strong interactions between metals.

Table 7 shows estimated values of surface tension for K-Rb alloy at different temperatures.

**Table 7. Estimated values of surface tension (σ) for K-Rb alloy at different compositions and varying temperatures by equation (6).**

| % of K in Rb | σ($Nm^{-1}$) |
|---|---|
| **T = 343.15 K** | |
| 0 | 15.35 |
| 10.08 | 14.95 |
| 19.04 | 14.58 |
| 32.29 | 14.32 |
| 40.11 | 14.21 |
| 52.78 | 14.24 |
| 67.71 | 14.54 |
| 74.02 | 14.31 |
| 89.72 | 14.42 |
| 100 | 16.08 |
| **T = 357.15 K** | |
| 0 | 16.03 |
| 10.08 | 15.61 |
| 19.04 | 15.22 |
| 32.29 | 14.95 |
| 40.11 | 14.84 |
| 52.78 | 14.88 |
| 67.71 | 15.18 |
| 74.02 | 14.95 |
| 89.72 | 15.08 |
| 100 | 16.80 |

| % of K in Rb | σ($Nm^{-1}$) |
|---|---|
| **T = 393.15 K** | |
| 0 | 17.73 |
| 10.08 | 17.31 |
| 19.04 | 16.87 |
| 32.29 | 16.55 |
| 40.11 | 16.45 |
| 52.78 | 16.49 |
| 67.71 | 16.81 |
| 74.02 | 16.56 |
| 89.72 | 16.76 |
| 100 | 18.62 |
| **T = 436.15 K** | |
| 0 | 19.71 |
| 10.08 | 19.29 |
| 19.04 | 18.78 |
| 32.29 | 18.41 |
| 40.11 | 18.31 |
| 52.78 | 18.38 |
| 67.71 | 18.71 |
| 74.02 | 18.44 |
| 89.72 | 18.73 |
| 100 | 20.73 |

| % of K in Rb | σ($Nm^{-1}$) |
|---|---|
| **T = 464.15 K** | |
| 0 | 20.96 |
| 10.08 | 20.55 |
| 19.04 | 19.99 |
| 32.29 | 19.59 |
| 40.11 | 19.5 |
| 52.78 | 19.58 |
| 67.71 | 19.91 |
| 74.02 | 19.63 |
| 89.72 | 19.98 |
| 100 | 22.07 |
| **T = 502.15 K** | |
| 0 | 22.6 |
| 10.08 | 22.2 |
| 19.04 | 21.59 |
| 32.29 | 21.14 |
| 40.11 | 21.06 |
| 52.78 | 21.16 |
| 67.71 | 21.48 |
| 74.02 | 21.20 |
| 89.72 | 21.65 |
| 100 | 23.84 |

| T = 386.15 K | | T = 452.15 K | | T = 518.15 K | |
|---|---|---|---|---|---|
| 0 | 17.40 | 0 | 20.43 | 0 | 23.27 |
| 10.08 | 16.98 | 10.08 | 20.01 | 10.08 | 22.88 |
| 19.04 | 16.55 | 19.04 | 19.47 | 19.04 | 22.24 |
| 32.29 | 16.24 | 32.29 | 19.09 | 32.29 | 21.77 |
| 40.11 | 16.14 | 40.11 | 18.99 | 40.11 | 21.70 |
| 52.78 | 16.18 | 52.78 | 19.07 | 52.78 | 21.81 |
| 67.71 | 16.50 | 67.71 | 19.40 | 67.71 | 22.13 |
| 74.02 | 16.25 | 74.02 | 19.12 | 74.02 | 21.84 |
| 89.72 | 16.43 | 89.72 | 19.45 | 89.72 | 22.34 |
| 100 | 18.26 | 100 | 21.50 | 100 | 24.57 |

Table 8 shows the estimated values of surface tension of Na-Cs alloy at different temperatures.

**Table 8. Estimated values of surface tension (σ) for Na-Cs alloy at different compositions and varying temperatures by equation (6).**

| % of Na in Cs | σ(Nm$^{-1}$) | % of Na in Cs | σ(Nm$^{-1}$) | % of Na in Cs | σ(Nm$^{-1}$) |
|---|---|---|---|---|---|
| T = 373.15 K | | T = 442.65 K | | T = 495.15 K | |
| 0 | 14.42 | 0 | 17.14 | 0 | 19.04 |
| 4.73 | 14.01 | 4.73 | 16.64 | 4.73 | 18.46 |
| 22.25 | 13.18 | 22.25 | 15.81 | 22.25 | 17.68 |
| 29 | 13.15 | 29.00 | 15.80 | 29 | 17.70 |
| 35.98 | 12.92 | 35.98 | 15.55 | 35.98 | 17.44 |
| 53.61 | 13.42 | 53.61 | 16.32 | 53.61 | 18.44 |
| 62.9 | 12.89 | 62.9 | 15.65 | 62.9 | 17.67 |
| 68.76 | 14.51 | 68.76 | 17.99 | 68.76 | 20.40 |
| 75.13 | 15.86 | 75.13 | 19.58 | 75.13 | 22.24 |
| 79.96 | 18.4 | 79.96 | 21.94 | 79.96 | 24.71 |
| 89.84 | 21.98 | 89.84 | 26.65 | 89.84 | 30.05 |
| 100 | 31.48 | 100 | 38.00 | 100 | 42.70 |
| T = 395.15 K | | T = 473.15 K | | T = 518.15 K | |
| 0 | 15.29 | 0 | 18.28 | 0 | 19.89 |
| 4.73 | 14.86 | 4.73 | 17.73 | 4.73 | 19.27 |
| 22.25 | 14.02 | 22.25 | 16.93 | 22.25 | 18.53 |
| 29 | 14.00 | 29 | 16.93 | 29 | 18.55 |
| 35.98 | 13.76 | 35.98 | 16.68 | 35.98 | 18.3 |
| 53.61 | 14.34 | 53.61 | 17.58 | 53.61 | 19.42 |
| 62.9 | 13.77 | 62.90 | 16.85 | 62.90 | 18.60 |
| 68.76 | 15.76 | 68.76 | 19.42 | 68.76 | 21.52 |
| 75.13 | 17.13 | 75.13 | 21.16 | 75.13 | 23.48 |
| 79.96 | 19.34 | 79.96 | 23.59 | 79.96 | 25.98 |
| 89.84 | 24.22 | 89.84 | 28.67 | 89.84 | 16.06 |
| 100 | 33.56 | 100 | 40.8 | 100 | 44.85 |
| T = 423.15 K | | T = 480.65 K | | T = 520.15 K | |
| 0 | 16.39 | 0 | 18.55 | 0 | 19.96 |
| 4.73 | 15.92 | 4.73 | 17.99 | 4.73 | 19.34 |
| 22.25 | 15.08 | 22.25 | 17.20 | 22.25 | 18.60 |
| 29 | 15.07 | 29 | 17.20 | 29 | 18.63 |
| 35.98 | 14.82 | 35.98 | 16.95 | 35.98 | 18.37 |
| 53.61 | 15.51 | 53.61 | 17.89 | 53.61 | 19.50 |
| 62.9 | 14.88 | 62.9 | 17.15 | 62.9 | 18.68 |
| 68.76 | 17.07 | 68.76 | 19.77 | 68.76 | 21.61 |
| 75.13 | 18.57 | 75.13 | 21.36 | 75.13 | 23.58 |
| 79.96 | 20.88 | 79.96 | 23.99 | 79.96 | 26.09 |
| 89.84 | 25.35 | 89.84 | 29.17 | 89.84 | 31.74 |
| 100 | 36.19 | 100 | 41.48 | 100 | 45.03 |

Table 9 displays the calculated values of surface tension of Sn-Pb alloy at varying temperatures.

**Table 9. Calculated values of surface tension (σ) for Sn-Pb alloy at different compositions and varying temperatures by equation (6).**

| % of Sn in Pb | σ | | |
|---|---|---|---|
| | $Nm^{-1}$ | | |
| | T=673 K | T=873 K | T=973 K |
| 10.00 | 0.49 | 0.67 | 0.77 |
| 20.00 | 0.47 | 0.66 | 0.76 |
| **30.00** | **0.45** | **0.63** | **0.73** |
| 45.00 | 0.44 | 0.62 | 0.71 |
| 60.00 | 0.43 | 0.60 | 0.68 |

The values of surface tension are decreasing till the ratio of the two metals in the alloy is 50% then it starts increasing which indicates that the second metal due to its larger size and volume causes more interaction between the atoms of alloy and thus rigorous flow of the alloy. In case of Sn-Pb there is a constant decrease in value of surface tension showing remarkable difference as they belong to a different block of elements in the periodic table.

## CONCLUSION

Density (ρ)-ultrasonic speed (u)-thermodynamic properties and density (ρ)-ultrasonic speed (u)-surface tension (σ) correlations have been successfully applied to three liquid metal alloys, namely K-Rb, Na-Cs and Sn-Pb at different compositions and varying temperatures. The properties computed are α, $\beta_T$, ϒ, $P_{int}$, Γ and σ. Further, some useful and important thermoacoustic parameters e.g. non linearity parameters B/A and $P_{int}$ were also computed from density and ultrasonic speed of three alloys. As far as our knowledge is concerned, this type of work has been done for the first time for liquid metal alloys.


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**Nomenclature**

u – Sonic speed
T – Temperature
$P_{int}$ – internal pressure
B/A – non-linearity parameter
V – Molar volume

**Abbreviation**

Na – sodium
K – potassium
Rb – rubidium
Cs – cesium
Sn – tin
Pb – lead

**Greek Letter**

ρ – Density
α – thermal expansion coefficient
β – Isothermal compressibility
σ – Surface tension
ϒ – Specific heat ratio
Γ – pseudo-Grüneisen parameter

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