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Evaluation and Comparative Study of Acoustic Non-Linearity Parameter of Liquid Metals and Alloys using Sound Speed and Density Data

SUBHASH CHANDRA SHRIVASTAVA*, RAMAKANT, SHEKHAR SRIVASTAVA and J.D. PANDEY

Department of Chemistry, University of Allahabad, Prayagraj-211002, India

*Corresponding author: E-mail: subhash.chem.au@gmail.com

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The non-linearity acoustic parameter (B/A) has been computed for six pure liquid metal alloys (Na, K, Rb, Cs, Pb and Sn), four liquid metal alloys (K-Rb, Na-Cs, Pb-Sn and Na-K) and other several liquid metals at different temperatures. This parameter has been calculated by using three different approaches *viz.* Hartmann method, Ballou rule and Johnson *et al.* method. The input data required density, sound speed and thermal expansivity were taken from literature. A comparative study has been carried out and quite satisfactory results are obtained.

Keywords: Non-linearity parameter, Liquid metals and alloys, Thermal expansivity, Ultrasonic velocity, Density.

INTRODUCTION

In non-linear acoustics, Beyer's non-linearity parameter has been extensively studied in past and the efforts are still continuing to get further insight into the various theoretical and physico-chemical aspects [1-5]. Acoustic non-linear effects occur due to greater attenuation of the high frequency components in comparison to low frequency ones when sound waves of high intensity are allowed to propagate in liquids. The deviation from linearity in the propagation process is expressed by the factor (B/A), called the non-linearity parameter. It is the ratio of the coefficients of the quadratic to the linear terms of a Taylor series used to express the equation of state of the medium in terms of pressure and density.

From the knowledge of this parameter, also called Bayer's parameter, internal pressure, intermolecular spacing, acoustic scattering and structural behaviour can be studied. Experimental study on this subject reveals that the non-linear interaction of two parallel beams could produce scattering. It is found that scattering does not take place when the incident beams are orthogonal. The non-linearity acoustic parameter (B/A) plays a significant role in non-linear acoustics as well as underwater acoustics. Thermodynamic simulation of the Bayer process has been employed by several workers for the determination of non-linearity parameter in case of the pure liquids [6-8] including higher alkanes [9-11], liquid xenon [12], liquid Hg [13] and liquid metals [14]. In the thermodynamic method, the values of the derivatives of sound speed with respect to temperature and pressure, as well as heat capacities at constant pressure and thermal expansion are desired.

Alternative to thermodynamic method, several empirical and semi-empirical approaches have been suggested by several workers [15-18]. These methods have been employed by several workers to compute non-linearity parameter for pure liquids [19], binary [20,21] and higher order [22] mixtures as well as isotopic liquids [23].

After an exhaustive literature survey, it appears that ultrasonic study of liquid metals and alloys is very scare. In the present work, the sound speed and density data of the studied liquid metals (Na, K, Rb, Cs, Pb and Sn) and liquid metal alloys (Na-Cs, K-Rb, Pb-Sn and Na-K) are computed for the non-linearity parameter and related properties.

Formulation: In present work, the non-linearity acoustic parameter (B/A) has been calculated using the following equations:

Hartmann-Balizer [24] method:

$$\frac{B}{A} = 2 + \left(\frac{0.98 \times 10^4}{u}\right) \quad (1)$$

Ballou rule [15]:

$$\frac{B}{A} = -0.5 + \left(\frac{1.2 \times 10^4}{u}\right) \quad (2)$$

Johnson *et al.* [17] proposed the following equation for calculation of B/A:

$$\left(\frac{B}{A}\right)^{I} = \gamma(C_1 - 1) \quad (3)$$

$$\left(\frac{B}{A}\right)^{II} = -(\gamma - 1)(\delta - 1) \quad (4)$$

$$\left(\frac{B}{A}\right) = \gamma(C_1 - 1) - (\gamma - 1)(\delta - 1) \quad (5)$$

where, $\gamma = C_p/C_v$, C_1 = Moelwyn-Hughes parameter; δ = Anderson-Grüneisen parameter, which are obtained as follows:

$$C_1 = \left(\frac{\partial \ln \beta}{\partial T}\right)_T = \frac{13}{3} + (\alpha.T)^{-1} + \frac{4}{3}(\alpha T)$$

$$= \frac{13}{3} + (\alpha.T)^{-1} + \frac{4}{3}(\alpha.T) \quad (6)$$

$$\delta = \frac{1}{\alpha}\left(\frac{\partial \ln \beta}{\partial T}\right)_P = 2k + 1 \quad (7)$$

The isobaric acoustical parameter, k, is given by

$$k = \frac{5}{3} = (2\alpha T)^{-1} + \frac{2}{3}(\alpha T) \quad (8)$$

where α and β are the thermal expansivity and isothermal compressibility, respectively.

RESULTS AND DISCUSSION

The above mentioned equations have been employed, for the first time, to six pure liquid metals (Na, K, Rb, Cs, Pb and Sn) and four liquid metal alloys (Na-Cs, K-Rb, Pb-Sn and Na-K) over a wide range of temperature and composition. The calculated values of B/A for liquid metals Na, K, Rb, Cs, Pb and Sn from eqns. 1, 2, 3 and 5 at different temperatures are shown in Table-1. Table-2 enlists the B/A for K-Rb alloys at different temperatures and varying composition of alloy. Similar results obtained for Na-Cs and Pb-Sn alloys reported respectively in Tables 3 and 4. For Na-K alloy, the computed values

TABLE-1
CALCULATED VALUES OF NON-LINEARITY ACOUSTIC PARAMETER (B/A) FOR LIQUID METALS Na, K, Rb, Cs, Pb AND Sn AT DIFFERENT TEMPERATURES

T (K)	$\alpha \times 10^{-4}$ (K^{-1})	B/A		
		Eqn. 1	Eqn. 2	Eqn. 5
		Sodium		
373.15	2.370	5.89	4.27	13.76
423.15	2.440	5.92	4.31	12.16
473.15	2.500	5.97	4.37	10.95
494.15	2.520	6.00	4.40	10.53
518.15	2.550	6.01	4.42	10.08
		Potassium		
343.15	2.673	7.23	5.91	13.36
386.15	2.731	7.31	6.00	11.96
436.15	2.800	7.37	6.08	10.68
464.15	2.840	7.42	6.13	10.10
502.15	2.894	7.48	6.22	9.41
536.15	2.944	7.54	6.28	8.88
		Rubidium		
316.15	2.720	9.84	9.10	14.08
357.15	2.779	9.96	9.25	12.54
393.15	2.832	10.02	9.32	11.46
452.15	2.921	10.18	9.52	10.08
481.15	2.967	10.26	9.61	9.53
518.15	3.025	10.37	9.75	8.92
		Cesium		
308.15	2.822	11.99	11.73	13.95
349.15	2.873	12.13	11.91	12.44
395.15	2.926	12.26	12.06	11.14
442.65	2.979	12.43	12.27	10.09
480.65	3.018	12.56	12.43	9.42
520.15	3.057	12.73	12.64	8.83
		Lead		
673.00	12.453	7.44	6.17	4.64
873.00	8.999	7.65	6.42	4.65
973.00	9.100	7.75	6.54	4.64
		Tin		
673.00	8.860	6.04	4.45	4.81
873.00	8.999	6.13	4.55	4.65
973.00	9.100	6.14	4.57	4.64

TABLE-2
CALCULATED VALUES OF NON-LINEARITY ACOUSTIC PARAMETER (B/A) FOR K-Rb ALLOY AT DIFFERENT TEMPERATURES

Weight % of K in alloy	$\alpha \times 10^{-4}$ (K^{-1})	B/A			$\alpha \times 10^{-4}$ (K^{-1})	B/A		
		Eqn. 1	Eqn. 2	Eqn. 5		Eqn. 1	Eqn. 2	Eqn. 5
	343.15 K				357.15 K			
0	9.88	9.91	9.18	6.73	9.87	9.94	9.23	6.64
10.08	9.97	9.66	8.88	6.71	9.96	9.69	8.91	6.62
19.04	10.06	9.47	8.65	6.69	10.05	9.50	8.68	6.60
32.29	10.12	9.14	8.24	6.68	10.11	9.17	8.28	6.58
40.11	10.14	8.95	8.02	6.67	10.13	8.98	8.05	6.58
52.78	10.14	8.62	7.60	6.67	10.12	8.64	7.64	6.58
67.71	10.07	8.19	7.08	6.69	10.06	8.22	7.12	6.60
74.02	10.12	8.13	7.01	6.68	10.11	8.15	7.04	6.58
89.72	10.09	7.80	6.60	6.68	10.08	7.82	6.63	6.59
100	9.73	7.23	5.91	6.77	9.72	7.25	5.93	6.68

386.15 K					393.15 K			
0	9.86	10.01	9.31	6.47	9.86	10.03	9.33	6.43
10.08	9.94	9.75	8.99	6.45	9.94	9.76	9.01	6.41
19.04	10.03	9.56	8.76	6.43	10.02	9.58	8.78	6.4
32.29	10.09	9.23	8.36	6.42	10.09	9.25	8.38	6.38
40.11	10.11	9.04	8.12	6.42	10.11	9.05	8.14	6.38
52.78	10.1	8.70	7.70	6.42	10.10	8.71	7.72	6.38
67.71	10.04	8.27	7.18	6.43	10.03	8.29	7.20	6.4
74.02	10.09	8.21	7.10	6.42	10.09	8.22	7.11	6.38
89.72	10.05	7.86	6.68	6.43	10.05	7.87	6.69	6.39
100	9.70	7.30	5.99	6.5	9.70	7.31	6.00	6.46
436.15 K					452.15 K			
0	9.85	10.14	9.47	6.23	9.85	10.18	9.52	6.17
10.08	9.92	9.86	9.12	6.22	9.92	9.89	9.16	6.16
19.04	10.01	9.67	8.90	6.21	10.01	9.71	8.94	6.15
32.29	10.08	9.35	8.49	6.19	10.08	9.38	8.54	6.14
40.11	10.1	9.14	8.25	6.19	10.09	9.18	8.29	6.13
52.78	10.08	8.79	7.82	6.19	10.08	8.82	7.85	6.14
67.71	10.02	8.37	7.30	6.20	10.02	8.40	7.34	6.14
74.02	10.07	8.30	7.21	6.20	10.07	8.33	7.25	6.14
89.72	10.02	7.93	6.76	6.20	10.02	7.95	6.79	6.14
100	9.69	7.38	6.08	6.26	9.69	7.40	6.11	6.20
464.15 K					481.15 K			
0	9.85	10.21	9.56	6.13	9.86	10.26	9.61	6.07
10.08	9.92	9.92	9.20	6.12	9.92	9.96	9.24	6.06
19.04	10.01	9.74	8.97	6.11	10.01	9.78	9.02	6.05
32.29	10.08	9.41	8.57	6.09	10.08	9.45	8.62	6.04
40.11	10.09	9.20	8.32	6.09	10.10	9.24	8.36	6.04
52.78	10.08	8.85	7.88	6.09	10.08	8.88	7.92	6.04
67.71	10.02	8.42	7.37	6.10	10.03	8.46	7.41	6.05
74.02	10.07	8.35	7.28	6.10	10.07	8.38	7.31	6.04
89.72	10.01	7.97	6.81	6.11	10.01	8.00	6.84	6.05
100	9.69	7.42	6.14	6.16	9.69	7.45	6.17	6.10
502.15 K					518.15 K			
0	9.87	10.32	9.68	6.01	9.87	10.36	9.74	5.97
10.08	9.92	10.00	9.30	6.01	9.93	10.04	9.35	5.96
19.04	10.02	9.83	9.08	5.99	10.02	9.86	9.13	5.95
32.29	10.09	9.50	8.68	5.98	10.09	9.54	8.73	5.94
40.11	10.10	9.28	8.42	5.98	10.10	9.32	8.46	5.94
52.78	10.08	8.92	7.97	5.98	10.09	8.95	8.01	5.94
67.71	10.03	8.50	7.46	5.99	10.04	8.53	7.50	5.95
74.02	10.08	8.42	7.36	5.98	10.08	8.45	7.40	5.94
89.72	10.01	8.03	6.88	5.99	10.01	8.05	6.91	5.95
100	9.69	7.48	6.21	6.04	9.69	7.51	6.24	5.99

TABLE-3
CALCULATED VALUES OF NON-LINEARITY ACOUSTIC PARAMETER (B/A) FOR Na-Cs ALLOY AT DIFFERENT TEMPERATURES

Na in alloy (%)	$\alpha \times 10^{-4}$ (K^{-1})	B/A			$\alpha \times 10^{-4}$ (K^{-1})	B/A		
		Eqn. 1	Eqn. 2	Eqn. 5		Eqn. 1	Eqn. 2	Eqn. 5
373.15 K					395.15 K			
0	10.38	12.20	11.99	6.43	10.37	12.27	12.08	6.32
4.73	10.48	12.10	11.86	6.41	10.47	12.17	11.96	6.30
22.25	10.69	11.53	11.18	6.37	10.68	11.59	11.24	6.27
29.00	10.70	11.23	10.80	6.37	10.68	11.28	10.86	6.27
35.98	10.77	11.03	10.56	6.36	10.75	11.07	10.61	6.25
53.61	10.63	10.14	9.47	6.38	10.60	10.17	9.50	6.28
62.90	10.77	10.05	9.36	6.36	10.74	10.08	9.39	6.26
68.76	10.36	9.27	8.41	6.44	10.27	9.22	8.34	6.34
75.13	10.06	8.69	7.70	6.50	9.99	8.67	7.66	6.39
79.96	9.57	7.96	6.79	6.61	9.59	8.04	6.90	6.48
89.84	9.02	7.11	5.76	6.75	8.90	7.02	5.65	6.65
100	8.00	5.89	4.26	7.08	7.98	5.91	4.28	6.93

		423.15 K				442.15 K		
0	10.37	12.37	12.20	6.20	10.37	12.44	12.28	6.12
4.73	10.47	12.27	12.08	6.18	10.48	12.34	12.16	6.11
22.25	10.66	11.66	11.33	6.15	10.66	11.71	11.39	6.08
29.00	10.67	11.34	10.94	6.15	10.66	11.38	10.99	6.08
35.98	10.73	11.13	10.68	6.14	10.71	11.17	10.73	6.07
53.61	10.56	10.20	9.54	6.17	10.54	10.22	9.56	6.10
62.90	10.71	10.11	9.43	6.14	10.69	10.14	9.46	6.08
68.76	10.23	9.24	8.36	6.22	10.21	9.25	8.38	6.15
75.13	9.95	8.68	7.68	6.27	9.92	8.69	7.69	6.20
79.96	9.57	8.07	6.94	6.34	9.55	8.10	6.96	6.26
89.84	8.97	7.16	5.81	6.47	8.95	7.17	5.83	6.39
100	7.96	5.93	4.31	6.75	7.95	5.95	4.33	6.64
		473.15 K				480.15 K		
0	10.38	12.54	12.41	6.02	10.38	12.57	12.44	6.00
4.73	10.49	12.45	12.30	6.01	10.49	12.48	12.34	5.99
22.25	10.65	11.78	11.48	5.99	10.65	11.80	11.50	5.97
29.00	10.65	11.46	11.08	5.99	10.65	11.47	11.10	5.97
35.98	10.7	11.24	10.81	5.98	10.70	11.25	10.83	5.96
53.61	10.52	10.25	9.61	6.01	10.51	10.26	9.62	5.99
62.90	10.66	10.18	9.51	5.99	10.66	10.19	9.52	5.97
68.76	10.17	9.27	8.41	6.05	10.17	9.28	8.41	6.03
75.13	9.89	8.71	7.71	6.09	9.91	8.75	7.77	6.07
79.96	9.53	8.13	7.01	6.15	9.53	8.14	7.02	6.13
89.84	8.93	7.20	5.87	6.26	8.93	7.21	5.88	6.24
100	7.94	5.98	4.37	6.50	7.94	5.98	4.38	6.46
		494.15 K				518.15 K		
0	10.39	12.62	12.50	5.97	10.40	12.71	12.61	5.91
4.73	10.50	12.53	12.40	5.95	10.51	12.62	12.51	5.90
22.25	10.65	11.84	11.55	5.94	10.65	11.90	11.62	5.88
29.00	10.65	11.51	11.14	5.94	10.65	11.56	11.21	5.88
35.98	10.70	11.28	10.87	5.93	10.70	11.34	10.93	5.88
53.61	10.50	10.28	9.64	5.95	10.48	10.30	9.67	5.90
62.90	10.65	10.20	9.54	5.94	10.64	10.23	9.58	5.88
68.76	10.15	9.29	8.42	6.00	10.13	9.31	8.45	5.94
75.13	9.86	8.72	7.73	6.04	9.84	8.73	7.74	5.97
79.96	9.52	8.15	7.04	6.09	9.52	8.18	7.07	6.02
89.84	8.92	7.22	5.89	6.19	11.17	10.23	9.58	5.83
100	7.94	5.99	4.39	6.41	7.93	6.02	4.42	6.31
		520.15 K						
0	10.40	12.71	12.62	5.90				
4.73	10.51	12.63	12.52	5.89				
22.25	10.65	11.91	11.63	5.88				
29.00	10.65	11.57	11.22	5.88				
35.98	10.70	11.34	10.94	5.87				
53.61	10.48	10.31	9.67	5.89				
62.90	10.64	10.24	9.59	5.88				
68.76	10.13	9.31	8.45	5.93				
75.13	9.84	8.73	7.74	5.97				
79.96	9.52	8.19	7.07	6.01				
89.84	8.91	7.24	5.92	6.11				
100	7.93	6.02	4.42	6.31				

of B/A are shown in Table-5. The input data for this alloy are limited as evident from the work of Amaral & Letcher [25]. Table-6 records the calculated values of B/A for several liquid metals at their melting point. These values are deduced from the sound speed and density data of Blairs and Abbasi [26].

For pure liquid metals (Na, K, Rb, Cs, Pb and Sn), the B/A values obtained from Hartmann method and Ballou rule increase by increasing the temperature whereas Johnson *et al.* method shows a reverse trend.

In the case of K-Rb alloy, the calculated values of B/A from all the methods vary with temperature and composition (Table-2). Again, Hartmann & Ballou methods show an increasing trend with temperature while a decrease is observed in the value of B/A with temperature. In the temperature range 343-518 K, a decrease is observed with increase in the weight fraction of K in the alloy. The decreasing trend in the value of (B/A) obtained from Johnson *et al.* method [17] with increasing weight fraction of K is followed upto 50%. Further increasing

TABLE-4
CALCULATED VALUES OF NON-LINEARITY ACOUSTIC PARAMETER (B/A) FOR Sn-Pb ALLOY AT DIFFERENT TEMPERATURES

Weight % of Sn in alloy	$\alpha \times 10^{-5}$ (K^{-1})	B/A		
		Eqn. 1	Eqn. 2	Eqn. 5
673 K				
10	9.801	6.15	4.58	18.73
20	10.248	6.23	4.68	18.09
30	10.884	6.38	4.87	17.26
45	11.099	6.51	5.02	17.02
60	12.784	6.71	5.27	15.33
873 K				
10	10.172	6.22	4.67	14.9
20	10.407	6.32	4.79	14.67
30	11.043	6.47	4.98	14.06
45	11.299	6.62	5.16	13.85
60	13.344	6.83	5.41	12.39
973 K				
10	10.186	6.25	4.71	13.77
20	10.486	6.36	4.83	13.5
30	11.15	6.52	5.03	12.95
45	11.417	6.68	5.23	12.75
60	13.607	6.89	5.49	11.41

TABLE-5
CALCULATED VALUES OF NON-LINEARITY ACOUSTIC PARAMETER (B/A) OF LIQUID METAL ALLOY Na-K AT DIFFERENT TEMPERATURES

T (K)	Na in alloy (%)	$\alpha \times 10^{-4}$ (K^{-1})	B/A		
			Eqn. 1	Eqn. 2	Eqn. 5
348	15	2.48	6.14	4.57	15.04
308	25	2.49	6.31	4.78	16.47
348	25	2.54	6.35	4.82	14.76
423	25	2.57	6.41	4.9	12.68
308	37	2.55	6.47	4.98	16.17
348	37	2.6	6.52	5.03	14.51
423	37	2.69	6.59	5.12	12.27
308	70	2.61	6.88	5.47	15.88
348	70	2.66	6.93	5.54	14.26
423	70	2.77	7.03	5.66	12.02

weight fraction of K content in alloy, yields reverse trend. B/A values slowly increase at all temperature.

In case of Na-Cs alloy, the B/A values were found to decrease by increasing the Na content at all temperatures. Such trend is observed in the B/A obtained from Hartmann and Ballou relations. Johnson *et al.* [17] values of B/A were found to decrease by increasing the weight percent of sodium at all

TABLE-6
CALCULATED VALUES OF NON-LINEARITY ACOUSTIC PARAMETER (B/A) FOR SEVERAL LIQUID METALS AT THEIR MELTING POINT

Metal	T_b (K)	B/A			Metal	T_b (K)	B/A		
		Eqn. 1	Eqn. 2	Eqn. 5			Eqn. 1	Eqn. 2	Eqn. 5
Li	453.69	4.15	2.14	6.87	W	3695.15	4.99	3.16	13.75
Be	1560.15	3.08	0.82	6.13	Pt	2041.45	5.21	3.43	9.55
Na	370.87	5.88	4.25	7.13	Au	1337.33	5.82	4.17	8.24
Mg	923.15	4.41	2.45	6.20	Hg	234.32	8.49	7.44	5.68
Al	933.47	4.15	2.13	6.56	Tl	577.15	7.94	6.77	6.91
Si	1687.15	4.50	2.56	5.73	Pb	600.61	7.38	6.09	6.93
K	336.53	7.22	5.90	6.82	Bi	544.45	7.98	6.82	6.88
Ca	1115.15	5.29	3.53	5.75	Pu	913.15	10.20	9.54	8.49
Mn	1519.15	6.01	4.41	5.84	Sc	1814.15	4.29	2.31	5.73
Fe	1811.15	4.33	2.36	6.06	Ti	1941.15	4.27	2.28	5.80
Co	1768.15	4.43	2.48	6.11	V	2183.15	4.30	2.32	5.78
Ni	1728.15	4.42	2.47	6.15	Cr	2180.15	4.68	2.78	5.76
Cu	1357.77	4.85	2.99	6.41	Y	1799.15	5.01	3.18	5.75
Zn	692.68	5.44	3.71	7.62	Zr	2128.15	4.69	2.79	5.75
Ga	302.91	5.41	3.68	11.48	Nb	2750.15	4.90	3.05	5.67
Ge	1211.45	5.64	3.96	6.14	Ru	312.45	5.05	3.23	13.54
Se	494.15	10.91	10.41	6.61	Rh	2237.15	5.32	3.57	5.81
Rb	312.46	9.83	9.09	6.97	Pd	1838.15	5.69	4.02	5.92
Sr	1050.15	7.15	5.81	5.76	Hf	189.55	5.83	4.19	17.72
Mo	2896.15	4.10	2.07	5.76	Re	3458.15	5.68	4.00	5.66
Ag	1234.93	5.51	3.80	6.47	Os	3306.15	5.94	4.33	5.67
Cd	594.22	6.34	4.82	7.94	Ir	2739.15	6.06	4.47	5.74
In	429.75	6.19	4.63	9.16	Nd	1289.15	6.43	4.92	6.02
Sn	505.08	5.98	4.37	8.56	Sm	1345.15	7.87	6.69	5.84
Sb	903.78	7.16	5.82	6.35	Eu	1099.15	8.25	7.15	5.87
Te	722.66	13.02	13.00	6.03	Gd	1586.15	6.80	5.38	5.81
Cs	301.59	11.97	11.71	6.93	Tb	1629.15	6.87	5.46	5.80
Ba	1000.15	9.36	8.52	5.75	Dy	1685.15	7.05	5.68	5.77
La	1192.15	6.83	5.41	5.99	Ho	1745.15	7.11	5.75	5.75
Ce	1071.15	7.79	6.58	6.04	Er	1802.15	7.25	5.93	5.73
Pr	1204.15	7.09	5.73	5.99	Lu	1936.15	6.50	5.01	5.76
Yb	1092.15	9.69	8.92	5.86	U	1405.15	6.62	5.16	6.36
Ta	3290.15	4.97	3.13	5.68					

temperatures and further found to increase when weight percent become 50% in the same temperature range.

Similarly, in case of Pb-Sn alloy, B/A values obtained from Hartmann and Ballou increase with increasing temperature. In the range of 673 to 973 K, the addition of tin shows parallel trend however, Johnson *et al.* [17] did not follow the usual trend.

The listed data in Table-5 available for Na-K alloy, the B/A values could only be calculated at 308, 348, 423 and 15, 25, 37 and 70 wt.% of Na in the alloy. The non-linearity acoustic parameter (B/A) values obtained by two previous methods (Johnson method and Hartmann & Ballou rule) were increased by increasing the temperature, whereas the addition of sodium content also increases the B/A at all temperatures. However, Johnson *et al.* method [17] fails to account the behaviour of this alloy also.

Similar to Na-K alloy, with the help of available data for the several liquid metals the B/A values could only be calculated at their melting points as presented in Table-6.

Conclusion

The non-linearity acoustic parameter (B/A) has been calculated for pure liquid metals (Na, K, Rb, Cs, Pb and Sn) four liquid metal alloys (K-Rb, Na-Cs, Pb-Sn and Na-K) and other several liquid metals employing Hartmann method and Ballou rule using density and sound speed data. Satisfactory results were obtained. Johnson *et al.* method does not work for liquid metals and liquid alloys.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this article.

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