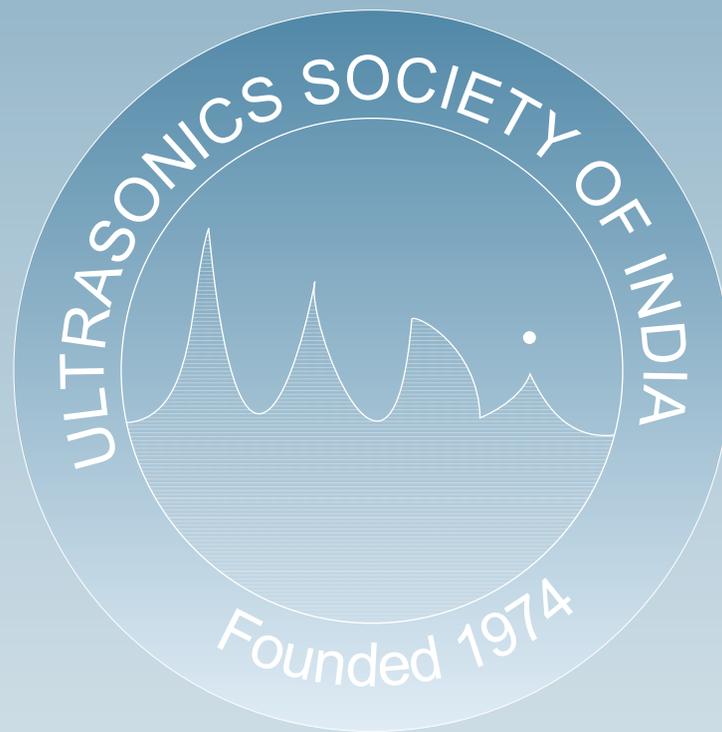
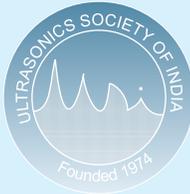


Journal of Pure and Applied
Ultrasonics



Website : www.ultrasonicsindia.org

A Publication of Ultrasonics Society of India



Ultrasonics Society of India

Ultrasonics Society of India established in 1974, is engaged in the promotion of research and diffusion of knowledge concerning the field of ultrasonics and allied areas.

Patrons : Dr. V.N. Bindal
vnbindal@yahoo.co.in

Executive Council :

President

Prof. Vikram Kumar
vkmr47@gmail.com

Vice-President

Dr. V.R. Singh
vrsingh@yahoo.com
Prof. R.R. Yadav
rryadav1@rediffmail.com

General Secretary

Dr. Yudhisther Kumar Yadav
kyadav6659@gmail.com

Joint Secretary

Prof. O.P. Chimankar
opchimankar28@gmail.com

Treasurer

Shri G.S. Lamba
gslamba1957@gmail.com

Publication Secretary

Dr. Devraj Singh
dsingh13@amity.edu

Members

Dr. S.K. Jain
skjainnpl@yahoo.co.in
Dr. (Mrs.) Kirti Soni
2006.kirti@gmail.com
Dr. Ganeswar Nath
ganesw_nath99@yahoo.co.in
Dr. N.R. Pawar
pawarsir1@gmail.com
Prof. S.S. Mathur
sartajmathur@yahoo.co.in
Dr. Janardan Singh
dr_janardansingh@yahoo.com
Dr. Mukesh Chandra
mchandra1948@yahoo.in
Shri G.K. Arora
gyanarora1935@yahoo.co.in
Dr. (Mrs.) Vyoma Bhalla
bhallavyoma@gmail.com
Prof. Pankaj
profpankaj99@gmail.com
Dr. Krishan Lal
krish41ster@gmail.com
(Immediate Past President)

Co-opted members

Dr. (Mrs.) J. Poongodi
poogodinagaraj@gmail.com
Dr. Chandra Prakash
cprakash2014@gmail.com

Special invitees

Dr. S.S.K. Titus
titus@nplindia.org
Mr. Gurmukh Singh
guru6850@gmail.com

Membership of the Society is open to individuals without distinction of sex, race or nationality and to bodies who subscribe to the aims and objectives of the Society.

The membership fee is as follows :

Class of Membership	Subscription (one time)
Honorary Fellow	Nil
Life Fellow / Member	Rs 3000/-
Associate Member	Rs 1000/- (for 5 yrs.)
Corporate Member	Rs 20000/-
Life Fellow / Member (Foreign)	US \$ 150
Corporate Member (Foreign)	US \$ 1000

Membership forms and the relevant information can be downloaded from the website or obtained from :

The General Secretary, Ultrasonics Society of India
CSIR-NPL, Dr. K.S. Krishnan Marg, New Delhi-110012
E-mail : ykyadav@nplindia.org

A Quarterly Publication of Ultrasonics Society of India

Journal of Pure and Applied *Ultrasonics*

No. 1	Volume 41	January-March 2019
-------	-----------	--------------------

Chief Editor : Dr. S.K. Jain
Former Chief Scientist
CSIR-National Physical Laboratory, New Delhi
skjainnpl@yahoo.co.in

Editorial Board :

Prof. S.S. Mathur Formerly Prof., Indian Institute of Technology, New Delhi
sartajmathur@yahoo.co.in

Dr. P. Palanichamy Formerly Scientist, IGCAR, Kalapakkam, Tamil Nadu
ppc9854@gmail.com

Prof. R.R. Yadav Vice-Chancellor, Veer Bahadur Singh Purvanchal
University, Jaunpur, U.P.

Publication Committee :

Dr. Devraj Singh AIAS, Amity University, Noida
Prof. Pankaj Dayalbagh Educational Institute, Agra
Dr. Sanjay Yadav CSIR-National Physical Laboratory, New Delhi
Dr. Y. K. Yadav CSIR-National Physical Laboratory, New Delhi
Dr. (Mrs.) Kirti Soni CSIR-National Physical Laboratory, New Delhi
Dr. (Mrs.) Vyoma Bhalla ASET Delhi, Noida
Shri G. S. Lamba CSIR-National Physical Laboratory, New Delhi
Dr. J. Poongodi Kamraj College, Thoothukudi, Tamil Nadu
Shri Gurmukh Singh Formerly Deputy Director, ERTL (North), New Delhi

SUBSCRIPTION (postage paid)

Single	Rs. 750/-	US\$ 60/-
Annual	Rs. 3000/-	US\$ 250/-
USI members	Free	

ADVERTISEMENT

The Journal offers opportunity of wide and effective publicity for the manufacturer, suppliers of ultrasonic equipment, devices and materials and also for scientific instruments and components. Tariff is as follows :

Back Cover	Rs. 5000/-	US \$ 200/-
Inside Cover	Rs. 3000/-	US \$ 150/-
Full page	Rs. 2000/-	US \$ 100/-
Half page	Rs. 1500/-	US \$ 60/-

Discount of 20% is admissible for 4 successive insertions.

The submission of papers and all other correspondence regarding the Journal may please be addressed to :

Publication Secretary
Journal of Pure and Applied Ultrasonics
C/o Ultrasonics Society of India
CSIR-National Physical Laboratory
Dr. K.S. Krishnan Road, New Delhi-110012
publicationsecretary.usi@gmail.com
www.ultrasonicsindia.org

Journal of Pure and Applied Ultrasonics

VOLUME 41

NUMBER 1

JANUARY-MARCH 2019

CONTENTS

Elastic and thermo-acoustic study of YM intermetallics Aftab Khan, Chandreshvar Prasad Yadav, Dharmendra Kumar Pandey, Dhananjay Singh and Devraj Singh	1
Non-destructive characterization of CaFe_2O_4 -ethylene glycol based nanofluids Alok Kumar Verma, Shakti Pratap Singh, Navneet Yadav, Gaurav Singh and Raja Ram Yadav	9
Study of excess thermoacoustical parameters of THF and strontium hydroxide V. R. Bhat, V.D. Bhandakkar, N.R.Pawar and O.P. Chimankar	14
Estimation of effective Debye temperature of multi component liquid mixtures at 298.15K Charu Kandpal, Arvind Kumar Singh, Ranjan Dey, Vinod Kumar Singh and Devraj Singh	19
Seminar Report State Level Seminar on Innovative Insights in Ultrasonic Methods at Kamaraj College, Thoothukudi-628003	24
Obituary Dr. Devanatha Srinivasan	25
Prof. Erode Subramanian Raja Gopal	26

(Authors have stated that the papers have not been published elsewhere)

Elastic and thermo-acoustic study of YM intermetallics

Aftab Khan¹, Chandreshvar Prasad Yadav^{1,*}, Dharmendra Kumar Pandey¹,
Dhananjay Singh² and Devraj Singh³

¹Department of Physics, P.P.N. (P.G.) College, Kanpur-208001, India

²Department of Chemistry, P.P.N. (P.G.) College, Kanpur-208001, India

³Amity Institute of Applied Sciences, Amity University, Noida-201313, India

*E-mail: cpy99physics@gmail.com

The work involves estimation of elastic, ultrasonic and thermo-physical properties of YM (Y: Yttrium, M=Zn, Cu, Ag) intermetallics at 300 K. Initially, second order elastic constants and elastic modulus of chosen intermetallics are determined in temperature range 300K-1200K under potential model approach. Later, the ultrasonic velocities are calculated using second order elastic constants and densities for wave propagation along $\langle 100 \rangle$, $\langle 110 \rangle$ and $\langle 111 \rangle$ crystallographic directions. Additionally, Debye temperature, specific heat at constant volume, thermal conductivity and thermal relaxation time are also calculated. The analysis reveals that compound YCu incorporates better mechanical and thermal properties than the other two compounds.

Keywords: Intermetallics, elastic properties; ultrasonic velocity; thermal relaxation time; thermal conductivity.

Introduction

Intermetallics are combination of materials of two or more types of metal atoms that differ in structure in comparison to the constituent metals. Binary rare-earth intermetallics have many practical applications due to their superior mechanical, thermo-dynamical, electrical and magnetic properties in comparison to ordinary metals¹⁻³. These materials possess high strength, ductility, melting point, good corrosion resistance and low specific heat which make them important for commercial applications. Rare-earth intermetallics YCu, YZn, and YAg are B2 structured (CsCl-type) crystalline material^{1,2}.

The elastic and mechanical behaviour of YCu, YZn, and YAg intermetallics have been reported in literature which is based on *ab initio* calculation¹. Similarly elastic and mechanical properties of YAg, YCu, YRh intermetallics have also been studied using first principle calculations². The Mechanical, electronic and thermo-dynamic properties of AgRE (RE: Rare earth metals) ScZn, YZn and YAg intermetallics are reported elsewhere⁴⁻⁶. Chen *et al.*⁷ determines intrinsic characteristics of dislocations in ductile YCu and YAg intermetallic by *ab initio* density functional theory. The

survey of literatures indicate that, in spite of technological importance of these rare earth intermetallics, a systematic theoretical study of structural, elastic, ultrasonic and thermo-physical properties of these materials, is still needed for future applications.

In the present work, elastic, ultrasonic and thermo-physical properties of YM (M=Zn, Cu, Ag) intermetallics are illustrated. The second order elastic constants (SOECs) are calculated using potential model approach in temperature range 300-1200 K. After that, we determined the elastic moduli (bulk modulus-*B*, Young's modulus-*Y*, shear modulus-*G*, Lamé modulus- Poisson's ratio- σ) and anisotropy (*A*) of chosen intermetallics. Later, the ultrasonic velocities along three crystallographic directions ($\langle 100 \rangle$, $\langle 110 \rangle$ and $\langle 111 \rangle$) and thermo-physical properties (Debye temperature, specific heat at constant volume, thermal conductivity and thermal relaxation time) have been determined.

Theory

According to Cauchy's definition, the second order strain derivative of elastic energy density provides SOECs of the crystalline material.

$$C_{IJ} = \frac{\partial^2 F}{\partial \eta_I \partial \eta_J}; \text{ I or J } = 1, 2, \dots, 6 \quad (1)$$

Where, F is elastic energy density and η is strain. The free energy density in square terms of strain for cubic structured material can be written as⁸:

$$F = \frac{1}{2!} C_{IJ} \eta_I \eta_J$$

$$F = (1/2) [C_{11} (\eta_{11}^2 + \eta_{22}^2 + \eta_{33}^2) + C_{12} (\eta_{11}\eta_{22} + \eta_{11}\eta_{33} + \eta_{22}\eta_{33}) + 2 C_{44} (\eta_{12}^2 + \eta_{23}^2 + \eta_{31}^2)] \quad (2)$$

Therefore, crystal symmetry of cubic crystals leads three SOECs (C_{11} , C_{12} and C_{44}). The elastic energy density (F) at finite temperature (T) is sum of energy density at 0 K and increase in energy (vibrational part of energy density) with enhancement in temperature⁹ by amount T .

$$F = F^0 + F^V \quad (3)$$

Where, F^0 is the internal energy of unit volume of the crystal when all atoms (ions) are at rest on their lattice point and F^V is the vibrational free energy density. Thus the SOECs can be separated into two parts.

$$C_{IJ} = C_{IJ}^0 + C_{IJ}^V \quad (4)$$

Here, C_{IJ}^0 and C_{IJ}^V are the static and vibrational parts of these SOECs and are equal to second order strain derivative of F^0 and F^V respectively. The quantity C_{IJ}^0 possesses a constant value while C_{IJ}^V varies with temperature as vibrational free energy density depends on temperature. Both these quantities can be determined with the formulations given elsewhere¹⁰. The estimation of SOECs requires only the lattice parameter (a) and non-linearity parameter which is determined under equilibrium condition. The evaluation of bulk modulus (B), Shear modulus (G), Young's modulus (Y), Lamé modulus (λ & μ), Poisson ratio (σ) and anisotropy (A) are directly/indirectly based on SOECs. The expression to compute B , G , Y , σ , λ , μ are given in literature^{11,12}.

There are three types of ultrasonic velocities for each direction of propagation in cubic crystals, one is longitudinal velocity (V_L) and other two are shear velocities (V_{S1} and V_{S2})^{13, 14}. The expressions for velocities are as follows:

Along $\langle 100 \rangle$ crystallographic direction

$$V_L = \left\{ \frac{C_{11}}{d} \right\}^{1/2}; V_{S1} = V_{S2} = \left\{ \frac{C_{44}}{d} \right\}^{1/2} \quad (5a)$$

Along $\langle 111 \rangle$ crystallographic direction

$$V_L = \left\{ \frac{C_{11} + 2C_{12} + 4C_{44}}{3d} \right\}^{1/2}; V_{S1} = V_{S2} = \left\{ \frac{C_{11} - C_{12} + 2C_{44}}{3d} \right\}^{1/2} \quad (5b)$$

Along $\langle 110 \rangle$ crystallographic direction

$$V_L = \left\{ \frac{C_{11} + C_{12} + 2C_{44}}{2d} \right\}^{1/2}; V_{S1} = \left\{ \frac{C_{44}}{d} \right\}^{1/2}; V_{S2} = \left\{ \frac{C_{11} - C_{12}}{d} \right\}^{1/2} \quad (5c)$$

The density of CsCl-structured material can be determined by following expression¹⁵.

$$d = \frac{M_w n}{N_A a^3} \quad (6)$$

Where, M_w , N_A , a and n are molecular weight, Avagadro number, lattice parameter and number of atoms per unit cell, respectively. Debye average velocity is an important parameter in the low temperature physics because it is related to elastic constants through ultrasonic velocities. Expression for Debye average velocity is given in literature¹⁶. Debye temperature (T_D) is indirectly related to elastic constants through Debye average velocity¹⁷.

On the propagation of ultrasonic wave, the thermal distribution of phonon will be disturbed. The time taken for re-establishment of equilibrium of the thermal phonons is called the thermal relaxation time (τ) It is a relation among thermal conductivity, specific heat and Debye average velocity.

Here, τ is thermal relaxation time

$$T = 3k/C_V V_D^2 \quad (7)$$

The quantities k and C_V are the thermal conductivity and specific heat per unit volume of the material. The specific heat per unit volume is function of T_D/T and can be taken from literature^{17,18}. The thermal conductivity of CsCl type material can be determined by following expression¹⁹:

$$k = \frac{\hat{A} M_w T_D^3 \delta^3}{\gamma^2 T n^{2/3}} \quad (8)$$

Where, \hat{A} is a constant; δ^3 is volume per atom; γ is Grüneisen parameter; T_D is the Debye temperature. The constant \hat{A} is function of Grüneisen parameter and is given by following expression.

$$\hat{A} = \frac{2.43 \times 10^{-8}}{1 - 0.514/\gamma + 0.228/\gamma^2}; \gamma = \frac{3(3C_{11}^2 - 4C_{44}^2)}{2(C_{11}^2 + 2C_{44}^2)} \quad (9)$$

Results and Discussion

The lattice parameters (a) of YZn, YCu and YAg intermetallics are 3.579Å, 3.478Å and 3.641Å respectively¹. The non-linearity parameters (b) for the chosen intermetallics are found 0.265Å, 0.305Å, and 0.255 Å respectively under equilibrium condition. These lattice and non-linearity parameters are used for the determination of SOECs of YM intermetallics at 300-1200 K. The obtained SOECs are depicted in Table 1 and Fig. 1. Elastic parameters B , G , Y , σ , λ , μ , B/G , A are also calculated in same temperature range with the expressions given in literature^{11,12} using evaluated SOECs which are presented in Table 1 and Fig 2.

A perusal of Table 1 indicates that our evaluated SOECs, B , Y , G , λ , σ and A of the YM intermetallics at 300K are approximately same as given in literature¹⁻⁷. Thus, calculated SOECs of chosen compounds under

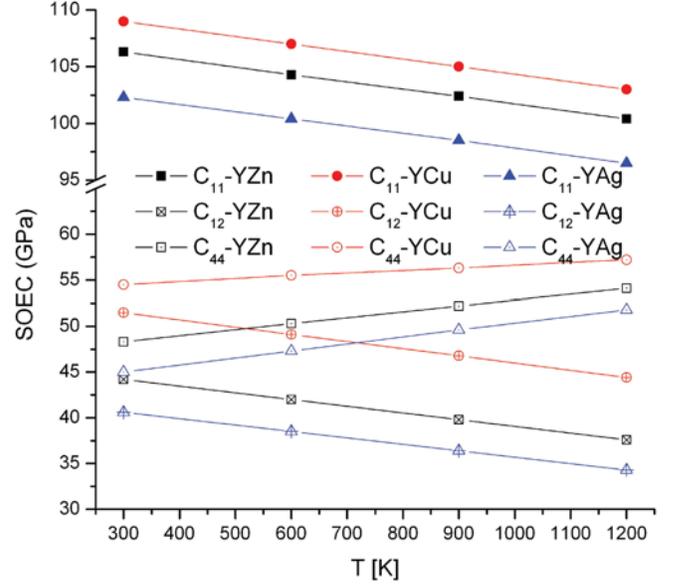


Fig. 1. SOEC vs. temperature of YZn, YCu and YAg

Table 1 – SOECs, elastic modulus and anisotropy of YM intermetallics at 300 K.

Compounds→ Parameters↓	YZn	YCu	YAg
C_{11} (GPa)	106.3 88.8 ¹ , 96.0 ⁵	109.0 121.9 ¹ , 113.6 ²	102.3 99.3 ¹ ,102.5 ² 98.3 ⁴ , 93.8 ⁶
C_{12} (GPa)	44.2 48.8 ¹ , 46.4 ⁵	51.4 49.1 ¹ 48.4 ²	40.6 54.3 ¹ , 56.6 ² 53.5 ⁴ , 48.9 ⁶
C_{44} (GPa)	48.3 48.1 ¹ 48.4 ⁵	54.6 35.7 ¹ 36.8 ²	45.0 38.5 ¹ , 37.8 ² 33.6 ⁴ , 34.4 ⁶
Y (GPa)	98.6 85.9 ¹	102.8 92.7 ¹	94.2 81.0 ¹ ,75.2 ⁴
B (GPa)	64.3 61.61 61.55	69.9 69.81 70.12	60.6 68.51,71.92 68.44,63.96
G (GPa)	39.6 33.8 ¹ , 37.1 ⁵	40.9 35.9 ¹	37.9 31.0 ¹ , 28.6 ⁴ , 29.0 ⁶
λ (GPa)	37.9	42.6	35.3
σ	0.244 0.269 ¹	0.255 0.289 ¹	0.241 0.305 ¹ ,0.317 ⁴
A	1.556 2.405 ¹	1.896 0.980 ¹	1.459 1.711 ¹ , 1.50 ⁴

potential model approach are justified. The electronic configuration of Zn,Cu and Ag are [Ar] 4s²3d¹⁰,[Ar] 4s²3d⁹ and [Kr] 3d¹⁰5s¹ respectively. The configuration shows that Cu has unfilled d sub-shell while Zn and Ag possess completely filled d sub-shell. Therefore, Cu will react more strongly with yttrium to form intermetallics than Zn and Ag. Thus, YCu is more covalent in nature as compared to YZn/Ag intermetallics. Thus, the elastic moduli of YCu intermetallics are found greater than YZn/Ag intermetallics. The compressibility and degree of stiffness of a material are directly co-related with bulk and Young moduli²⁰⁻²². The large bulk and Young moduli of YCu intermetallics in comparison to rest two intermetallics confirm that YCu possesses strong bonding strength, low compressibility, high hardness and large stiffness with respect to YZn/Ag.

Figure 1 indicates that SOECs C_{11} and C_{12} decrease while C_{44} increases with temperature for all the intermetallics under study. Thus, interatomic force in linear/axial direction decreases with temperature while it increases in transverse directions. Therefore, the interatomic forces among the atoms increase from linear to transverse direction with temperature for the chosen intermetallics. The average percent of decay in C_{11} and C_{12} of chosen intermetallics are found ~6% and ~14% respectively within the selected range of temperature while average growth in C_{44} is observed 5%. It is observed from Fig. 2 that the mechanical parameters Y , G , μ , A and G/B increase with temperature while

quantities B , λ and σ decrease with temperature. The decay in C_{11} and C_{12} causes reduction in bulk modulus with temperature while growth in C_{44} is reason behind the increase in shear modulus (G or μ) with temperature (Fig. 2). Young's modulus of $B1$ structured rare-earth monoarsenides is reported to increase with temperature²³.

Similar characteristic of Young's modulus is also obtained for YZn , YCu and YAg rare-earth intermetallics. The enhancement in parameter Y is due to increase in average elastic potential energy with temperature. The decay of B with temperature indicates that compressibility of chosen intermetallics increases with temperature.

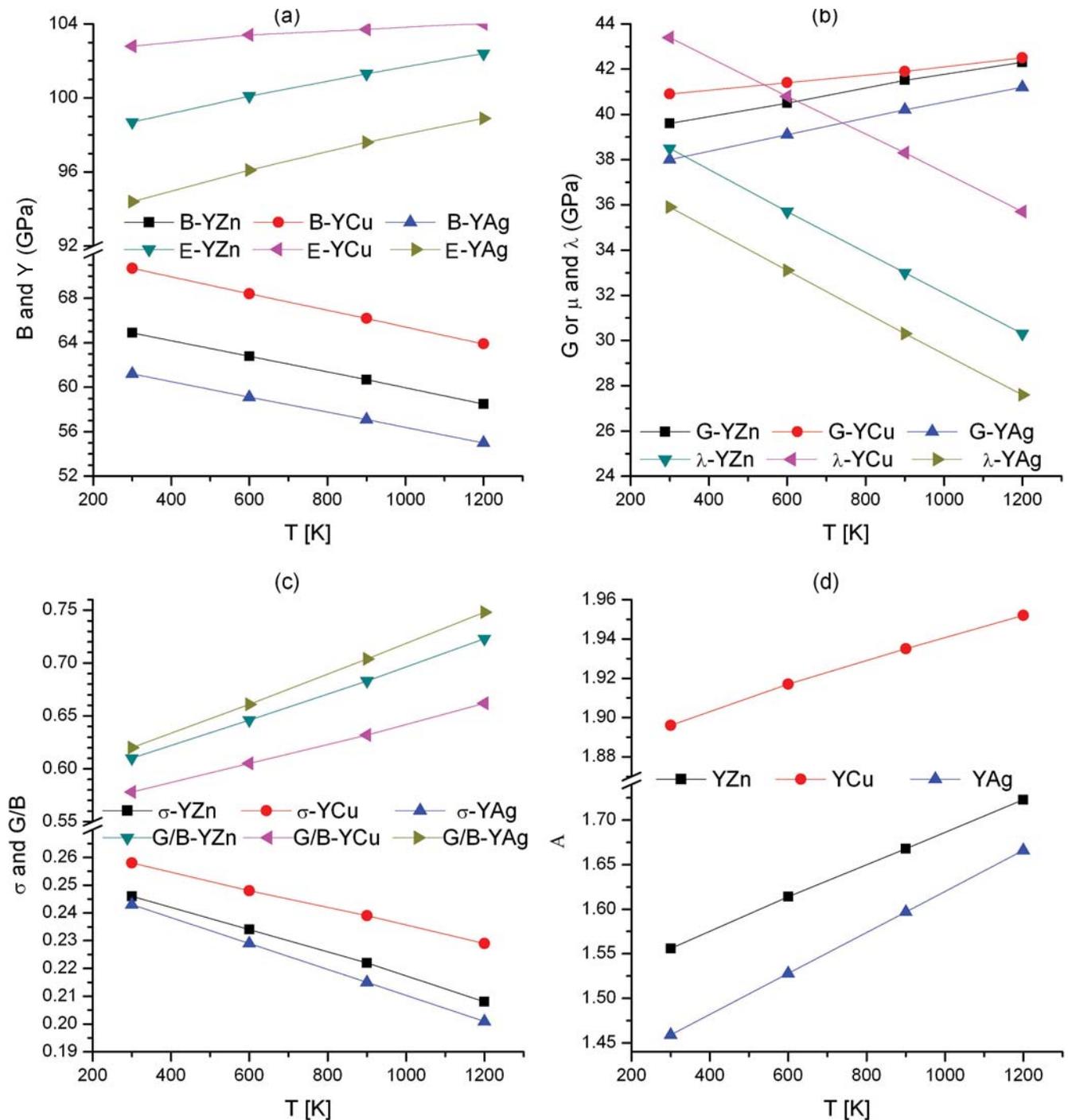


Fig. 2. (a) B and Y vs T ; (b) G and λ vs T ; (c) σ and G/B vs T ; (d) A vs T

If toughness/fracture ratio (G/B) ≤ 0.57 or fracture/toughness ratio (B/G) ≥ 1.75 then material will be ductile^{1,23}. The value of G/B is found to increase linearly with temperature for all the three members of chosen intermetallics which reveals that brittleness or ionic nature of these materials increase with temperature. Since the room temperature values of G/B for YZn, YCu and YAg are 0.61, 0.58 and 0.62 respectively, therefore these intermetallics will show better ductility at lower temperature region. Intermetallic YCu is most ductile as it possesses large covalent nature due to vacant d sub-shell. Intermetallic YAg possesses least ductility among these three intermetallics because it has least covalent nature due to completely filled d sub-shell of Cu and half filled sub-shell. The ionic, covalent and metallic nature of bonding forces among atoms can also be recognized on the basis of Poisson's ratio. The values of Poisson's ratio of complete ionic, covalent and metallic compounds are 0, 0.25 and 0.33 respectively as well as, the bonding forces among atoms are non-central for $\sigma \sim 0-0.25$ and are central for $\sigma \sim 0.25-0.50$ ²³. The room temperature value of σ for YZn, YCu and YAg are 0.246, 0.258 and 0.243 respectively. This shows that bonding forces of YCu among these three intermetallics are more central and covalent in nature. The ionic or non-central bonding temperament of these intermetallics will increase with temperature as σ is found to decrease with temperature. The anisotropic character will increase with temperature as parameter A is found to increase with temperature (Fig. 2).

The densities of YZn, YCu and YAg intermetallics are determined with help of corresponding lattice parameter and Eq. (6) which are 5.588 gm cm⁻³, 6.016 gm cm⁻³ and 6.768 gm cm⁻³ respectively. The densities of materials Y, Zn, Cu and Ag are 4.472 gm cm⁻³, 7.14 gm cm⁻³, 8.960 gm cm⁻³ and 10.5 gm cm⁻³ respectively. Thus the density of chosen intermetallics belongs between the densities of individual materials and YCu has moderate density between YZn and YAg. It indicates that materials Zn, Cu and Ag become lighter after alloying with yttrium.

The ultrasonic velocities are evaluated using Eq. (5) for wave propagation along $\langle 100 \rangle$, $\langle 110 \rangle$ and $\langle 111 \rangle$ crystallographic directions. The calculated velocities are shown in Table 2. As the C_{11} is found to be greater than C_{12} or C_{44} for all materials under study thus the longitudinal ultrasonic velocities are obtained large than that of shear ultrasonic velocity for each direction of

propagation (Table 2). Due to largest value of C_{11} and moderate density for YCu among the materials under study, the longitudinal velocity of ultrasonic wave is obtained maximum for YCu along $\langle 100 \rangle$ direction of propagation. Therefore second order elastic constants are affecting factor towards the ultrasonic velocity in YM intermetallics. Since C_{11} is decreasing while C_{44} is increasing with temperature for these YM intermetallics (Fig. 1) therefore longitudinal velocity will reduce and shear velocity will enhance with temperature in these materials. The ultrasonic wave will propagate with low hindrance and highest speed in YCu along axial direction as the Debye average velocity is obtained maximum for YCu along $\langle 100 \rangle$ direction (Table 2). Since the number of atom involved in the momentum transfer for wave propagation along axial direction is least than the non-axial direction in B2 structured materials therefore due to low energy dissipation and high stiffness along axial direction, the phonon of maximum frequency will propagate with maximum speed. This is reason for maximum V_D of YCu along $\langle 100 \rangle$ direction. Along non-axial direction, number of atom involved in propagation of wave will be large for B2 structured materials, thus density of material will play deciding role for velocity of wave. This means that the average velocity of maximum frequency of phonon will be large along non-axial direction for low density of B2 structured material. Since, YZn and YAg comprise the lowest and highest densities respectively among the chosen

Table 2 – The velocities in (km/s) and thermal relaxation time (τ) in (ps) of YM intermetallics along $\langle 100 \rangle$, $\langle 110 \rangle$ and $\langle 111 \rangle$ directions at 300K.

Compounds→ Parameters↓	Direction	YZn	YCu	YAg
V_L	$\langle 100 \rangle$	4.342	4.257	3.888
V_S		2.912	3.013	2.579
V_D		3.139	3.226	2.786
τ		49.3	72.3	46.7
V_L	$\langle 110 \rangle$	4.658	4.735	4.148
V_{S1}		2.912	3.013	2.579
V_{S2}		2.340	2.188	2.135
V_D		2.823	2.733	2.546
τ		60.9	100.7	55.9
V_L	$\langle 111 \rangle$	4.764	4.884	4.232
V_S		2.545	2.393	2.292
V_D		2.807	2.759	2.526
τ		61.6	98.8	56.8

intermetallics therefore Debye average velocity is found maximum for YZn while minimum for YAg along non-axial directions $\langle 110 \rangle$ and $\langle 111 \rangle$ of propagation (Table 2).

The Debye temperature (T_D) are calculated using the expression given in literature¹⁷. Specific heat at constant volume (C_V) is function of T_D/T and is determined using literature^{17, 18}. Thermal relaxation time (τ), thermal conductivity (k) and Grüneisen parameter (γ) are also determined using Eqs. (7)-(9). The obtained value of T_D , C_V , k and γ are given in Table 3.

Table 3 – The Debye temperature (T_D) in (K), specific heat at constant volume C_V in ($10^5 \text{J/m}^3 \text{K}$), Grüneisen parameters (γ), thermal conductivity (k) in (W/cm K) of YM intermetallics at 300K.

Compounds→ Parameters↓	YZn	YCu	YAg
T_D	336.7	352.5	290.7
C_V	8.606	9.351	8.445
γ	0.928	0.746	0.990
κ	1.394	2.345	1.020

The temperature corresponding to maximum frequency of phonon that can propagate through crystalline media is termed as Debye temperature. Therefore, Debye temperature is directly proportional to Debye frequency ($\nu_D = V_D/\lambda_{\min}$). As V_D is found large for wave propagation along $\langle 100 \rangle$ direction therefore T_D is governed by V_D along this direction. Since V_D has maximum value for YCu therefore Debye temperature is found comparatively large for YCu with respect to YZn/Ag intermetallics. For the calculation of specific heat, the Debye temperature is required. Since T_D depends on V_D which is found to possess relatively large value for YCu than YZn/Ag intermetallics therefore, specific heat at constant volume is received high for YCu with respect to YZn/Ag intermetallics (Table 3).

High thermal conductivity is found for YCu in comparison to YZn/Ag intermetallics (Table 3). The lattice part of thermal conductivity at fixed temperature is proportional to molecular weight (M_w), cube of Debye temperature (T_D^3), atomic volume (δ^3) and γ^{-2} . The molecular weight of YZn, YCu and YAg intermetallics are 154.3 g, 152.45 g and 196.77 g respectively while volume per atom of these compounds are $2.29 \times 10^{-29} \text{m}^3$, $2.10 \times 10^{-29} \text{m}^3$ and $2.39 \times 10^{-29} \text{m}^3$ respectively.

The value of T_D^3/γ^3 is received large for YCu in comparison to YZn/Ag. Yet the molecular weight and volume per atom is maximum for YAg but thermal conductivity is maximum for YCu. Since high phonon frequency and maximum energy/momentum transfer are associated with a material having high Debye temperature and low Grüneisen parameter. Thus the thermal conductivity of these YM intermetallics are predominantly affected by Debye temperature and Grüneisen parameter.

The thermal relaxation time (τ) is directly proportional to thermal conductivity and inversely proportional to specific heat and square of Debye average velocity. The τ is obtained minimum along axial directions $\langle 100 \rangle$ and maximum along non-axial direction $\langle 110 \rangle$ and $\langle 111 \rangle$ in chosen YM intermetallics. The maximum value of V_D in chosen intermetallics along axial direction is reason for minimum value of τ along this direction. Hence, the direction dependent thermal relaxation time is highly affected with the Debye average velocity. Along a particular direction of propagation of wave, the thermal conductivities of YM intermetallics are dominating factor towards the thermal relaxation as for each directions of propagation of ultrasonic waves, τ received minimum in YAg and maximum in YCu intermetallics. The value of τ in chosen YM intermetallics is found in between 46ps to 100ps. The value of τ for metals/rare-earth metals/semi-metals/alloys and semiconductors are reported to be $<16\text{ps}$ and $>16\text{ps}$ respectively^{10,24-26}. The reported value of τ for B1 structured rare-earth monoarsenides^{23/} polonides²⁷ are in range 7ps-16ps. Therefore rare earth compounds can have thermal relaxation time up to 100ps depending upon their thermal conductivity. Furthermore, these YM compounds possess high thermal relaxation time in comparison to metals/alloys and semiconductors. Since, the ultrasonic attenuation at high temperature is caused by phonon-phonon interaction and thermo-elastic relaxation mechanism, which is proportional to thermal relaxation time/thermal conductivity²⁷⁻²⁹ therefore these YM intermetallics shall have relatively high loss of ultrasonic energy in comparison to loss in semi-conductors.

Conclusions

On the basis of above discussion we conclude that our potential model approach for evaluation of SOECs is justified for YM intermetallics. Significant high value of bulk and Young moduli of YCu intermetallics in

comparison to YZn/Ag intermetallics substantiate that YCu possesses strong bonding strength, low compressibility, high hardness and large stiffness with respect to YZn/Ag. As the physical quantities C_{11} , C_{12} , B , λ and σ are found to decay with temperature while C_{44} , Y , G , μ and A are received to enhance with temperature therefore brittleness or ionic nature of these materials increase with temperature. Hence, these YM intermetallics will represent superior ductility at lower temperature region. The reduction in density of materials Zn, Cu and Ag is found after alloying with Yttrium. Second order elastic constants play dominating role towards the ultrasonic velocity in YM intermetallics. Elastic moduli, ultrasonic velocity, thermal conductivity and thermal relaxation time of YCu intermetallics are found greater than YZn/Ag intermetallics thus elastic, ultrasonic and thermal behaviour of YCu intermetallics will be better than YZn/Ag intermetallics. The obtained results provide a good understanding of elastic, mechanical, thermal and ultrasonic properties of chosen YM intermetallics that may be used for further investigation and also in material manufacturing industries.

Acknowledgments

Authors express their high gratitude to Prof. R.R. Yadav, Vice Chancellor, V.B.S. Purvanchal University, Jaunpur and Dr. Satish Chandra, P.P.N. (P.G.) College, Kanpur for their valuable discussion and support during the course of manuscript preparation.

References

- 1 **Chouhan S. S., Soni P., Pagare G., Sanyal S. P. and Rajagopalan M.**, Ab-initio study of electronic and elastic properties of B2-type ductile YM (M=Cu, Zn and Ag) intermetallics, *Physica B* **406** (2011) 339-344.
- 2 **Wu Y., Hu W. and Han S.**, First principle calculation of the elastic constants, the electronic density of the states and the ductility mechanism of the intermetallic compounds: YAg, YCu and YRh, *Physica B* **403** (2008) 3792-3797.
- 3 **Wang R., Wang S. and Xiaozhi Wu.**, On third-order elastic constants for ductile rare-earth intermetallic compounds: A first-principles study, *Intermetallics* **18** (2010) 1653-1658.
- 4 **Tao X., Chen H., Li X., Ouyang Y. and Liao S.**, The Mechanical, electronic structure and thermodynamic properties of B2 based AgRE studied from first principles, *Phys. Scr.* **83** (2011) 045301.
- 5 **Soyalp F., Yavuz M. and Yalçın Z.**, Ab initio investigations of phonons and thermodynamic properties of ScZn and YZn in the B2 structure, *Comput. Mater. Sci.* **77** (2013) 72-80.
- 6 **Pu C., Zhou D., Song Y., Wang, Z., Zhang F. and Lu Z.**, Phase transition and thermodynamic properties of YAg alloy from first-principles calculations, *Comput. Mater. Sci.* **102** (2015) 21-26.
- 7 **Chen Q., Ji M., Wang C.Z., Ho K.M. and Biner S.B.**, Core properties of dislocations in YCu and YAg B2 intermetallic compounds, *Intermetallics* **18** (2010) 312-318.
- 8 **Brugger K.**, Thermodynamics definition of Higher Order Elastic coefficients, *Phys. Rev.* **133**(6A) (1964) A1611.
- 9 **Yadav R.R. and Singh D.**, Ultrasonic attenuation in lanthanum monochalcogenides, *J. Phys. Soc. Jpn.* **70** (2001) 1825-1832.
- 10 **Yadav R.R. and Pandey D.K.**, Size dependent acoustical properties of bcc metal, *Acta Phys. Pol. A* **107** (2005) 933-946.
- 11 **Moakafi M., Khenata R., Bouhemadou A., Semari F., Reshak A.H. and Rabah M.**, Elastic, electronic and optical properties of cubic antiperovskites SbNCa3 and BiNCa3, *Comput. Mat. Sci.* **46** (2009) 1051-1057.
- 12 **Kalarasse F., Kalarasse L., Bennecer B. and Mellouki A.**, Elastic and Electronic properties of Li2ZnFe, *Comput. Mat. Sci.* **47** (2010) 869-874.
- 13 **Kakani S.L. and Hemrajani C.**, *Solid State Physics*, Sultan Chand & Sons, New Delhi India, (2005).
- 14 **Truell R., Elbaum C. and Chick B. B.**, *Ultrasonic Methods in Solid State Physics*, Academic Press, New York, (1969).
- 15 **Pillai S. O.**, *Solid State physics: Crystal Physics*, 7th Ed., New Age International Publisher, (2005) 100-111.
- 16 **Pandey D. K. and Pandey S.**, in *Acoustic Waves: Ultrasonic: a technique of material characterization*, Eds: Don W. Dissanayake, Scio Publisher, Scio Croatia, (2010) 397-430.
- 17 **Kittel C.**, *Introduction to Solid State Physics*, 7th edition John Wiley & Sons, Inc. Singapore New York, (2003) 24.
- 18 **Gray D. E.**, *AIP Handbook, IIIrd edition*. McGraw Hill Co. Inc., New York, (1956) 4-44, 4-57.
- 19 **Morelli D. T. and Slack G. A.**, *High Lattice Thermal Conductivity Solids in: High Thermal Conductivity of*

- Materials*, Eds: by Shinde SL, Goela J. XVIII Ed. Springer, (2006) 37-68.
- 20 **Pandey D. K., Singh D., Bhalla V., Tripathi S. and Yadav R. R.**, Temperature dependent elastic and ultrasonic properties of Yt terbium mononictides, *Indian J. Pure Appl. Phys.* **52** (2014) 330-336.
- 21 **Gaith M. and Alhayek I.**, Correlations between overall elastic stiffness, bulk modulus and interatomic distance in anisotropic materials: semiconductors, *Rev. Adv. Mater. Sci.* **21** (2009) 183-191.
- 22 **Pugh S. F.**, Relations between the elastic moduli and the plastic properties of polycrystalline pure metals, *Philos. Mag.* **45** (1954) 823- 843.
- 23 **Bhalla V., Singh D., Jain S. K. and Kumar R.**, Ultrasonic attenuation in rare-earth monoarsenides, *Pramana* **86** (2016) 1355-1367.
- 24 **Yadawa P. K., Singh D., Pandey D. K. and Yadav R. R.**, Elastic and acoustic properties of heavy rare-earth metals, *The Open Acoustic Journal* **2** (2009) 61-67.
- 25 **Yadav A. K., Yadav R. R., Pandey D. K. and Singh D.**, Ultrasonic study of fission products precipitated in the nuclear field, *Mat. Lett.*, **62** (2008) 3258-3261.
- 26 **Pandey D. K., Singh D. and Yadav R. R.**, Ultrasonic wave propagation in IIIrd group nitrides, *Appl. Acoust.* (2007) 766-777.
- 27 **Singh D., Bhalla V., Bala J. and Wadhwa S.**, Ultrasonic investigations on polonides of Ba, Ca, and Pb, *Z. Naturforsch. A* **72** (2017) 977-983.
- 28 **Yadav C.P., Pandey D.K. and Singh D.**, Ultrasonic study of Laves compounds ScOs₂ and YO₂, *Indian J. Phys.* (2019). <http://doi.org/10.1007/s12648-019-01389-8>.
- 29 **Jyoti B., Singh D., Kanshik S., Bhalla V., Wadhwa S. and Pandey D.K.**, Ultrasonic attenuation in yttrium monochalcogenides, *J. Pure Appl. Ultrason.* **40** (2018) 93-99.

Non-destructive characterization of CaFe₂O₄-ethylene glycol based nanofluids

Alok Kumar Verma*, Shakti Pratap Singh, Navneet Yadav, Gaurav Singh and Raja Ram Yadav

Department of Physics, University of Allahabad, Allahabad-211002, India

*E-mail: alok9369@gmail.com

In the present work, CaFe₂O₄ nanoparticles have been synthesized using sol-gel method. The prepared nanoparticles have been characterized using X-Ray diffraction (XRD) and transmission electron microscopy (TEM). CaFe₂O₄ nanoparticles have been dispersed in the ethylene glycol using high power ultrasonicator to prepare CaFe₂O₄-ethylene glycol based nanofluids of different volume fraction (*viz.* 0.1 vol%, 0.2 vol%, 0.5 vol%, and 1.0 vol%). Particle size distribution of synthesized nanofluids has been investigated by acoustical particle sizer (APS-100). Frequency and concentration dependent ultrasonic attenuations in the nanofluids have been measured by APS-100. A comparative study of the results, obtained by XRD, TEM and APS, has been done. Various factors responsible for ultrasonic attenuation and their correlation have been made to understand the inter-particle and intra-particle interactions.

Keywords: Nanofluids, ultrasonic attenuation, acoustical particle sizer, particle size distribution.

Introduction

Nanoparticles have attracted research community's attention extensively because of their superior physiochemical properties, compared to their bulk part, which depend on their size, shape, and morphology¹. Nanofluids are suspension of nano-sized particles in conventional fluids such as water, ethylene glycol, glycerol and engine oil. Acoustical and thermal properties of base fluids got enhanced after nanoparticle loading in base fluids. Due to exceptional properties, nanofluids have potential applications in the field of automotive, heat transfer management, electronic cooling, and biotechnology².

Spinel-type ferrites provide better thermal and chemical stability under ambient operating condition³. In recent times, ferrites materials of different shape and size have been studied because of their possible applications in magnetic behaviour, data storage system, gas sensor, and photocatalysis³⁻⁴. Orthorhombic nanostructured CaFe₂O₄ nanoparticles are of great importance because the constituting metal ions at tetrahedral and octahedral site, *viz.* Ca²⁺ (d⁰), Fe³⁺ (d⁵) respectively, exhibit zero crystal field stabilization

energy⁴. In the present work, we have synthesized CaFe₂O₄ nanoparticles-ethylene glycol nanofluids of different volume fraction and their ultrasonic investigations have been performed.

Acoustics have opennew possibilities for non-destructive testing (NDT) of highly sophisticated industrial as well as biomedical materials⁵. Reliability and consistency of the materials can be gauged not only after production but also throughout the processing of the material by means of ultrasonic NDT⁶. For this drive, high frequency sound wave is extensively applied not only in industrial sector but also in medical sectors⁷. Ultrasonic attenuation of the wave in the medium provides an understanding of other physical properties of materials such as elastic constants, thermal conductivity, structural inhomogeneity, and dislocation that can predictthe potential usage of the materials for suitable applications⁸. Further, frequency dependent ultrasonic absorption may be utilized for detection of microstructure, grain size and extensional rheology of the materials⁹. In the present work acoustical spectroscopic technique has been applied to determine particle size distribution of nanoparticles in CaFe₂O₄ nanofluids. Frequency and concentration dependent

ultrasonic attenuations in the nanofluids have also been measured.

Materials and Methods

Synthesis

CaFe₂O₄ nanoparticles were prepared by chemical route via sol-gel method. The precursors used in the synthesis process were calcium chloride (CaCl₂) and ferric nitrate nonahydrate (Fe(NO₃)₃·9H₂O). The required weights of calcium chloride and ferric nitrate were taken in 1:2 molar ratios respectively and were dissolved separately in 100 ml of distilled water. The solutions were magnetically stirred for 3h and then both were mixed to each other. The obtained solution was heated at 80°C and stirred vigorously for 3 h. After that, 50 ml aqueous solution of the citric acid was added in the mixed solution and stirring was continued for another 3 h. The precipitation was obtained by changing pH of the solution. Obtained precipitate was dried and annealed at 400°C for 3 h which resulted in the formation of CaFe₂O₄ powder. The fabricated nanoparticles were dispersed in ethylene glycol using a probe sonicator for 20 minutes. We have prepared CaFe₂O₄-ethylene glycol nanofluids by dispersing 0.1 vol %, 0.2 vol %, 0.5 vol % and 1.0 vol % CaFe₂O₄ nanoparticles into ethylene glycol. Pure ethylene glycol has been taken as the reference sample.

Characterization

For structural analysis, powder sample of synthesized CaFe₂O₄ was characterized using X-ray diffractometer (X-Pert PRO) having monochromatic Cu-K_α radiation of wave length 1.5406 Å. To analyze the particle size and morphology of the calcium ferrite nanoparticles, transmission electron microscopy (TEM) was used. The powder sample of CaFe₂O₄ was dispersed in distilled water for TEM measurement.

Measurement techniques

The particle size distribution of dispersed CaFe₂O₄ in ethylene glycol and frequency dependent ultrasonic attenuations in different samples of nanofluids were analyzed by acoustical particle sizer (APS-100).

There is no need of sample dilution for APS measurements. By this technique, ultrasonic attenuations were measured at different places of the medium in the frequency range 1-100 MHz. Particle size distribution

of suspended particles in the base fluid is determined using these attenuations data with the help of a software based on Carhart and Epstein theory¹⁰. The APS can measure size of particles in the range 10 nm - 1 mm. In this technique, ultrasonic velocity and echo amplitude are measured by a specially designed reflector which can compare the reflected and transmitted ultrasonic wave using the same transducer. For this, most precise motion stage is used to determine the fluid path span at various stage. This process allows the phenomenon of coherent tone bursts. To achieve high accuracy, resolution, and reproducibility, the APS can be used in the mode of optimal signal averaging with the help of many repetitive measurements. It advances the precise measurement of reflector position by computing ultrasonic attenuations and fixing possible position errors at the same time¹¹.

Results and Discussion

Figure 1 displays the X-Ray diffraction pattern (XRD) of CaFe₂O₄ nanoparticles. The XRD patterns are indexed with JCPDS Card No. 721199. The XRD profile confirms the formation of CaFe₂O₄ nanostructures.

The observed peaks at $2\theta = 19.16^\circ, 25.52^\circ, 33.30^\circ, 33.57^\circ, 35.49^\circ, 40.32^\circ, 42.80^\circ, 49.70^\circ, 52.29^\circ, 54.30^\circ, 56.34^\circ, 61.30^\circ, \text{ and } 71.70^\circ$ correspond to (200), (220), (040), (320), (201), (131), (311), (401), (440), (260), (431), (521) and (322) planes respectively. The observed patterns belong to an orthorhombic structure with space group, *Pnma*(62). The average crystallite size (*D*) is estimated using the Scherer formula given by Eq. (1).

$$D = \frac{0.9\lambda}{\beta \cos \theta} \quad (1)$$

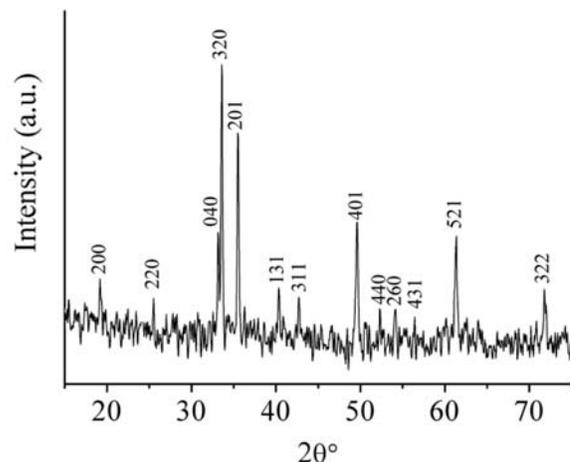


Fig. 1. XRD pattern of CaFe₂O₄ nanoparticles

Where λ is the wavelength of the $\text{CuK}\alpha 1$ (1.54 \AA), β is the full-width at half-maximum (FWHM) of diffraction peak measured in radian, θ is the Bragg angle. The average crystalline size of CaFe_2O_4 nanoparticles, calculated corresponding to each peak, was found $\sim 34 \text{ nm}$.

TEM image and corresponding histogram, representing size distribution of CaFe_2O_4 nanoparticles, are shown in Fig. 2(a) and size distribution of the nanoparticles are in the range of 22-54 nm with maximum particles 2(b) respectively. From Fig. 2(a), it is clear that particles are distributed uniformly but their size distribution is not uniform. Most of the particles have spherical shape. Figure 2(b) indicates that are of size $\sim 37 \text{ nm}$. Particle size profile in nanofluids can be better analyzed by using APS technique because in TEM only a small portion of the sample is used while in APS whole profile of nanofluids can be analyzed. The PSD, by APS 100, of CaFe_2O_4 nanoparticles (1.0 Vol %) in ethylene glycol has been presented by Figure 3. It shows that suspended particles are in the range of 28-60 nm with maximum particles are of the size $\sim 40 \text{ nm}$. Generally, crystalline size obtained by XRD is found to be slightly smaller than that determined by TEM¹² and APS. In XRD we get lengths of coherence without considering grain boundaries. Lattice dislocation and twinning defects cause microstraining of the lattice points which results in broadening of peaks. Spontaneous arrangement of lattice atoms through nucleation is the main reason behind such defects¹². The size measured by APS comes, to some extent, greater than that measured by TEM due to agglomeration of particles in the base matrix.

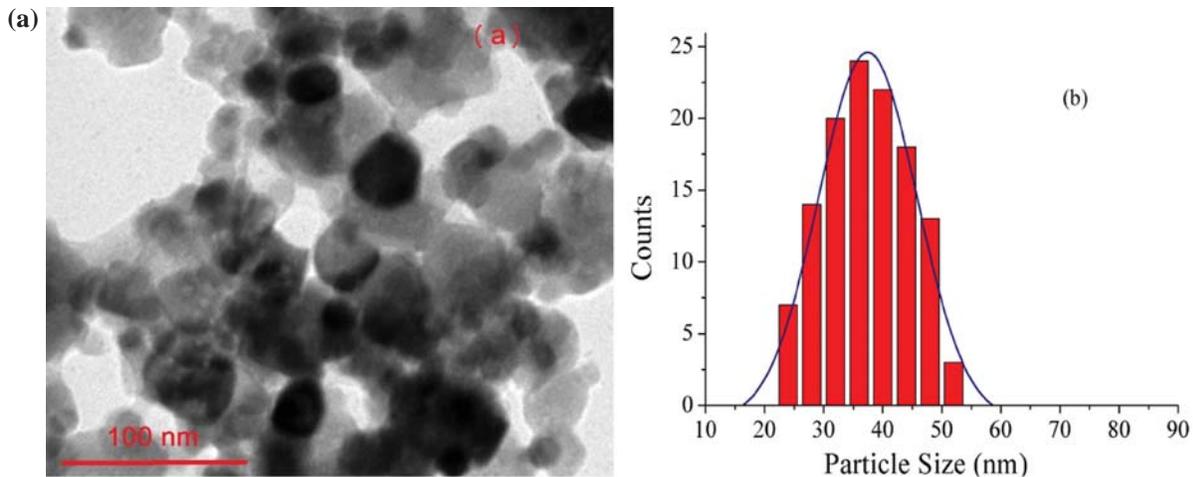


Fig. 2. (a) TEM image and (b) Histogram showing the particle size distributions of CaFe_2O_4 nanoparticles.

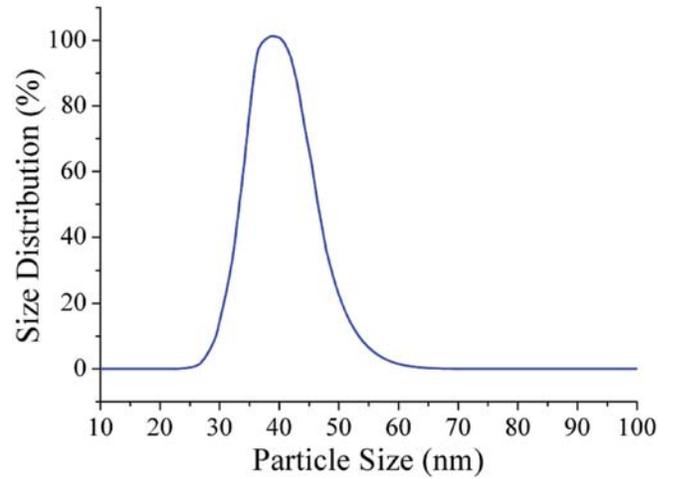


Fig. 3. Normalized particle size distribution of CaFe_2O_4 nanoparticles in ethylene glycol.

The behaviour of ultrasonic attenuation with frequency is shown in Fig. 4. From Fig. 4, it is clear that the attenuation increases nonlinearly with the frequency at all concentration of the nanoparticles in ethylene glycol. Also, the attenuation is minimum for pure ethylene glycol and it increases as concentration of CaFe_2O_4 nanoparticles in ethylene glycol increases. Ultrasonic attenuation is greatly sensitive to the local environment of the medium. The total ultrasonic attenuation in nanofluids can be express by Eq. (2)¹³.

$$\alpha = \alpha_m + \alpha_b + \alpha_{mb} \quad (2)$$

Where α_m and α_b represent the attenuation due to CaFe_2O_4 nanoparticles and base fluids respectively. α_{mb} is the modification to the final value of α due to the

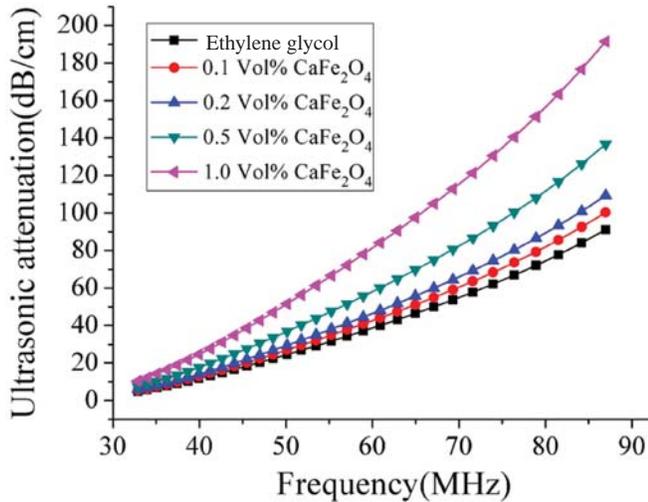


Fig. 4. Ultrasonic attenuation vs. frequency CaFe₂O₄ nanoparticles-ethylene glycol nanofluids.

interaction between nanoparticles and base-fluids molecules in conjunction with modified thermo-physical properties of nanofluids.

Biwa *et al.*¹⁴ studied the sound absorption in mm sized particles liquid suspensions in which they reported significant particles-reinforced attenuation due to scattering of the wave. But the observed attenuation due to scattering loss is insignificant in nano-sized CaFe₂O₄ particles liquid suspensions since the wavelength of the wave is not comparable to the size of particles. From the graph (Fig. 4), it is clear that, for all volume fractions of CaFe₂O₄ nanoparticles, the attenuations in the nanoparticles-liquid suspension are nearly same as for ethylene glycol upto 38 MHz. After this frequency, the attenuation increases rapidly with frequency as well as with concentration of nanoparticle in ethylene glycol.

The present behaviour of the nanofluids with frequency and particle volume fraction can be explained using the concept of the viscous wavelength ($\lambda_v = \sqrt{2\eta / (\sigma\omega)}$) and thermal wavelength ($\lambda_t = \sqrt{2K / (\rho C\omega)}$); Where η is the viscosity of the base fluids and K, ρ and C are thermal conductivity, density, and specific heat of the suspended particles. ω is the frequency of the sound wave¹⁵. For Lower frequency ($f < 38$ MHz), the viscous wavelength is comparable to the particle size of nanoparticles. Hence, for lower frequency, viscous loss plays dominating role to ultrasonic attenuation. For higher frequency ($f > 38$ MHz), thermal wavelength becomes comparable to size of suspended particles. Hence, for higher frequency, thermal loss and viscous drag loss becomes prominent.

Thermal loss is initiated due to the temperature gradient, formed because of the propagation of sound wave through the medium¹⁶. A polynomial fit analysis to sound absorption indicates that the attenuation in particle-fluid suspensions can be expressed as $\alpha = \sum \alpha_i f^i$. For $i = 0$, the coefficient of frequency is equivalent to absorption in ethylene glycol matrix. While for $i \neq 0$, the coefficient of frequency depends on size of suspended particles. With frequency, the effective viscosity of a base matrix decreases continuously towards zero. This indicates that the viscous drag losses are the dominant cause for the sound absorption in this region.

Conclusions

We have successfully synthesized CaFe₂O₄ nanoparticles-ethylene glycol nanofluids using sol-gel and ultrasonication method. XRD characterization confirms the formation of CaFe₂O₄ nanoparticles. The crystalline size obtained by XRD method is less than the particle size obtained by TEM and APS measurements. The size measured by APS comes, to some extent, greater than that measured by TEM due to agglomeration of particles in the base matrix. Ultrasonic attenuation increases nonlinearly with frequency and concentration of nanoparticles in base fluids. For lower frequency, viscous loss and, for higher frequency thermal loss and viscous drag loss along with concentration of nanoparticles become dominating factors for ultrasonic attenuation. The study demonstrates the potential application of CaFe₂O₄ nanofluids for industrial and biomedical applications.

Acknowledgments

The authors acknowledge the financial support provided by the University Grants Commission, India.

References

1. **Khan I., Saeed K. and Khan I.**, Nanoparticles: Properties, applications and toxicities, *Arab. J. Chem.* (2017) 1-24 (In Press).
2. **Mashali F., Languri E. M., Davidson J., Kern D., Johnson W., Nawaj K. and Cunningham G.**, Thermo-physical properties of diamond nanofluids: A review, *Int. J. Heat Mass Transf.* **129** (2019) 1123-1135.
3. **Singh A., Singh S., Tandon P., Yadav B.C. and Yadav R.R.**, Synthesis, characterization and performance of

- zinc ferrite nanorods for room temperature sensing applications, *J. Alloy. Compd.* **618** (2015) 475-483.
- 4 **Yadav A., Choudhary P., Saxena P., Patel S., Rai V. N., Varshney M. D. and Mishra A.**, Size dependent strain analysis of CaFe_2O_4 nano ceramics, *AIP Conf. Proc., Nat. Conf. on Physics and Chemistry of Materials, Indore, India* (2018) 1-4.
 - 5 **Smetana M., Chudacik V. Konar R. and Mician M.**, Austenitic biomaterial cracks evaluation by advanced nondestructive techniques, *Adv. Elect. and Electron. Eng.* **15**(2) (2017) 169-175.
 - 6 **Yadav R. R. and Singh D.**, Behaviour of ultrasonic attenuation in intermetallics, *Intermetallics.* **9** (2001) 189-194.
 - 7 **Carovac A., Smajlovic F. and Junuzovic D.**, Application of ultrasound in medicine, *Acta Inform Med.* **19**(3) (2011) 168-171.
 - 8 **Singh D., Tripathi S., Pandey D. K., Gupta A. K., Singh D. K. and Kumar J.**, Ultrasonic wave propagation in semimetallic single crystals, *Mod. Phys. Lett.* **B25** (2011) 2377-2390.
 - 9 **Singh D., Kaushik S., Tripathi S., Bhalla V. and Gupta A. K.**, Temperature-dependent elastic and ultrasonic properties of berkelium mononictides, *Arab. J. Sci. Eng.* **39** (2014), 485-494.
 - 10 **Epstein P. S. and Carhart R. R.**, The absorption of sound in suspensions and emulsions. I. water fog in air, *J. Acoust. Soc. Am.* **25** (1953) 553-565.
 - 11 **Wang Y. and Forssberg E.**, Production of carbonate and silica nano-particles in stirred bead milling, *Int. J. Miner. Process.* **81** (2006) 1-14.
 - 12 **Deepika and Singh H.**, Study of size distribution in nanostructured $\text{Se}_{58}\text{Ge}_{39}\text{Pb}_3$ glass using various characterization methods, *Mapan* **33**(2) (2018) 165-168.
 - 13 **Yadav R. R., Mishra G., Yadawa P. K., Kor S. K., Gupta A. K., Raj B. and Jayakumar T.** Ultrasonic properties of nanoparticles-liquid suspensions, *Ultrasonics* **48** (2008) 591-593.
 - 14 **Biwa S., Watanabe Y., Motogi S. and Ohno N.**, Analysis of ultrasonic attenuation in particle-reinforced plastics by a differential scheme, *Ultrasonics* **43**(1) (2004) 5.
 - 15 **Pandey V., Mishra G., Verma S. K., Wan M. and Yadav R. R.**, Synthesis and ultrasonic investigations of CuO-PVA nanofluids, *Mat. Sci. Applicat.* **3** (2012) 664-668.
 - 16 **Singh D. K., Pandey D. K., Yadav R. R. and Singh D.**, A study of ZnO nanoparticles and ZnO-EG nanofluids, *J. Exp. Nanosci.* **8**(5) (2013) 731-741.

Study of excess thermoacoustical parameters of THF and strontium hydroxide

V. R. Bhat^{1,*}, V.D. Bhandakkar², N.R. Pawar³ and O.P. Chimankar⁴

¹Department of Physics, Lokmanya Tilak College, Wani-445304, India

²Department of Electronics, Anand Niketan College, Warora-442914, India

³Department of Physics, Arts, Commerce & Science College, Maregaon-445303, India

⁴Department of Physics, RTM Nagpur University, Nagpur-440 033, India

*E-mail: vinayak.bhat@gmail.com

The ultrasonic velocity density and viscosity of binary liquid mixture of tetrahydrofuran and strontium hydroxide (solvent) have been measured over the entire range of compositions at the temperatures 298K, 303K, 308K at fixed and frequency 7 MHz. The observed basic experimental data have been utilized to evaluate some of the derived thermoacoustic parameters such as adiabatic compressibility, molar volume relaxation time. The behavior of these derived parameters and their excess values of, adiabatic compressibility, molar volume relaxation time were evaluated with composition of the mixture and have been discussed in terms of nature and strength of molecular interactions between the constituents. Broad classification study also helps to understand the molecular interaction types.

Keywords: Uracil, thermoacoustic parameters, ultrasonic absorption, IDR

Introduction

In the recent years, ultrasonic technique has become more powerful tool in providing information regarding the behavior of liquids and solids owing to its ability of characterising physiochemical behavior of the medium¹⁻³. Ultrasonic velocity measurements are useful in the field of interactions and structural aspect studies, for characterizing the physico-chemical behavior of liquid mixtures⁴⁻⁷. Ultrasonic measurements of acoustic parameters with change in mole fraction give an insight in to the molecular process⁸⁻¹⁰. This type of study has increased in recent years due to industrial applications. Many researchers have undertaken these studies qualitatively through ultrasonic velocity, density adiabatic compressibility and viscosity measurements¹¹⁻¹⁸.

Materials and Methods

The liquids used were of BDH analar grade and were redistilled in the laboratory. In this study the measurements have been made at temperatures 298K, 303K and 308K. The temperature of the liquid mixture

was kept constant by the use of thermostat U-10 with ± 0.01 K accuracy. Density measurement was carried out by using hydrostatic sinker method with an accuracy $\pm 0.01\%$. A monopan electrical balance of least count as 0.0001 gm was used to record change in plunger weight dipped in the solutions correct to fourth place of decimal. Ultrasonic velocity measurements were made with an ultrasonic multi-frequency interferometer at frequency 7 MHz with an accuracy of $\pm 0.1\%$.

Results and Discussion

Table 1 shows the experimentally measured values of ultrasonic velocity (U), density (ρ), viscosity (η) and the calculated values of adiabatic compressibility (β_a), isothermal compressibility (β_i), w.r.t. concentration (vol%) of THF in aqueous strontium hydroxide (0.1N) respectively at temperatures 298.15K, 303.15K, 308.15K and at fixed frequency 7 MHz.

Table 2 shows calculated molar volume (V_m), relaxation time (τ), excess relaxation time (τ^E), excess adiabatic compressibility (β_a^E), excess molar volume (V_m^E) w.r. to concentration (vol. %) of THF in aqueous

Table 1. Thermoacoustic parameters w.r.t.% Volume of THF +Aqueous Sr(OH)₂ 8 H₂O.

Vol. %	(U) m/s	ρ Kg/m ³	$\eta c p$	$\beta\alpha^*10^{-10}$ m ² N ⁻¹	βr^*10^{-10} m ² N ⁻¹
T=298.15K					
0	1450	1014	0.8268	4.687	5.625
10	1519	1008	0.8241	4.301	5.161
50	1605	982	1.2006	3.951	4.741
80	1428	923	0.8152	5.316	6.379
100	1275	881	0.5012	6.979	8.375
T=303.15K					
0	1420	1011	0.717	4.903	5.883
10	1484	1005	0.7052	4.517	5.420
50	1575	980	1.0422	4.113	4.936
80	1391	918	0.7117	5.635	6.762
100	1255	873	0.4537	7.268	8.722
T=308.15K					
0	1390	1008	0.6553	5.135	6.162
10	1456	1002	0.6193	4.710	5.652
50	1547	976	0.8989	4.283	5.140
80	1344	912	0.636	6.072	7.286
100	1235	864	0.4012	7.582	9.098

Table 2. Excess thermoacoustic parameters w.r.t.% Volume of THF +Aqueous Sr(OH)₂ 8 H₂O.

Vol.	Vm^*10^5	τ^*10^{-12} Sec	τ^E*10^{-12} Sec	$\beta\alpha^E*10^{-10}$ Pa ⁻¹	Vm^E*10^{-5} m ³ /mol
T=298.15K					
0	26.19	0.5167	0.0000	0.000	0.0000
10	24.45	0.4726	-0.0391	-0.6155	0.0544
50	17.20	0.6325	0.1410	-1.8818	0.0115
80	12.01	0.5778	0.1013	-1.2051	0.2281
100	8.18	0.4664	0.0000	0.000	0.0000
T=303.15K					
0	26.28	0.4687	0.0000	0.000	0.0000
10	24.51	0.4247	-0.0411	-0.6225	0.0348
50	17.24	0.5716	0.1174	-1.9722	-0.0305
80	12.08	0.5347	0.0892	-1.1602	0.2165
100	8.258	0.4397	0.0000	0.000	0.0000
T=308.15K					
0	26.37	0.4486	0.0000	0.000	0.0000
10	24.60	0.3889	-0.0554	-0.6699	0.0299
50	17.32	0.5134	0.0863	-2.0752	-0.0425
80	12.16	0.5149	0.1007	-1.0208	0.2061
100	8.344	0.4056	0.0000	0.000	0.0000

strontium hydroxide (0.1N) at temperatures 298.15K, 303.15K, 308.15K and at fixed 7MHz frequency.

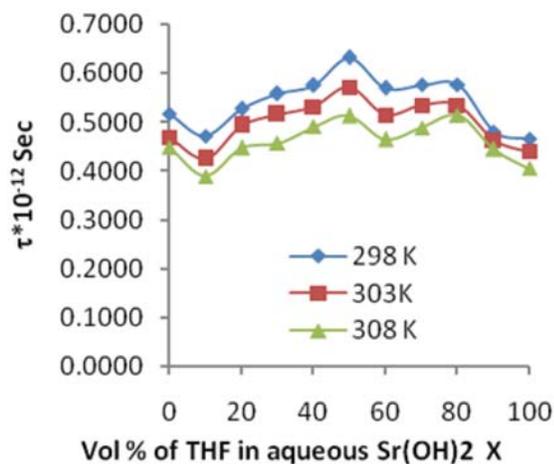
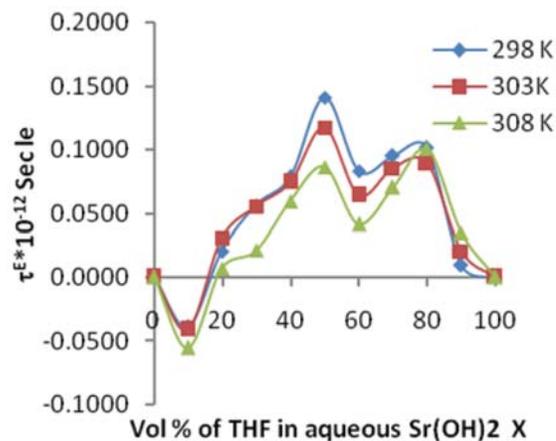
Excess parameters play a vital role in assessing the compactness, due to molecular arrangement and the extent of molecular interaction in the liquid mixtures through charge transfer, dipole-dipole and dipole-induced dipole interaction¹⁶. Non-ideal liquid mixtures show considerable deviation from linearity in their physical behavior (positive or negative) with respect to concentration and these have been interpreted as arising from

the presence of strong or weak interaction¹⁷.

The excess parameter curves with concentration are always zero at end points. This is a curve with either positive or negative values.

Figures 1 and 2 show relaxation time τ and the variation of excess values of relaxation time τ^E versus concentration (vol %) of THF in aqueous strontium hydroxide.

It is observed that, not all excess values are positive

Fig. 1. Relaxation time τ Fig. 2. Excess relaxation time τ^E

in the liquid system over the entire range of concentration (viscosity of constituent molecules also plays important role) (positive excess values are varying, shows peaks at 50% and 80% concentration with negative dip at 10%) The positive excess values of relaxation time τ^E and Z^E ($\tau^E \propto Z^E$)¹⁷ indicates that, there exist a strong molecular interaction between the unlike component molecules of liquid mixture¹⁸. According to Reed *et al.*¹⁹ the positive excess values can be attributed to specific interaction like hydrogen bonding and charge transfer. Nature and force existing between molecules is known. (may be solvent -solute or ion-dipole interaction). When temperature is increased positive excess values of relaxation time τ^E slightly decreases with same trend of variation.

The decrease in excess values of relaxation time at lower concentration at 10% and then increase up to zero, to positive excess values, is due to the possible structural relaxation process plays a predominant role over thermal relaxation process. Viscosity of constituent molecules also plays very important role in some negative values of relaxation time. It is a characteristic property of individual constituents, but supports strong interaction²¹. Excess values of adiabatic compressibility β_a^E are negative and excess molar volume V_m^E are positive. $\beta_a \propto 1/Z_a$, $V_m = M_{eff}/\rho$. The negative deviation of excess values is an indication of existence of strong interaction between the component molecules. Also indicates strong molecular dissociation between the unlike molecules.

Figures 3 and 4 show the variation of excess values of adiabatic compressibility β_a^E and molar volume V_m^E versus concentration (vol.%) of THF in aqueous

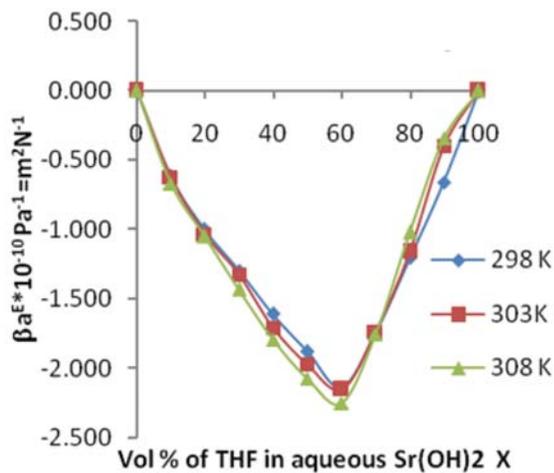


Fig. 3. Excess adiabatic compressibility β_a^E

strontium hydroxide, respectively. In Fig. 3, it is observed that, all excess values (β_a^E) are negative in the binary liquid system over the entire range of concentration (vol. %). For excess values of adiabatic compressibility β_a^E and L_f^E , with the increase in concentration (vol. %) of THF in aqueous strontium hydroxide, the varying excess values of β_a^E decreases negatively in magnitude and approach to minimum at around 60% concentration (vol. %) and again increases up to zero. Which shows that maximum structural changes take place in this region of the mixture. It further suggests that the negative excess values of β_a^E are due to the closely packed molecules which account for the existence of strong molecular interaction. With increase in temperature, for entire range of concentration (vol %), there are decreasing negative excess values of β_a^E and L_f^E , indicates molecular dissociation, which leads to less closer packing in binary mixture and hence decrease in adiabatic compressibility and free length, at lower concentration and increase at higher concentration, as ($\beta_a \propto L_f$).

Figure 4 shows the variation of excess values of molar volume V_m^E versus concentration (vol %) of THF in aqueous strontium hydroxide. It is observed that, all excess values are positive and negative in the binary liquid system over the entire range of composition. There are mostly positive excess values of V_m^E with peaks at 30-40% with the increase in concentration (vol%). At 50% concentration, decrease/dip takes place, (V_m^E decreases negatively in magnitude) and then increases, showing positive peak at 80% concentration (strong interaction). This is due to characteristic property of the components and supports strong interaction. So

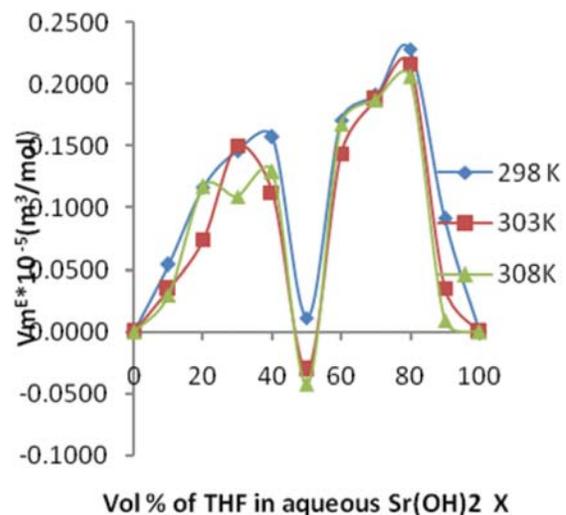


Fig. 4. Excess molar volume V_m^E

maximum structural changes take place in this region of the mixture. A positive excess value V_m^E indicates less density, strong interaction, strong molecular association between unlike molecules. With increase in temperature, positive excess values of molar volume V_m^E again decreases keeping same variation trend.

These positive and negative excess values of V_m^E at the same time, is due to large M_{eff} of Sr(OH)₂·8H₂O (octahydrate) (large molecular weight) and characteristic property of components. (supports strong interaction) The propagation of US wave through binary liquid mixture disrupts thermal and structural equilibrium of constituents in the liquid medium and produces energy

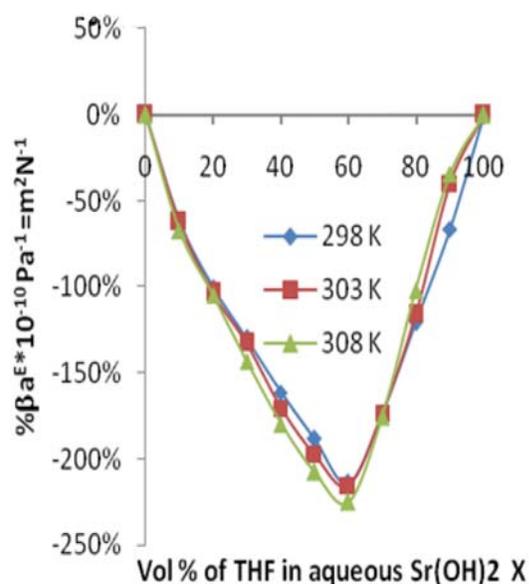


Fig. 5. Excess adiabatic compressibility β_a^E (%)

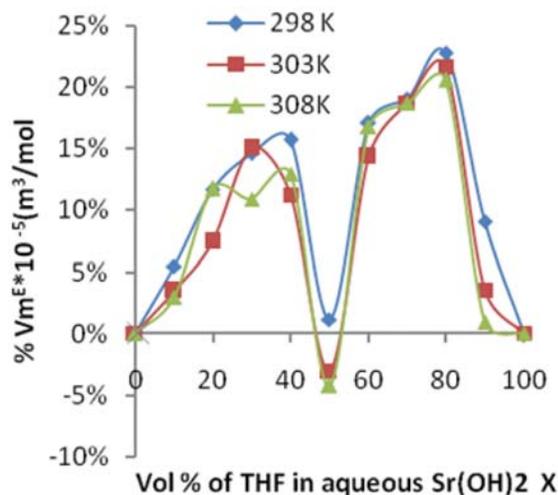


Fig. 6. Excess molar volume V_m^E (%)

Table 3 – Broad classification.

S. No.	β_a^E	V_m^E	Nature*
1	Negative	Negative	Association
2	Positive	Positive	Dissociation
3	Negative	Positive	Ordering
4	Positive	Negative	Conceal

transfer between different modes of the molecules. In this binary system, structural relaxation plays a predominant role over thermal relaxation process. The positive or negative excess values are due to structural relaxation process and viscosity factor. Table 2 Figures 5 (β_a^E %) and Fig. 6 (V_m^E %) have similar positive/negative excess values and trend, are used in Broad classification.

Conclusions

Strong or weak dispersive type molecular interactions exist between solute and solvent in binary liquid mixtures. Positive or negative excess parameters plays very important role by comparing experimental and ideal values which gives knowledge about molecular interactions. The heteromolecular AB interaction doesn't lead to complex formation. The system investigated is classified as case III (both β_a^E is negative and V_m^E is positive in broad classification).

References

- 1 **Ali A.** and **Nair A.K.**, Ultrasonic study of molecular interaction in binary liquid mixtures at 30°C, *Pramana*. **58** (2002) 695-701.
- 2 **Nayeema S.K.** and **Krishna Rao D.**, Ultrasonic Investigations of Molecular Interaction in binary mixtures of benzyl benzoate with isomers of butanol. *Int. J.P. Res. Rev.* **3** (2014) 65-78.
- 3 **Ali A.** and **Nair A.K.**, Ultrasonic study of molecular interaction in N-N dimethyl formamide + ethanol binary liquid mixtures at various temperatures, *Acoust. Lett.* **19** (1996) 181-187.
- 4 **Sumathi T.** and **Varalakshmi M.**, Ultrasonic velocity, density, viscosity measurement of methionine in aqueous electrolytic solution at 303 K. *Ras. J. Chem.* **3** (2010) 550-555.
- 5 **Bhandakkar V.D.**, **Tabhane V.A.** and **Ghosh S.**, Ultrasonic study of molecular interactions in binary liquid

- mixtures: acrolien & cinnamaldehyde in methanol, cyclohexane & p-dioxane. *Indian J. Pure Appl. Phys.* **41** (2003) 849-854.
- 6 **Bhandakkar V.D.** and **Rode S.S.**, Acoustical studies on molecular interactions in binary liquid mixtures at 303K, *Adv. Appl. Sci. Res.* **3**(5) (2012) 3223-3229.
 - 7 **Bhandakkar V.D.**, **Bhat V.R.**, **Chimankar O.P.** and **Asole A.W.**, Thermoacoustical study of tetrahydrofuran with ethanol using ultrasonic technique at 323K, *Adv. Appl. Sci. Res.* **5**(2) (2014) 80-85.
 - 8 **Bhandakkar V.D.**, **Rode S.S.** and **Maddi P.A.** Thermoacoustical and nonlinear molecular interaction studies in binary liquid mixtures at 303K, *Arch. Appl. Sci. Res.* **4**(6) (2012) 2546-2551.
 - 9 **Bhandakkar V.D.**, **Bedare G.R.**, **Muley V.D.** and **Suryavanshi B.M.**, Molecular interactions of Acrylonitrile and methyl methacrylate in methanol, cyclohexane and p-dioxane. *Adv. Appl. Sci. Res.* **2**(4) (2011) 380-386.
 - 10 **Srinivasulu V.** and **Naidu P.R.**, Ultrasonic behaviour of liquid mixtures of n-hexane with 1-alknaols at 303.15K, *J. Pure and Appl. Ultrason.*, **17** (1995) 14-28.
 - 11 **Jamankar G.M.** and **Deshpande M.S.**, Ultrasonic investigations of molecular interaction in binary mixtures of ellagic acid with acetone, *J. Pure Appl. Ultrason.* **40** (2018) 12-15.
 - 12 **Bhandakkar V.D.**, **Chimankar O.P.** and **Pawar N.R.** Ultrasonic study of molecular interactions in some bio-liquids. *J. Chem. Pharm. Res.* **2** (2010) 873-877.
 - 13 **Bhandakkar V.D.**, An accurate representation of molecular clusters in liquid mixtures using Khasare's equation of state. *Adv. Appl. Sci. Res. J.* **2** (2011) 198-207.
 - 14 **Bhandakkar V.D.**, **Chimankar O.P.** and **Pawar N.R.**, Thermo dynamic behaviour of methyl methacrylate in methanol, p-dioxane and cyclohexane, *Indian J. Pure Appl. Phy.* **49** (2011) 550-556.
 - 15 **Prasad N.** and **Rajendra H.**, Excess free volume and internal pressure of binary solutions of N, Ndimethyl aniline and halomethanes. *J. Pure. Appl. Ultrason.* **25** (2003) 25.
 - 16 **Bageshwar P.D.**, **Chimankar O.P.** and **Pawar N.R.**, Ultrasonic characterization of thymine in aqueous solution by non-destructive technique. *J. Pure Appl. Ultrason.* **38** (2016) 40-42.
 - 17 **Rajgopal K.** and **Chenthilnath S.**, Excess thermodynamic studies of binary mixtures of 2-methyl-2 propanol with ketones, *Indian J. Pure Appl. Phy.* **48** (2010) 326-333.
 - 18 **Bhandakkar V.D.** and **Asole A.W.**, Excess thermo dynamic parameters of binary liquid mixtures at 303K. *J. Pure Appl. Indust. Phys.* **3** (2013) 80-86.

Estimation of effective Debye temperature of multi component liquid mixtures at 298.15K

Charu Kandpal¹, Arvind Kumar Singh², Ranjan Dey³, Vinod Kumar Singh^{1,*} and Devraj Singh⁴

¹Department of Physics, V.S.S.D. College, Kanpur-208002, India

²College of Engineering Science & Technology, Lucknow-226010, India

³Department of Chemistry, BITS Pilani, K.K. Birla Goa Campus, Zuarinagar, Goa-403726, India

⁴Amity Institute of Applied Sciences, Amity University, Noida-201313, India

*E-mail: vks1969@gmail.com

The Debye temperature has been computed for four quaternary mixtures over the entire range of composition at 298.15K. We have applied three different approaches and evaluated the Debye temperature using experimental data of ultrasonic velocity and density. This paper aims to portray the comparison of all the three approaches applied on the four quaternary mixtures which is being done for the first time to the best of authors knowledge. A good agreement is observed among the values computed with all the three approaches.

Keywords: Debye temperature, quaternary liquid mixtures, ultrasonic velocities, density.

Introduction

In thermodynamics, post findings that vibrational energies of liquid mixtures can be characterized by Debye like distribution just like in solids, the theoretical and experimental studies of thermodynamic properties of liquid mixtures have gained much importance earlier¹⁻¹³ as multicomponent liquid mixtures and their formulations are relevant to chemical industries. Especially liquid mixtures are widely used in processing and product formulation in many industrial applications. Thermodynamic and transport properties of the liquids provide useful information about physical forces acting between the molecules of different substances in liquid mixtures. When the different liquids are mixed together, the resulting changes in physical and thermodynamics properties can be considered as a sum of several contributions due to free volume changes, change in energy, change in molecular orientations *etc.* Properties such as ultrasonic velocity and their variations with temperature and composition of the liquid mixtures are useful to design engineering processes and in chemical and biological industries.

Assuming the quasi crystalline model for the liquids to be similar to solids, Debye temperature was computed for the liquid mixtures^{1,14}. Dey *et al.*¹⁵ extended the

evaluation of the effective Debye temperature to liquid metal alloys and molten salt mixtures. Literature survey¹⁶⁻¹⁹ indicates that, to best of our knowledge, no attempt have been made to evaluate the Debye temperature for quaternary liquid mixtures with different approaches at 298.15K.

In the present work, three different approaches for theoretical evaluation of θ_D have been applied to four quaternary liquid systems n-decane + n-hexane + cyclohexane + benzene, pentane + n-hexane + benzene + toluene, pentane + cyclohexane + heptane + toluene, pentane + n-hexane + cyclohexane + benzene at 298.15 K and a comparative study has been carried out to check the applicability and their efficacy in terms of their applications to quaternary liquid mixtures. The experimental values of ultrasonic velocity and density for the quaternary systems²⁰ have been presented and discussed.

Theory

For solids, the expression for Debye temperature is given by

$$\theta_D = \frac{h}{k} \left[\left(\frac{9N}{4\pi V} \right) / \left(\frac{1}{C_l^3} + \frac{2}{C_t^3} \right) \right]^{1/3} \quad (1)$$

where h =Planck's constant, k =Boltzmann's constant, N =Avagadro number and V =Molar volume

C_l and C_t = longitudinal wave velocity and transverse wave velocity respectively.

The values of C_l and C_t are as follows

$$\left(\frac{1}{C_l^3} + \frac{2}{C_t^3}\right) = (\rho\beta_T)^{3/2} + \left[\left\{\frac{1+\sigma}{3(1-\sigma)}\right\}^{3/2} + 2\left\{\frac{2(1+\sigma)}{3(1-2\sigma)}\right\}^{3/2}\right] \quad (2)$$

where β_T ($\approx\beta_s$) is the isothermal compressibility and has been evaluated by employing the expression²¹⁻²³.

$$\beta_T = \left(\frac{1.71 \times 10^{-3}}{u^2 T^{4/9} \rho^{4/3}}\right) \quad (3)$$

where u , T and ρ are ultrasonic velocity, temperature and density respectively.

Poisson ratio σ can be computed as follows

$$\sigma = \left(\frac{3A-2}{6A+2}\right) \quad (4)$$

where $A = 4/3\gamma$, γ is the ratio of isothermal compressibility to adiabatic compressibility,

$$\gamma = \frac{\beta_T}{\beta_s} \quad (5)$$

Molar volume,

$$V = \left(\frac{\sum x_i m_i}{\rho}\right) \quad (6)$$

For Ideal mixing, the formula for evaluation of θ_D is given as:

$$\theta_{D(\text{ideal})} = \sum x_i \theta_{Di} \quad (7)$$

Where x_i = mole fraction and θ_{Di} = Debye temperature of the i^{th} component.

The Debye temperature can also be evaluated by Lorentz Bertholet Combination Rule²⁴. If mass changes to mole fraction, specific heat changes to molar heat capacity and temperature changes to Debye temperature. Thus,

$$\begin{aligned} X_1 \cdot C_{p1} \cdot (\theta_{D1} - \theta_D) &= X_2 \cdot C_{p2} \cdot (\theta_D - \theta_{D2}) \\ \theta_D &= \frac{X_1 \cdot C_{p1} \theta_{D1} + X_2 \cdot C_{p2} \theta_{D2}}{X_1 \cdot C_{p1} + X_2 \cdot C_{p2}} \\ \theta_D &= \sum \frac{X_i \cdot C_{pi} \theta_{Di}}{X_i \cdot C_{pi}} \end{aligned} \quad (8)$$

Where C_{pi} is molar specific heat capacity at constant

pressure of the i^{th} component.

Results and Discussion

Thermodynamic parameter like Debye temperature θ_D is diagnostic parameter for describing various properties of liquids and liquid mixtures. The computed parameter θ_D give more comprehensive information about the structural and interactional aspects of the mixture at the microscopic level. To illustrate the physical significance and existence of Debye temperature of structurally disordered liquid matter, four quaternary liquid mixtures n-decane + n-hexane + cyclohexane + benzene(1), pentane + n-hexane + benzene + toluene(2), pentane + cyclohexane heptane + toluene(3), pentane + n-hexane + cyclohexane + benzene(4) have been undertaken for the study. The experimental values of ultrasonic velocity u ²², density ρ ²² and specific heat C_p ²⁵ of all the pure components measured at 298.15K are recorded in Table 1. Theoretically evaluated values of Debye temperature for all the pure components using Eq.1 are mentioned in third column of Table 1.

Computed values of Debye Temperature (θ_D) for all the four quaternary liquid mixtures using all the three approaches are listed in Tables 2-5.

The variation of θ_D obtained by all the three approaches for all quaternary systems has been graphically represented with the mole fraction of the first component (x_1) of every mixture in Figs. 1-4.

Scrutiny of the graphs presented in Fig. 1 shows the inconsistent values of θ_D which are resulting from the collapse of order in the mixture¹⁴. And the values of θ_D varies in same manner on the application of all three approaches. Addition of n-alkanes creates disruption in the structure of the pure components thereby leading to contraction while the Figs. 2-4 show that the values of

Table 1 – Debye Temperature of pure components (θ_D), density(ρ), ultrasonic velocity (u), specific heat (C_p) at temp 298.15K

	u (m/s)	(g/cm ³)	θ_D (K)	C_p (J/mol-K)
Pentane	990	0.6216	50.62	167.19
n-hexane	1076	0.6552	52.76	194.64
n-decane	1224	0.7263	65.98	315.46
cyclohexane	1253	0.7734	65.58	156
Benzene	1296	0.8736	71.38	134.8
Toluene	1304	0.8627	68.55	155.96
Heptane	1131	0.6791	53.39	224.64

Table 2 – Debye temperature (θ_D) using all three approaches, ultrasonic velocity (u), density (ρ) of quaternary mixture n-decane (x_1) + n-hexane (x_2) + cyclohexane (x_3) + benzene (x_4) at 298.15K, $x_4 = 1 - (x_1 + x_2 + x_3)$.

x_1	x_2	x_3	ρ mix (gm/cm ³)	u mix (cm/s)	θ_D (K) using Eq. (1)	θ_D (K) using Eq. (7)	θ_D (K) using Eq. (8)
0.1171	0.1768	0.1883	0.7719	125530	64.53	66.37	65.46
0.1169	0.1772	0.2769	0.7636	125580	64.19	65.85	65.05
0.117	0.1769	0.3968	0.7553	125730	63.86	65.15	64.53
0.1245	0.1889	0.4607	0.7479	125600	63.36	64.52	64.05
0.1244	0.3438	0.2035	0.7379	125260	62.98	63.13	62.37
0.1195	0.2478	0.1951	0.7558	125480	63.87	64.99	64.09
0.1158	0.1758	0.1911	0.7708	125640	64.57	66.37	65.47
0.1243	0.1898	0.4087	0.7506	125420	63.42	64.80	64.22
0.1241	0.257	0.3445	0.7431	125350	63.14	63.93	63.29
0.1253	0.3435	0.256	0.7346	125230	62.78	62.82	62.17
0.1252	0.4161	0.1828	0.7267	125470	62.65	61.89	61.25
0.2366	0.1992	0.2154	0.7476	125540	62.02	65.15	64.58

Table 3 – Debye temperature (θ_D) using all three approaches, ultrasonic velocity (u), density (ρ) of quaternary mixture pentane (x_1) + n-hexane (x_2) + benzene (x_3) + toluene (x_4) at 298.15K, $x_4 = 1 - (x_1 + x_2 + x_3)$.

x_1	x_2	x_3	ρ mix (gm/cm ³)	u mix (cm/s)	θ_D (K) using Eq. (1)	θ_D (K) using Eq. (7)	θ_D (K) using Eq. (8)
0.0943	0.0918	0.4587	0.8216	126010	67.41	66.71	65.97
0.1278	0.1288	0.3589	0.8054	123730	65.62	65.24	64.41
0.1843	0.1484	0.2711	0.7855	120010	63.12	63.67	62.83
0.1819	0.1601	0.3842	0.7824	120010	63.45	63.85	62.85
0.1691	0.2041	0.2218	0.7769	120130	62.79	62.93	62.04
0.1372	0.1579	0.5548	0.7926	121140	64.72	65.17	64.04
0.0524	0.1434	0.4201	0.8176	126050	67.04	66.54	65.69

Table 4 – Debye temperature (θ_D) using all three approaches, ultrasonic velocity (u), density (ρ) of quaternary mixture pentane (x_1) + cyclohexane (x_2) + heptane (x_3) + toluene (x_4) at 298.15K, $x_4 = 1 - (x_1 + x_2 + x_3)$.

x_1	x_2	x_3	ρ mix (gm/cm ³)	u mix (cm/s)	θ_D (K) using Eq. (1)	θ_D (K) using Eq. (7)	θ_D (K) using Eq. (8)
0.0404	0.6358	0.1544	0.8023	127010	66.38	63.59	62.91
0.0735	0.5474	0.112	0.7997	124350	64.92	63.91	63.35
0.1145	0.5054	0.0793	0.7927	122370	63.88	63.79	63.34
0.1511	0.4602	0.0487	0.7857	121870	63.58	63.74	63.38
0.1071	0.4099	0.0783	0.7855	123450	64.03	64.23	63.77
0.1783	0.2174	0.1637	0.7498	120150	61.17	62.23	61.50
0.1794	0.602	0.1481	0.7842	123320	64.53	61.29	60.69
0.0948	0.3338	0.2524	0.7615	122750	62.48	62.03	61.10

θ_D for all the quaternary liquid mixtures are lowered as the mole fraction of the first component increases. A close perusal of result and graphs presented here clearly reveals the utility of Debye temperature in understanding

the nature and extent of interactions. Analysing all the four graphs it is clear that same pattern is observed by all the approaches and any one of them can be utilized for estimating θ_D of multicomponent liquid mixtures.

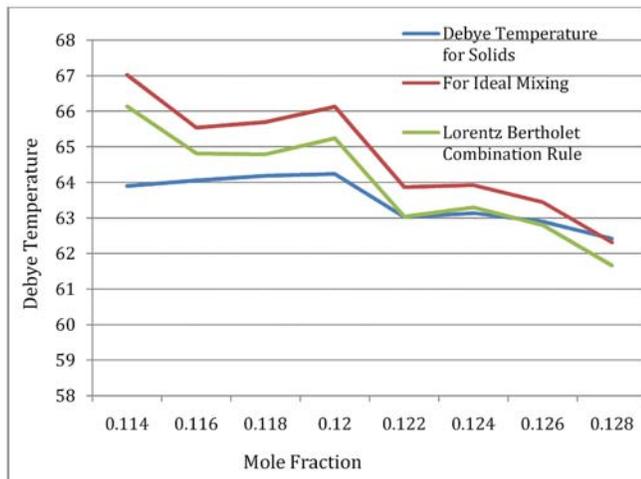


Fig. 1. Variation in Debye temperature θ_D with mole fraction of the first component (x_1) using all three approaches for quaternary mixture n-decane + n-hexane + cyclohexane + benzene

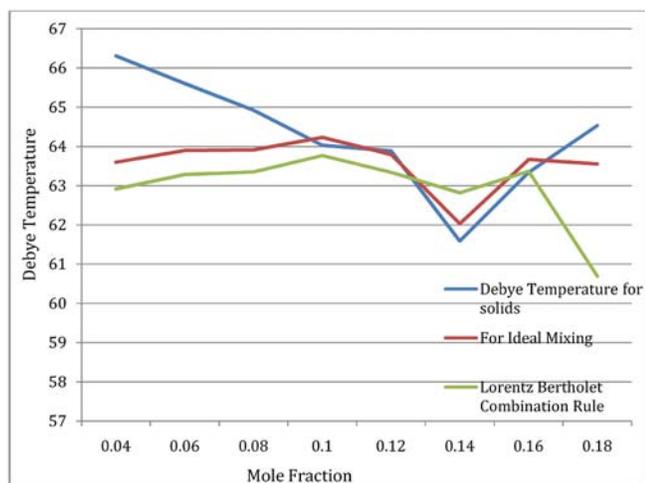


Fig. 3. Variation in Debye temperature θ_D with mole fraction of the first component (x_1) using all three approaches for quaternary mixture pentane + cyclohexane + heptane + toluene

Conclusion

The present investigation points out that calculated values of Debye temperature (θ_D) for four quaternary liquid mixtures at 298.15K by all the three approaches are in reasonable agreement. Using the assumption that β_S is nearly equal to β_T which is used only for solids, the obtained values of θ_D vary in same manner as for the other two approaches. This study will be useful for studying many thermophysical properties of the ternary mixtures.

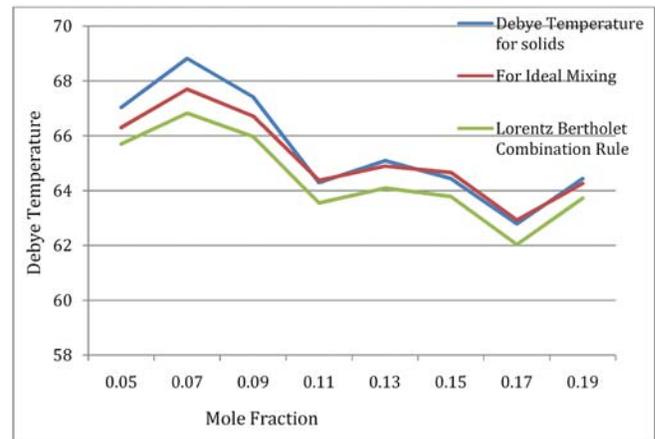


Fig. 2. Variation in Debye temperature θ_D with mole fraction of the first component (x_1) using all three approaches for quaternary mixture pentane + n-hexane + benzene + toluene

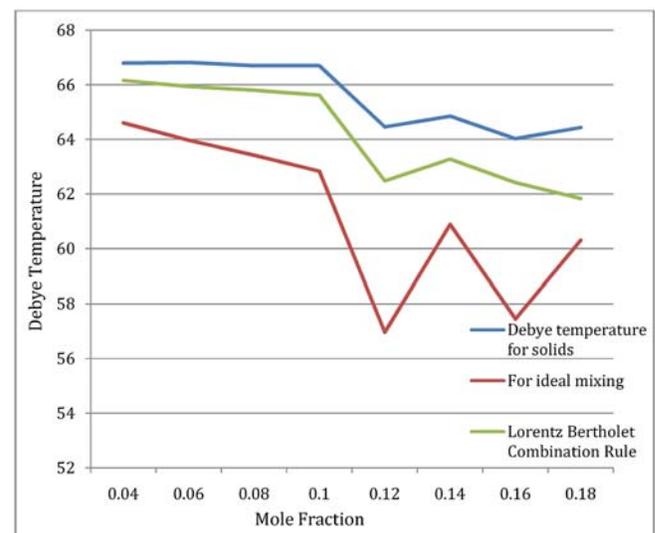


Fig. 4. Variation in Debye temperature θ_D with mole fraction of the first component (x_1) using all three approaches for quaternary mixture Pentane + n-hexane + cyclohexane + benzene

References

- 1 **Egelstaff P. A.**, *Thermal Neutron Scattering*, Academic Press, New York, (1965).
- 2 **Pandey J. D., Pant U. R. and Bhatt T.**, Quasi crystalline structure of liquid and the effective Debye temperature, *Physik. Chemie* **257** (1976) 775-778.
- 3 **Shukla R. K., Shukla S. K., Pandey V. K. and Awasthi P.**, Sound velocity, effective Debye temperature and Pseudo-Grüneisen parameters of Pb-Sn mixtures at

- elevated temperatures, *Phys. Chem. Liq.* **45**(2) (2007) 169-180.
- 4 **Pandey J. D.** and **Pandey H. C.**, Specific Debye temperature and specific heat ratio in liquid hexane and pentane, *Indian J. Phys.* **49** (1975) 869-872.
 - 5 **Pandey J. D.**, Effective Debye temperature of liquids on the basis of quasicrystalline structure, *Indian J. Chem.* **14 A** (1976) 607.
 - 6 **Pandey J. D.**, **Pant U. R.** and **Bhatt T.**, Acoustical behaviour of liquid diborane, *Acustica* **34** (1976) 247-249.
 - 7 **Pandey J. D.**, Acoustical parameters of liquids fluorine, *Acustica* **34** (1975) 119-122.
 - 8 **Pandey J. D.**, Acoustical behavior of plastic crystals, *Acustica* **35** (1976) 87-88.
 - 9 **Pandey J. D.** and **Pandey H. C.**, The study of effective Debye temperature of liquid Ar, *Acustica* **34** (1976) 243-245.
 - 10 **Pandey J. D.**, **Jain P.** and **Vyas V.**, Isothermal compressibility and sound velocity of binary liquid systems: Applications of hard sphere models, *Pramana J. Phys.* **43** (1994) 361-372.
 - 11 **Yasmin M.**, **Singh K. P.**, **Parveen S.**, **Gupta M.** and **Shukla J. P.**, Thermoacoustical excess properties of binary liquids mixtures- a comparative experimental and theoretical study, *Acta Phys. Pol. A* **115** (2009) 890-900.
 - 12 **Singh S.**, **Singh A.** and **Badal S.**, Computation of effective Debye temperature of binary liquid mixtures, *IJRPC* **7**(3) (2017), 302-305.
 - 13 **Vyas V.**, **Sarika** and **Krishna V.**, Ultrasonic speeds of multicomponent liquid systems-a comparison with theory, *J. Pure Appl. Ultrason.* **19** (1997) 50-53.
 - 14 **Kor S. K.** and **Tripathi N. D.**, Temperature and pressure dependence of effective Debye temperature in associated liquids based on quasi crystalline model, *J. Phys. Soc. Jpn.* **36** (1974) 552-554.
 - 15 **Dey R.**, **Mishra R. K.**, **Soni N. K.** and **Mittal R. C.**, Effective Debye temperatures of liquid metal alloys and molten salt mixtures, *Univ. Alld. Studies (NMS)* **2**(1) (2003) 15-20.
 - 16 **Vyas V.**, Excess molar volumes and densities of multicomponent liquid systems at 298.15K. A comparison with flory's statistical theory, *Phys. Chem. Liq.*, **41** (2003), 55-64.
 - 17 **Vyas V.**, **Jain P.** and **Nautiyal T.**, Excess effective Debye temperature of binary liquid mixtures from sound velocity measurements at 298.15K, *Ind. J. Phys.* **77B**(5) (2003) 533-536.
 - 18 **Singh R. N.**, **George A.K.** and **Arafin S.**, Specific heat ratio, Gruneisen parameter and Debye temperature of crude oil, *J. Phys. D.* **39** (2006) 1220-1225.
 - 19 **Vyas V.**, Ultrasonic investigation of effective Debye Temperature in multi-component liquid systems at 298.15K , *Phys. Chem. Liq.* **42** (2004) 229-236.
 - 20 **Pandey J. D.**, **Srivastava T.**, **Chandra P.**, **Dwivedi D. K.** and **Sanguri V.**, Estimation of thermodynamic properties of multi component systems on the basis of generalized hole theory, *J. Mol. Liq.* **157** (2010) 158-161.
 - 21 **Pandey J. D.**, **Singh A. K.** and **Dey R.**, Effect of isotopy on thermoacoustical properties, *J. Pure Appl. Ultrason.* **26** (2004) 100-104.
 - 22 **Pandey J. D.**, **Singh A. K.** and **Dey R.**, An ultrasonic study of multicomponent liquid systems, *Indian J. Chem. Techn.* **12** (2005) 598-592.
 - 23 **Dey R.** and **Kumar P.**, A study of thermoacoustical and non-linearty parameters of binary liquid mixtures at different temperatures, *Acta Acustica united with Acustica.* **99** (2011) 1-3.
 - 24 **Singh A. K.**, Thermophysical and thermoacoustical parameters of liquids and liquid mixtures, D.Phil Thesis, Department of Chemistry, *University of Allahabad*, (2004).
 - 25 **Eugene S. Domalski** and **Elizabeth D. Hearing**, *Journal of Physical and Chemical Reference Data*, (1988).

Seminar Report

State Level Seminar on Innovative Insights in Ultrasonic Methods at Kamaraj College, Thoothukudi-628003

The Third Students' Chapter of Ultrasonics Society of India at the Department of Physics, Kamaraj College organized a *State Level Seminar on Innovative Insights in Ultrasonic Methods (IIUM)* on National Science Day on 28.02.2019

Mr. Joe Amal Sachin (B.Sc.III), President of USI-SC-III, Department of Physics, Kamaraj College, welcomed the gathering. *Dr. D. Nagarajan, Principal*, Kamaraj College, delivered the inaugural address and spoke about the importance of Ultrasonics in today's world. He further emphasized the interdisciplinary nature of the field of Ultrasonics which finds applications in various fields such as medicine, engineering, science, nanotechnology, etc.



Dr. A. Sivadhas (HOD), Dr. G. Narayanasamy (IQAC Co-ordinator), Dr. X. Helan Flora (Asst. Prof), Dr. S. Kanagaprabha (Asst. Prof), Department of Physics, Kamaraj College in their felicitation address, inspired the students to take up research in the field of Ultrasonics and explore new avenues in taking its benefits to the Society.

Dr. R. Sabesan (Life Fellow of ASI), Prof. & Head (Retd.), Department of Physics, Alagappas University, Karaikudi, in his special address expressed his views in the field of Ultrasonics for the benefits of Students. In



the Technical Session-I, *Dr. S. Rajakarthishan (Life Member of USI)*, Asst. Prof. of Physics, Thiagarajar College, Madurai delivered a lecture on the topic Basic concept of Nondestructive Testing Methods and in the Technical Session-II, *Dr. K. Sakthipandi (Life Member of USI)*, Associate Prof. of Physics, Sethu Institute of Technology, Kariapatti delivered a lecture on the topic "Evaluating the state of Materials at high temperature using In-Situ Ultrasonic measurements" for students.

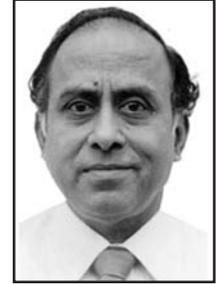
This event was convened by *Dr. J. Poongodi*, (Executive Member & Life Fellow of USI) Co-ordinator of this Chapter III & Associate Professor of Physics, Kamaraj College and organized by Members of USI Students' Chapter III, Department of Physics, Kamaraj College, Thoothukudi. In the valedictory session best papers from the UG & PG levels were awarded. In UG level *Mr. R. Sathasivam*, Kamaraj College, Thoothukudi & *Mr. M. HameedIrshad*, Aditanar College of Arts and Science, Thiruchendur shared their award and in PG level *Ms. A. Nandhini Surya*, St. Mary's College, Thoothukudi won the Best paper award.

On the day of seminar around 150 students, scholars and more than 10 faculty members participated from the chapter and from the nearby colleges.

Dr. J. Poongodi, Associate Professor
Department of Physics, Kamaraj College, Thoothukudi-628003, T.N.

Dr. Devanatha Srinivasan

[06. 02. 1927 - 04. 10. 2018]



Dr. Srinivasan obtained his B.Sc. (Hons.) Degree in Physics in 1947, and his M.A. (Physics) Degree in 1949, from the Madras University. He started his research career in July 1949 as Scientific Assistant in the Acoustics Division, National Physical Laboratory, (NPL), New Delhi, headed by Dr. S Parthasarathy. In June 1952 he left NPL to pursue his research for a Doctorate Degree at the University of Missouri, Columbia USA, and obtained his Ph.D Degree in 1955. Thereafter he reverted to NPL as Post-Doctoral Fellow.

In April 1957 he left NPL to join the Indian Naval Physical Laboratory (INPL), Cochin, of Defence R & D Organisation to better his prospects. By 1962 he had been appointed as the Head of that Laboratory as Principal Scientific Officer. After the re-naming of the Laboratory as Naval Physical & Oceanographic Laboratory (NPOL), he served as its Director during 1967-69; and 1973-83. Thereafter he took over as Director, Naval Science & Technology Laboratory (NSTL), Visakhapatnam (1983-85). For some time he also held dual charge of both NPOL and NSTL. He was the Director of Scientific Research (Navy) in the Ministry of Defence and later Scientific Adviser to the Chief of Naval Staff 1969-73.

After his retirement from NSTL, Dr. Srinivasan served as first as Professor, Department of Ocean Engineering, IIT, Madras, then as CSIR Emeritus Scientist, Department of Physics, IIT, Madras, and lastly as Advisor, National Institute & Ocean Technology (NIOT), Chennai.

He mentored a number of young scientists, many of whom rose to great heights such as Dr V K Aatre, Scientific Advisor to Raksha Mantri (1999-2005) and Prof A J Paulraj, winner of the Marconi Prize in 2016.

Dr. Srinivasan's areas of specialization included Ultrasonics; Underwater Acoustics; Ocean Acoustics - the areas in which NPL was also actively involved, which

provided grounds of active interaction between him and Dr. V N Bindal. He developed good Testing & Calibration facilities, for underwater acoustics transducers at NPOL and got a water tank constructed there on the design for a special huge tank that had been developed and constructed at NPL for testing underwater transducers. He also guided Dr. C Madhavan (NPOL) and Dr. Disha (NIOT) in their Doctorate Degrees.

He authored more than 50 research papers most of which were published in international journals. He co-authored the book 'Principles of Electro-Acoustic Transducers'.

Dr Srinivasan made a pioneering and lasting contribution to Defence R&D by developing a sonar system called APSOH which was the beginning of a range of sonars for Indian Navy, bringing national recognition of NPOL and its emergence as a major systems laboratory of DRDO.

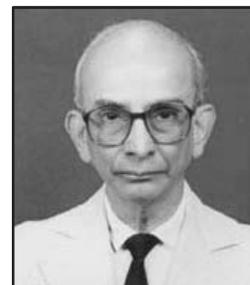
He had been the President of the Acoustical Society of India during 1983-84 and was also an Honorary Fellow of the Ultrasonics Society of India. He encouraged and mentored the formation of Ocean Society of India. He was the first Chairman of Ocean Research Panel of Naval Research Board, Ministry of Defence.

He had to his credit the Albert Einstein Award, University of Missouri (1955); Salwan Award, Defence Indigenisation of Salwan Trust (1966); Hari Om Ashram Trust Award for Ocean Sciences (1985); Life Time Achievement Award, Department of Ocean Engineering, Govt. of India (2005); Life Time Achievement Award, DRDO, Ministry of Defence, Govt. of India (2007); Dr. S Bhagwantam Award, Acoustical Society of India; and Eminence Award, Organizing Committee of the International Symposium on Ocean Electronics (2013).

G.K. Arora
LF 099

Prof. Erode Subramanian Raja Gopal

[12. 05. 1936 - 15. 11. 2018]



Prof. Gopal - the name that he was generally known by, had his pre-graduation studies at the St. Joseph's College, Tiruchirappalli and after earning his B.Sc. (Hons.) Degree from the Madras University, obtained his M.A. (Physics) and M.Sc. (Physics - By Research) Degrees from that University in 1956 and 1958 respectively. He had his Ph.D. Degree from the Indian Institute of Science Bangalore in 1961, for his work on investigations on the elastic behaviour of crystals, done under the guidance of Prof. R.S. Krishnan. He spent three years (1961-64) in post-doctoral research at Clarendon Laboratory, University of Oxford, UK, with Kurt Mendelssohn (FRS) to understand the low temperature specific heat and super flow of liquid helium.

He joined the Indian Institute of Science (IISc), Bangalore as CSIR Pool Officer in the Department of Physics, in 1964. There he held various positions as Assistant Professor in 1965, a full Professor in 1969 and the Dean of the Faculty of Science in 1976. He chaired the Department of Physics during 1977-80 and Regional Sophisticated Instrumentation Centre from 1983-1989.

He took over as the Director, National Physical Laboratory (NPL) on 12.09.1991. He retired from this position on 11.09.1997, on completion of his tenure and reverted to IISc.

Prof. Gopal had been the Editor of the Journal of the Acoustical Society of India (1982-87) and Pramana - Journal of Physics being its Chief Editor (1984-89). He had also been actively involved with the editorial work of various other research journals as also as reviewer of papers published therein. He was Fellow of the all the three National Science Academies of India. He had also been the President of the Indian Cryogenics Council (1986-89), Acoustical Society of India (1990-92), Indian Society of Mass Spectroscopy (1992-95); Metrology Society of India (1993-97) and Ultrasonics Society of India (1995-99), and also the Vice President of Indian Physics Association. He had been associated with various other scientific associations in other capacities also.

He had over 250 research publications to his credit, and had also published two books - one on Specific Heat at Low Temperatures, and the other on Statistical Physics, and edited two more. He had been a pioneer of several path-breaking

papers and was a walking example of brilliance and industry. The large number of Journals and the Scientific Bodies that he had been associated with give an indication of his areas of specialization. In particular, his areas of specialization included Precision Measurements; Condensed Matter Physics; Phase Transitions in Liquids; Disordered Materials; High Pressure Physics; Electronics/Computer and Thermal Instrumentation; Acoustics and Ultrasonics. He had guided more than 60 students for their Doctorate Degrees, including Dr. S Silakumar Titus - a member of the Ultrasonics Society of India.

He had to his credit a large number of Awards which included: CSIR's Shanti Swarup Prize (1978); Sir C V Raman Award of the Acoustical Society of India (1980); NRDC's Invention Promotion Award (1984); Dr. S Bhagavantam Award of the Acoustical Society of India (1993); Homi Jehangir Bhabha Medal of INSA (1994); Biotech Research Society of India (BRSI) Life Time Achievement Award (2005); ISOI Annual Award (2005); and Distinguished Alumnus Centenary Award (2008) of the Indian Institute of Science Bangalore. He had also been conferred D.Sc. (hc) by the Burdwan University in 1999 and by the Indian Institute of Engineering and Technology, Shibpur in 2017.

Prof. Gopal had commitment to develop a culture of instrumentation and he travelled far and wide to participate in scientific activities and gave lectures all over the country.

After completing his tenure as Director, NPL, he was appointed as CSIR Emeritus Scientist (1997-2001) and thereafter as INSA Scientist (2001-06), and then as INSA Honorary Scientist at the Indian Institute of Science Bangalore, where he continued to serve as Emeritus Professor at the Department of Physics.

Prof. Gopal continued to be very active and his advice was sought by the various Government Departments viz. Department of Electronics and Department of Science & Technology, for providing financial support to projects funded by them as also by the various Universities and Institutions of higher learning for appointment of persons in senior positions.

G.K. Arora
LF 099

Journal of Pure and Applied Ultrasonics

(INDEXED IN: Indian Citation Index, Google Scholar, i-Scholar, UGC List)

INFORMATION FOR AUTHORS

1. Type of Contribution

JOURNAL OF PURE AND APPLIED ULTRASONICS welcomes contributions on all aspects of ultrasonics including ultrasonic studies in medical ultrasonics, NDT, underwater, transducers, materials & devices and any other related topic. Contributions should fall into one of the following classes.

Paper - These should be on original research work contributing to scientific developments. They should be written with a wide readership in mind and should emphasize the significance of the work.

Reviews and Articles - Includes critical reviews and survey articles.

Research and Technical notes - These should be short descriptions of new techniques, applications, instruments and components.

Letters to the editor - Letters will be published on points arising out of published articles and papers and on questions of opinion.

Miscellaneous - Miscellaneous contributions such as studies, interpretive and tutorial articles, conference reports and news items are also accepted. Recommended contribution lengths are: Papers 2000-4000 words. Reviews and Surveys 2000-5000 words; Conference Reports 500-1500 words; News Items, Research and Technical Notes up to 1000 words.

2. Manuscripts

Manuscripts should be typed on one side of the paper in double spacing with 25 mm margin on all sides of A4 size paper. A soft copy of the manuscript in MS

WORD for text and MS EXCEL for illustrations and a PDF file thereof may be sent by e-mail or CD/DVD. Colour images should be formatted as JPEG files. Figures submitted in colour would be published in colour. Colour should be avoided unless it is required in order to convey a message or serve a purpose in the image.

Title - Titles should be short and indicate the nature of the contribution.

Abstract - An abstract of 100-200 words should be provided on the title page of paper and review article. This should indicate the full scope of the contribution and include the principal conclusions.

Mathematics - Mathematical expressions should be arranged to occupy the minimum number of lines consistent with clarity e.g., $(x^2+y^2)/(x-y)^{1/2}$.

Illustration - The line illustrations along with captions should be clearly drawn with black Indian ink. Figures in Excel are preferred.

References - References should be referred to in the text by number only. The reference number should be given as superscript. The corresponding reference shall contain the following information in order; names and initials of author (s)(bold), title of the work, journal or book title (italic), volume number (bold), year of publication in brackets, page number, e.g., **Kumar S.** and **Furuhashi H.**, Anisotropic divergence controlled ultrasonic transmitter array for three dimensional range imaging, *J. Pure Appl. Ultrason.*, **38** (2016) 49-57.

Units and Abbreviations - Authors should use SI units wherever possible.

KappaWave ULTRASONIC FLAW DETECTOR Model K1 & K8

State-of-the art Gate movements.

Scientific calculator for UT work

Large display. Less eye strain. See everything in detail

Save Test files easily
Save several thousands of files. Review any file in the instrument with relevant info

Beam plot in an Angle beam test helps you interpret signals easily

Echo store control. Ideal for transfer correction and corrosion monitoring work

Echo store

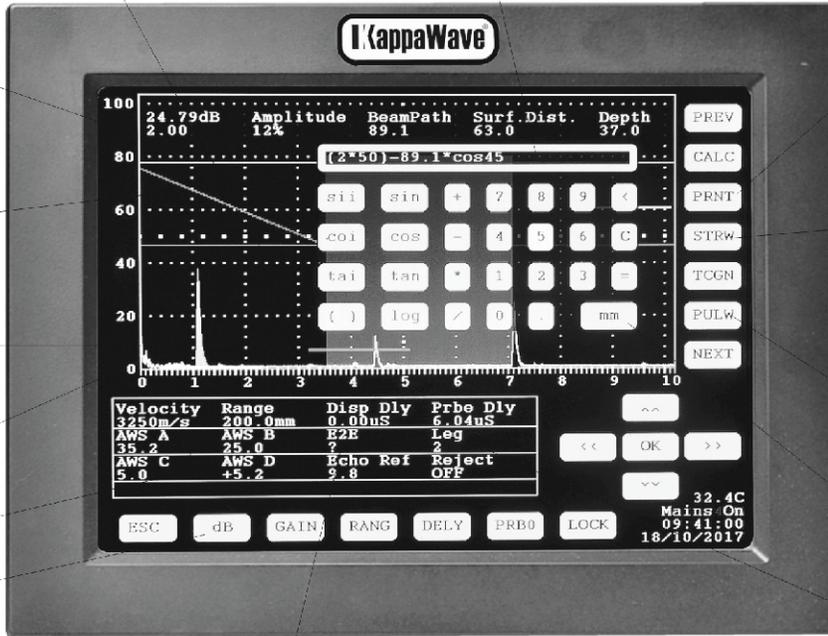
Better near surface resolution with this Pulse width control

7 Colour options

Direct mm to inch conversion

AWS D1.1 'D' value
.03, .2, 1, 2, 6 & 12 dB increment

Leg info in an Angle beam test

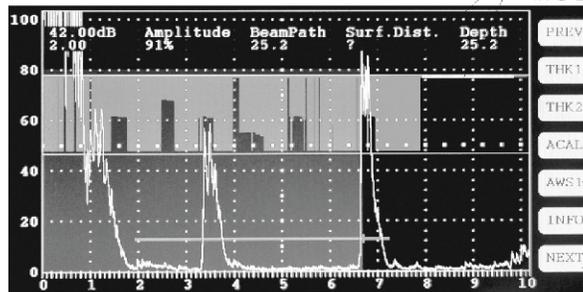


Model K1 with 26.4cm touchscreen display

- 26.4 & 17.7cm Touchscreen display
- Ease of use, All touch controls
- A, B Scan & Beam plot ability
- RF Wave
- 16GB memory
- 16 hours Li-ion battery
- PC Connectivity & Reporting software
- 14 point DAC & TCG
- AWS D1.1 Weld evaluation
- Echo Store for comparisons
- Scientific calculator
- Two point Auto calibration
- VGA out
- Adjustable PRF, Damping, Pulse width and Pulse energy
- New Reject control
- Low noise
- Penetrative power
- Clear visibility in any light

Single Gate provides Echo to Echo distance

Material cross section in a B Scan



Two Point Auto Calibration

AWS D1.1 Weld evaluation

Easy to access functions

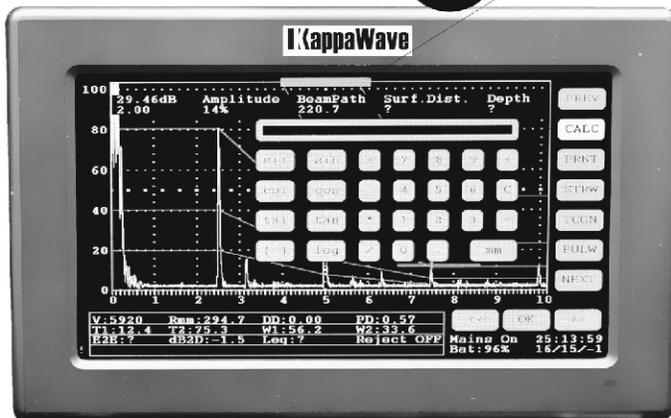
100 small divisions. 25mm to 6m Range in Steel

Select any file to open in computer

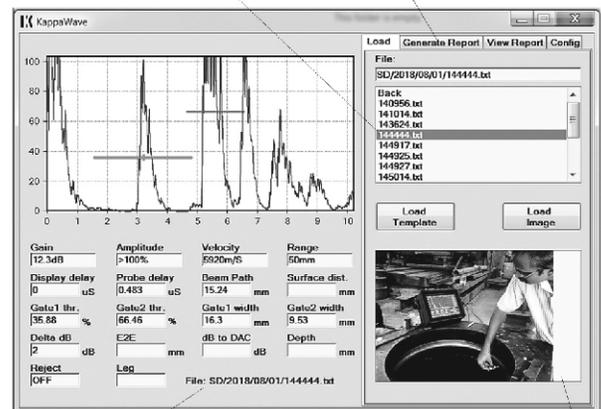
Enter data for report

1.2Kg
16Hr Li-ion

Visual & Audible Alarm



Model K8 with 17.7cm touchscreen display



Test file info

Add photos or drawings to report

KAPPAWAVE