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REVIEW

Solubility Data of Glycine in Water and Justification of Literature Results

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Glycine has been studied more than other amino acids. However, there are still insufficient reviews in the field related to glycine solubility data which is why in the present review authors have collected many solubility data of glycine in pure water and in the presence of inorganic and organic electrolytes from previous articles. In the current review, authors have considered 145 results reported in 45 published articles. On the origin of the reported results on the solubility, a very easy linear model was applied to get a better fit for accurate solubility measurement. By analyzing the results authors expressed the solubility of glycine as a linear function of temperature with a change of solubility of 0.0866 mol kg^{-1}/K. The results were applied for the statistical analysis to estimate an accurate value of solubility which was found as 3.318 mol kg^{-1} at 298.15 K.

Keywords: Solubility, Glycine, Linear model, Standard deviation.

INTRODUCTION

The anomalous properties of amino acids in biological systems make them important class of chemical compounds in the arena of biochemical research. Due to the presence of both basic and acidic groups in this class of molecules, they associate forming complex peptides and proteins which are the basic materials of life. The solubility of glycine in water is imperative to many industries as well as nutrition research [1]. Glycine is an important metal complexing agent and it is used as intermediate in the production of a large quantity of chemical products. The solubility results of glycine are not only applied in industries but also used for some food supplements and protein drinks, some drug formulations to expand gastric absorption of drug, pet food, various products or its derivatives such as production of rubber, sponge products and fertilizers.

On the other hand, the accumulation of solubility data may help to determine the rules governing the solubility processes [2]. Before using amino acids in industrial processes as an element of pharmaceutical products or food additives; it should be extracted from mixtures, *e.g.* hydrolyzation of protein containing materials or from fermentation. This purification process can be done by fractional crystallization or by other appropriate methods of separation such as chromatographic methods. The designing and optimization of such methods are highly dependent on the solubility behaviour of amino acids. The information of the nature of interactions between polar and nonpolar groups and water is useful in understanding the behaviour of more complex systems in aqueous solutions such as proteins can be clarified by the solubility behaviour of amino acids [3-11]. In particular, solubility data of glycine have been applied to describe their thermodynamic and kinetic behaviour in terms of glycine-glycine, glycine-water and water-water interactions as well as in the design and optimization of several industrial processes [12,13].

The solubility of glycine has been accounted by most of the workers at 298.15 K, which are found to be very much similar. However, Lu *et al*. [14] and Seidell and Linke *et al*. [15] reported significantly less solubility of glycine in comparison to other. In many theoretical studies, the solubilities of glycine have been analyzed at different temperatures including at and above the boiling point of water at 373 K [16]. The theoretical results are compared with the experimental values in the present review. In some studies, it is observed that the solubility of glycine in water is decreased with the increase in temperature till a certain values and then the solubility increases with more increase in temperature [4]. The aim of the current review is to summarize and correlate the investigational and theoretical solubility data of glycine in pure water at various temperatures reported earlier. The theoretical and experimental solubility data differ significantly which might be due to expertise or experimental error. In this review, an attempt has been made in finding more accurate solubility values by applying appropriate theoretical model.

Glycine solubility in water: Solubility of glycine in various solvents including water are important in various fields such as cosmetic application, human nutrition, food product industries, biodegradable plastics and drug design [1]. In Table-1, the reported solubility of glycine in water with a variation of temperature are summarized. In the literature, solubility data were reported in different units, which is why in the present report authors converted temperature in K and solubility in molality for the better understanding of the results citing original reference and method of measurement. The reported solubility values of glycine in water were plotted against temperature range which is presented in Fig. 1.

The solubility of a substance can gives the idea about its physical and chemical properties in the experimental solution at particular temperature, pressure and pH. So, there are a lot

TABLE-1
BIBLIOGRAPHY OF STUDIES REPORTING GLYCINE SOLUBILITY IN WATER BETWEEN 273.15 AND 423 K

Temp. (K)	Method of measurement	Original units	Solubility	Solubility (mol kg^{-1})	Ref.
293.15	Gravimetric method	g/100 g water	22.553	3.007	[3]
298.15	Gravimetric method	g/100 g water	23.435	3.125	[3]
303.15	Gravimetric method	g/100 g water	24.097	3.213	[3]
308.15	Gravimetric method	g/100 g water	25.094	3.346	[3]
313.15	Gravimetric method	g/100 g water	25.345	3.379	[3]
318.15	Gravimetric method	g/100 g water	26.897	3.586	[3]
323.15	Gravimetric method	g/100 g water	26.940	3.592	[3]
293.15	Not reported	Mass fraction	23.87	3.183	[4]
298.15	Not reported	Mass fraction	20.13	2.684	[4]
303.15	Not reported	Mass fraction	21.26	2.835	[4]
313.15	Not reported	Mass fraction	24.81	3.308	[4]
323.15	Not reported	Mass fraction	26.62	3.549	[4]
288.15	Gravimetric method	g/100 g water	20.19	2.692	[5]
298.15	Gravimetric method	g/100 g water	25.02	3.336	[5]
308.15	Gravimetric method	g/100 g water	30.17	4.023	[5]
288.15	Formal titration	Mass fraction	19.95	2.660	[6]
293.15	Formal titration	Mass fraction	22.55	3.007	[6]
298.15	Formal titration	Mass fraction	24.99	3.332	[6]
303.15	Formal titration	Mass fraction	27.60	3.680	[6]
308.15	Formal titration	Mass fraction	30.16	4.021	[6]
273.15	Theoretical calculation	g/1000 g solvent	141.8	1.891	[7]
278.15	Theoretical calculation	g/1000 g solvent	160.3	2.137	[7]
283.15	Theoretical calculation	g/1000 g solvent	180.4	2.405	[7]
288.15	Theoretical calculation	g/1000 g solvent	202.0	2.693	[7]
293.15	Theoretical calculation	g/1000 g solvent	225.2	3.003	[7]
298.15	Theoretical calculation	g/1000 g solvent	249.9	3.332	[7]
303.15	Theoretical calculation	g/1000 g solvent	275.9	3.679	[7]
308.15	Theoretical calculation	g/1000 g solvent	303.2	4.043	[7]
313.15	Theoretical calculation	g/1000 g solvent	331.6	4.421	[7]
318.15	Theoretical calculation	g/1000 g solvent	361.0	4.813	[7]
323.15	Theoretical calculation	g/1000 g solvent	391.0	5.213	[7]
328.15	Theoretical calculation	g/1000 g solvent	421.8	5.624	[7]
333.15	Theoretical calculation	g/1000 g solvent	452.6	6.035	[7]
338.15	Theoretical calculation	g/1000 g solvent	483.5	6.447	[7]
343.15	Theoretical calculation	g/1000 g solvent	513.9	6.852	[7]
348.15	Theoretical calculation	g/1000 g solvent	543.9	7.252	[7]
373.15	Theoretical calculation	g/1000 g solvent	671.7	8.956	[7]
273.15	Gravimetric method	g/100 g water	14.31	1.908	[8]
298.15	Gravimetric method	g/100 g water	25.31	3.375	[8]
323.15	Gravimetric method	g/100 g water	40.15	5.353	[8]
348.15	Gravimetric method	g/100 g water	57.49	7.665	[8]
373.15	Calculation	g/100 g water	75.2	10.027	[8]
298.15	High-pressure method	mol kg^{-1}	3.35	3.35	[9]
298.10	Dry weight method	g/100 g water	25.16	3.355	[10]
298.15	Gravimetric method	molal	2.90	2.90	[11]
298.15	Gravimetric method	g/mL	0.2178	2.904	[12]
298.15	Dry weight method	mol dm^{-3}	2.31	2.31	[13]

298.15	Gravimetric method	mol dm^{-3}	3.504	3.504	[29]
298.15	Gravimetric method	Mass fraction	0.19074	3.140	[30]
313.15	Gravimetric method	Mass fraction	0.23871	4.181	[30]
323.15	Gravimetric method	Mass fraction	0.27128	4.964	[30]
333.15	Gravimetric method	Mass fraction	0.30598	5.878	[30]
333.15	Dry weight method	g/g of water	0.4526	6.035	[31]
293.15	Gravimetric method	g/1000 g solvent	196.1	2.615	[32]
294.00	Gravimetric method	g/1000 g solvent	196.4	2.619	[32]
298.15	Gravimetric method	g/1000 g solvent	216.6	2.888	[32]
298.15	Gravimetric method	g/1000 g solvent	235.70	3.143	[33]
298.15	Dry weight method	mol kg^{-1}	3.338	3.338	[34]
288.15	Formal titration	g/l00 g solvent	20.19	2.692	[35]
298.15	Formal titration	g/l00 g solvent	25.02	3.336	[35]
303.15	Formal titration	g/l00 g solvent	30.17	4.023	[35]
298.15	Dry weight and Kjeldahl methods	g/l00 g solvent	25.0	3.333	[36]
298.15	Dry weight method	s/mg mL^{-1}	206.41	2.752	[14]
298.15	–	s/mg mL^{-1}	214.25	2.857	[15]
298.15	Dry weight method	s/mg mL^{-1}	205.77	2.744	[37]
323.15	Gravimetric method	g/100 g of water	37.23	4.964	[38]
290.20	Analytical procedure using an interferometer	mmol/1 mol water	50.04	2.777	[2]
292.70	Analytical procedure using an interferometer	mmol/1 mol water	52.25	2.899	[2]
294.70	Analytical procedure using an interferometer	mmol/1 mol water	53.64	2.977	[2]
296.20	Analytical procedure using an interferometer	mmol/1 mol water	55.61	3.086	[2]
297.70	Analytical procedure using an interferometer	mmol/1 mol water	57.98	3.218	[2]
300.70	Analytical procedure using an interferometer	mmol/1 mol water	60.19	3.341	[2]
303.20	Analytical procedure using an interferometer	mmol/1 mol water	63.17	3.506	[2]
305.70	Analytical procedure using an interferometer	mmol/1 mol water	65.71	3.647	[2]
307.00	Analytical procedure using an interferometer	mmol/1 mol water	66.81	3.708	[2]
310.70	Analytical procedure using an interferometer	mmol/1 mol water	68.06	3.777	[2]
310.70	Analytical procedure using an interferometer	mmol/1 mol water	69.81	3.874	[2]
312.70	Analytical procedure using an interferometer	mmol/1 mol water	72.28	4.012	[2]
313.70	Analytical procedure using an interferometer	mmol/1 mol water	74.99	4.162	[2]
315.60	Analytical procedure using an interferometer	mmol/1 mol water	76.29	4.234	[2]
317.20	Analytical procedure using an interferometer	mmol/1 mol water	80.53	4.469	[2]
310.70	Analytical procedure using an interferometer	mmol/1 mol water	82.31	4.568	[2]
318.70	Analytical procedure using an interferometer	mmol/1 mol water	82.91	4.602	[2]
319.70	Analytical procedure using an interferometer	mmol/1 mol water	85.02	4.719	[2]
321.70	Analytical procedure using an interferometer	mmol/1 mol water	87.63	4.880	[2]
324.70	Analytical procedure using an interferometer	mmol/1 mol water	91.31	5.068	[2]
326.40	Analytical procedure using an interferometer	mmol/1 mol water	93.08	5.166	[2]
328.20	Analytical procedure using an interferometer	mmol/1 mol water	96.78	5.371	[2]
329.20	Analytical procedure using an interferometer	mmol/1 mol water	98.33	5.457	[2]
331.50	Analytical procedure using an interferometer	mmol/1 mol water	100.28	5.566	[2]
298.15	Gravimetric method	g/1000 g solvent	235.70	3.143	[39]
298.20	Dry weight method	m/mol kg^{-1}	3.333	3.333	[40]
298.10	Dry weight method	g/100 solvent	25.1	3.347	[41]
298.10	Dry weight method	g/100 solvent	25.0	3.333	[42]
298.10	Dry weight method	g/100 solvent	25.09	3.345	[43]
298.15	Gravimetric method	mol kg^{-1}	3.32	3.32	[44]
293.15	Dynamic laser method	Mole fraction	0.0512	2.995	[25]
303.15	Dynamic laser method	Mole fraction	0.0619	3.662	[26]
313.15	Dynamic laser method	Mole fraction	0.0726	4.345	[25]
323.15	Dynamic laser method	Mole fraction	0.0844	5.116	[25]
333.15	Dynamic laser method	Mole fraction	0.0963	5.914	[25]
343.15	Dynamic laser method	Mole fraction	0.1098	6.846	[25]
298.20	Dry weight method	g/1000 g solvent	249.9	3.332	[45]
288.15	Gravimetric method	mol kg^{-1}	2.998	2.998	[46]
293.15	Gravimetric method	mol kg^{-1}	3.303	3.303	[46]
298.15	Gravimetric method	mol kg^{-1}	3.389	3.389	[46]
303.15	Gravimetric method	mol kg^{-1}	3.547	3.547	[46]
308.15	Gravimetric method	mol kg^{-1}	3.791	3.791	[46]
288.15	Formal titration	mol dm^{-3}	2.680	2.680	[47]
293.15	Formal titration	mol dm^{-3}	3.009	3.009	[47]
298.15	Formal titration	mol dm^{-3}	3.330	3.330	[47]
303.15	Formal titration	mol dm^{-3}	3.670	3.670	[47]
308.15	Formal titration	mol dm^{-3}	4.020	4.020	[47]
298.15	Theoretical calculation	Molality	3.370	3.370	[16]
323.00	Theoretical calculation	Molality	5.295	5.295	[16]
373.00	Theoretical calculation	Molality	10.005	10.005	[16]
423.00	Theoretical calculation	Molality	14.932	14.932	[16]

473.00	Theoretical calculation	Molality	19.113	19.113	[16]
283.15	Dynamic method	mol kg^{-1}	2.3331	2.3331	[48,49]
293.15	Dynamic method	mol kg^{-1}	2.9865	2.9865	[48,49]
303.15	Dynamic method	mol kg^{-1}	3.6383	3.6383	[48,49]
313.15	Dynamic method	mol kg^{-1}	4.3856	4.3856	[48,49]
323.15	Dynamic method	mol kg^{-1}	5.0641	5.0641	[48,49]
333.15	Dynamic method	mol kg^{-1}	5.8068	5.8068	[48,49]
343.15	Dynamic method	mol kg^{-1}	6.7132	6.7132	[48,49]
298.00	Solvent evaporation and HPLC methods	g/Kg solvent	250	3.333	[50]
288.15	Formal titration	mol kg^{-1}	2.720	2.720	[17,19]
293.15	Formal titration	mol kg^{-1}	3.060	3.060	[17,19]
298.15	Formal titration	mol kg^{-1}	3.340	3.340	[17,19]
303.15	Formal titration	mol kg^{-1}	3.720	3.720	[17,19]
308.15	Formal titration	mol kg^{-1}	4.060	4.060	[17,19]
288.15	Formal titration	mol kg^{-1}	2.700	2.700	[20]
293.15	Formal titration	mol kg^{-1}	3.045	3.045	[20]
298.15	Formal titration	mol kg^{-1}	3.339	3.339	[20]
303.15	Formal titration	mol kg^{-1}	3.680	3.680	[20]
308.15	Formal titration	mol kg^{-1}	4.042	4.042	[20]
298.15	Gravimetric method	mol kg^{-1}	3.320	3.320	[21]
288.15	Gravimetric method	mol kg^{-1}	2.749	2.749	[22]
293.15	Gravimetric method	mol kg^{-1}	3.048	3.048	[22]
298.15	Gravimetric method	mol kg^{-1}	3.339	3.339	[22]
303.15	Gravimetric method	mol kg^{-1}	3.680	3.680	[22]
308.15	Gravimetric method	mol kg^{-1}	4.046	4.046	[22]
298.15	Gravimetric method	mol kg^{-1}	3.332	3.332	[23]
323.15	Gravimetric method	mol kg^{-1}	4.082	4.082	[23]

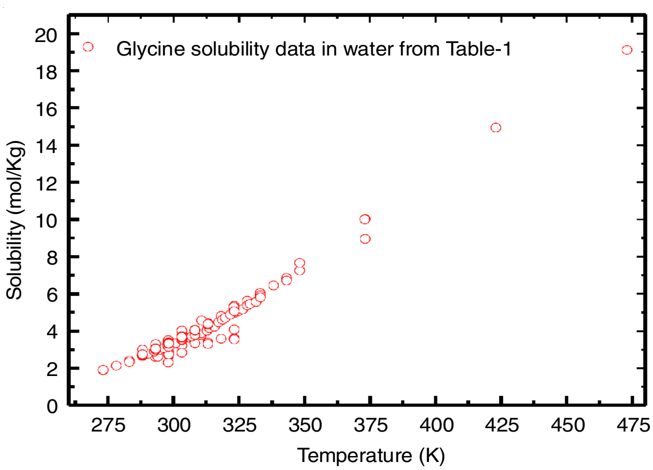

Fig. 1. Solubility of glycine as a function of temperature in water reported by the literature in Table-1

of studies in the literature on glycine-water solutions determining the solubility to describe their physical and chemical properties of it in the solution. As an example, Roy *et al.* [17-24] reported their solubility data of glycine in water at different temperature ranges to describe the solute-solute, solute-solvent, solvent-solvent interactions, which are directly related to the solvation of amino acids. Sun *et al.* [25] introduced the solubility data to clarify the dissolution mechanism based on van't Hoff equation. Such studies reported the solubility of many amino acids including glycine in many solvents composition and also homologous solvent mixtures at different temperature range [26,27]. Sometimes researcher has determined solubility of glycine in water only to compare with homologous solvents, *e.g.* Jelinska-Kazimierczuk and Szydlowski [2] reported the solubility of glycine in H_2O and D_2O by analytical procedure using an interferometer to find the isotopic effects on solubility and the solution enthalpy.

Investigations of solubility data: As maximum solubility data have been reported at 298.15 K in the literature than any other temperature, using this data a statistical analysis was performed because this temperature has been used as a common reference temperature in thermodynamics. By applying large number of data a mean concentration and confidence interval around this mean were calculated. To find the temperature dependencies of scattered data deviated from central tendency, a linear regression model was employed. The data of linear regression parameter for glycine solubility in water at 298.15 K and the linear regression parameter for glycine solubility in water as a function of temperature are summarizing in Tables 2 and 3, respectively.

Earlier solubility data have been expressed in the units of g/100 g water, g/1000 g solvent, mol kg^{-1}, g/mL, mole fraction mol dm^{-3}, s/mg mL^{-1}, mmol/1 mole-water, *etc*. In the present

TABLE-2
LINEAR REGRESSION PARAMETER FOR GLYCINE SOLUBILITY IN WATER AT 298.15 K (FOR THE DATA PRESENTED IN Fig. 2)

Parameter	Value	Standard error	R	Number of results	Squared deviation from mean m
A	3.14598	3.46305×10^{13}	9.96466×10^{-16}	27	0.07
B	5.78704×10^{-4}	1.16151×10^{11}			

The data were fit with a simple linear model: S = A + B * T; S = solubility of glycine, T = temperature in kelvin, A and B are the empirically determined parameters.

TABLE-3
LINEAR REGRESSION PARAMETER OF GLYCINE SOLUBILITY IN WATER AS A FUNCTION OF TEMPERATURE FORM THE LITERATURE DATA

Parameter	Value	Standard error	R	Number of results	Squared deviation (r^2) from mean
A	-21.73081	0.46053	0.97829	144	2.09
B	0.0835	0.00148			

review, for comparison of results, different units were converted to molality using which we performed a statistical analysis. Aitchison has clarified in his book [28,51] that wt.% is an undesirable unit for statistical analysis as all of the component percentages are constrained to sum up to 100%. This restriction cancels the expectations built into the statistics employed here and the molality (moles per kg of water) which is a ratio of components is more appropriate unit for performing statistical analysis.

Glycine solubility data analysis at 298.15 K: The summarization of statistical calculation is shown in Table-4 including estimated mean, the standard error of the estimated mean and 95% confidence interval of the estimated mean where mean value is the best estimate of true glycine solubility in water at 298.15 K. The standard error of glycine solubility data is related to the measured saturated glycine molality at 298 K. The standard deviation may be used along with the *t*-distribution to build a (1 – α)% confidence interval for the estimated solubility of glycine according to eqn 1:

$$S \pm t_{\alpha/2,n-1} S_E \quad (1)$$

where, n represents the number of observations in the data set and S represents the reported solubility of glycine in molality.

TABLE-4
SUMMARY STATISTICS OF THE SOLUBILITY OF GLYCINE IN WATER AT 298.15 K (FOR THE DATA PRESENTED IN Fig. 2)

Statistic	Full data	Lower cluster of data excluded
Estimated mean	3.19684	3.31852
Estimated standard deviation	0.26099	0.06728
Standard error	0.0428	0.01295
95 % confidence interval upper limit for	3.28386	3.34514
95 % confidence interval lower limit for	3.10982	3.29190
n (observations in data set)	37	27

In Table-2, 'full data' column showed the calculated statistics. It was observed that cluster 'f' of 24 data points lie around 3.32 molal, cluster 'd' of 4 data points lie around 2.90 molal and cluster 'e' of 4 data points lie around 3.1 molal representing in Fig. 3. Fig. 2 shows the linear regression of glycine solubility in water at 298.15 K and data are presented in Table-3. At 298.15 K, more data in the cluster of points a, b and c dare below the lower 95% confidence interval of the estimated mean of glycine concentration, these smaller clusters were assumed to be less accurate. Fig. 3 shows the clusters of points (a to g) of glycine solubility in water reported earlier in the literature which is shown in Table-1 at 298.15 K whereas, Fig. 3 represents the density (*i.e.* numbers of observations) *vs.* glycine solubility in water reported in the literature shown in Table-1 at 298.15 K.

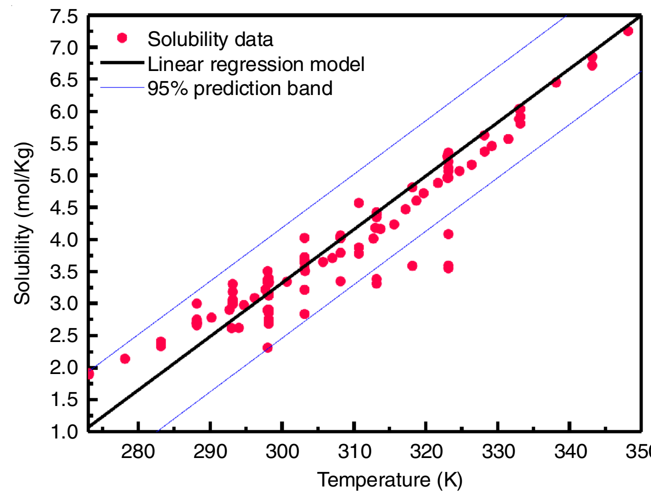

Fig. 2. Linear fit of the solubility of glycine as a function of temperature in water (with 95% confidence interval) reported by the literature in Table-1

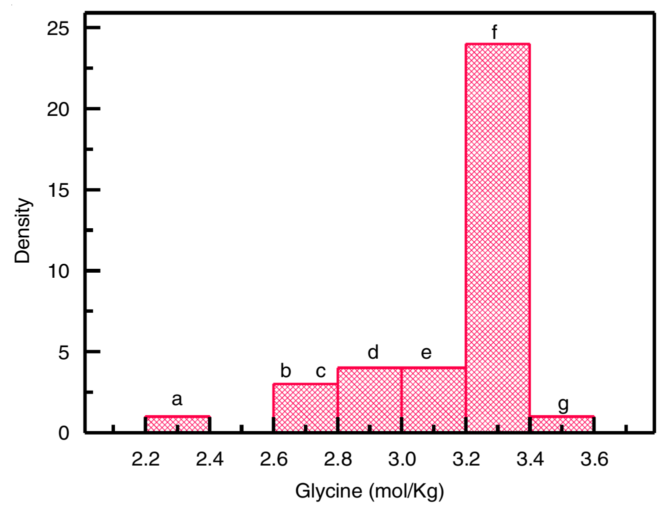

Fig. 3. Density (*i.e.* numbers of observations) *vs.* glycine solubility in water reported by the literature in Table-1 at 298.15 K

In second column the 'lower cluster of data points (a,b,c & d) and higher cluster of points (g) were excluded' only the cluster of data having 27 point (f) were included to find the mean, standard deviation, standard error, 95% confidence interval upper limit for $\hat{\mu}$ and 95% confidence interval lower limit for $\hat{\mu}$.

These results shown in the column lower cluster of data points excluded in Table-2, more likely, represent the true solubility of glycine in water at 298.15 K. Fig. 4a shows 3.318 molal solubility of glycine at 298.15 K, which approves the maximum cumulative counts 82.0 in water, which was reported in the literature in between the solubility data 3.125 to 3.389 taken from Table-1. Fig. 3 represents the counts (*i.e.* numbers of obser-

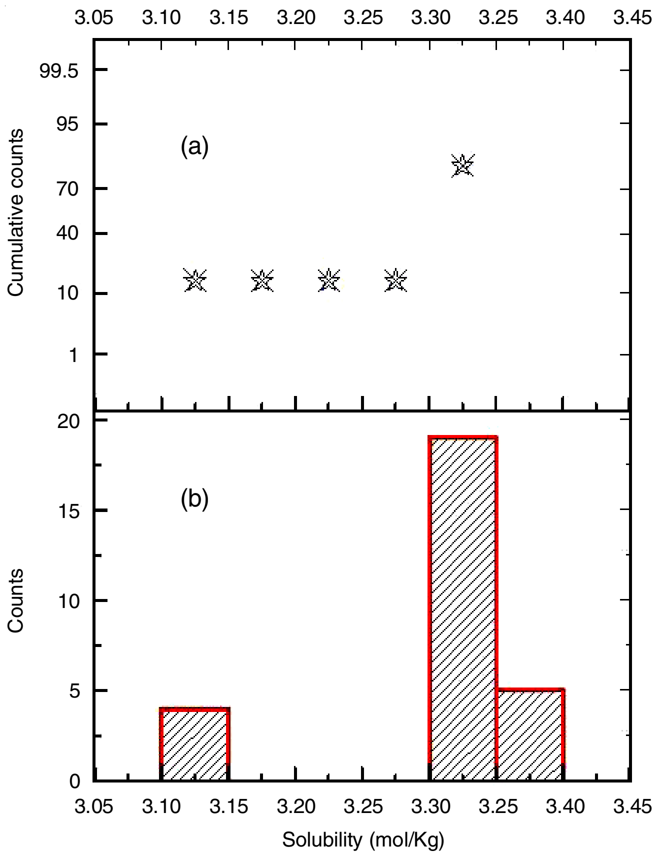

Fig. 4. (a) Solubility results of glycine 3.318 shows maximum cumulative counts 82.0 in water reported by the literature in between the solubility data 3.125 to 3.389 taken from Table-1 at 298.15 K: (b) Counts (*i.e.* numbers of observations) *vs.* glycine solubility in water reported by the literature in between the solubility data 3.125 to 3.389 taken from Table-1 at 298.15 K

vations) *vs.* glycine solubility in water reported in the literature in between the solubility data 3.125 to 3.389 taken from Table-1 at 298.15 K.

The statistical investigated accurate value of solubility, which was found as 3.318 mol kg^{-1} at 298.15 K is more precisely determined by simple gravimetric [52] and formol titrimetric methods by most of the research groups. By these methods most of the results except Romero and Oviedo [3] & Yalkowsky [4] showed less than 1.5% error and the results excellently supports the theoretical results [7].

Data analysis between 273.15 and 373.15 K: Linear fitting of the solubility data of glycine as a function of temperature in water (with 95% confidence interval) reported in the literature as shown in Table-1 is presented in Fig. 2. Temperature dependent solubility data spread has been found near about same for maximum reported papers in the literature. The six data sets that had two or more data points are called out in the graphic. The following simple linear model was applied to fit the experimental and theoretical solubility data of glycine in water.

$$S = A + B \times T \quad (2)$$

where, S = solubility of glycine in water media, T = temperature in Kelvin, A and B are the empirically determined parameters. Linear regression parameter for glycine solubility in water as a function of temperature from the literature data are given in Table-4. Reference range calculation using normal distribution (lower and upper limits of the standard reference range) is given in Table-5. The reference range calculation (for all data from Table-1) using normal distribution (lower and upper limits of the standard reference range) is given in Table-6.

TABLE-5
REFERENCE RANGE CALCULATION (DATA ARE PRESENTED IN Fig. 2) USING NORMAL DISTRIBUTION (LOWER AND UPPER LIMITS OF THE STANDARD REFERENCE RANGE)

Number of observations	Values	Deviation from mean (m)	Squared deviation from mean (m)
1	3.125	0.19	0.04
2	3.336	-0.02	0
3	3.332	-0.01	0
4	3.332	-0.01	0
5	3.375	-0.06	0
6	3.35	-0.03	0
7	3.355	-0.04	0
8	3.143	0.18	0.03
9	3.338	-0.02	0
10	3.336	-0.02	0
11	3.333	-0.01	0
12	3.143	0.18	0.03
13	3.333	-0.01	0
14	3.347	-0.03	0
15	3.333	-0.01	0
16	3.345	-0.03	0
17	3.32	0	0
18	3.332	-0.01	0
19	3.389	-0.07	0
20	3.33	-0.01	0
21	3.37	-0.05	0
22	3.333	-0.01	0
23	3.34	-0.02	0
24	3.339	-0.02	0
25	3.32	0	0
26	3.339	-0.02	0
27	3.332	-0.01	0
n = 27	Mean = 3.32	Sum/(n-1) = 0.12/26 = 0 s.d = sqrt(0) = 0.07	

The fitted model explains much of the variance in the measured molalities (r^2 = 0.07), but there is a few of noise in the data. It might be probable that some solubility performance is not perfectly captured by the simple linear model, but any nonlinearity is hidden by the scatter in the data. Consequently, this linear model signifies the best empirical approximation of the solubility of glycine in water as a function of temperature presently existing but should be re-evaluated as more data is collected.

Conclusion

In this review, the authors collected a large number of solubility data of glycine in water between 273.15 to 473.0 K. There is a large extent of scattering in the values reported at all temperatures range. The authors summarized the statistics calculation reports including estimated mean, the standard error of the estimated mean and 95% confidence interval of the estimated mean at 298.15 K. It is observed that the glycine solubility is a linear function of temperature. Here, it is represented the solubility data of glycine at different temperatures ranges with plotting

TABLE-6
REFERENCE RANGE CALCULATION (FOR ALL DATA FROM TABLE-1) USING NORMAL DISTRIBUTION (LOWER AND UPPER LIMITS OF THE STANDARD REFERENCE RANGE)

No.	Values	Deviation from mean (m)	Squared deviation from mean (m)	No.	Values	Deviation from mean (m)	Squared deviation from mean (m)
1	3.007	1.09	1.17	73	3.506	0.59	0.34
2	3.125	0.97	0.93	74	3.647	0.45	0.2
3	3.213	0.88	0.77	75	3.708	0.39	0.15
4	3.346	0.75	0.55	76	3.777	0.32	0.1
5	3.379	0.72	0.51	77	3.874	0.22	0.05
6	3.586	0.51	0.25	78	4.012	0.08	0.01
7	3.592	0.5	0.25	79	4.162	-0.07	0.01
8	3.183	0.91	0.82	80	4.234	-0.14	0.02
9	2.684	1.41	1.98	81	4.469	-0.37	0.14
10	2.835	1.26	1.58	82	4.568	-0.47	0.23
11	3.308	0.79	0.61	83	4.602	-0.51	0.26
12	3.549	0.55	0.29	84	4.719	-0.62	0.4
13	2.692	1.4	1.95	85	4.88	-0.79	0.62
14	3.336	0.76	0.57	86	5.068	-0.97	0.96
15	4.023	0.07	0	87	5.166	-1.07	1.16
16	2.66	1.43	2.04	88	5.371	-1.28	1.64
17	3.007	1.09	1.17	89	5.457	-1.36	1.87
18	3.332	0.76	0.57	90	5.566	-1.47	2.18
19	3.68	0.41	0.17	91	3.143	0.95	0.9
20	4.021	0.07	0	92	3.333	0.76	0.57
21	1.891	2.2	4.84	93	3.347	0.75	0.55
22	2.137	1.96	3.81	94	3.333	0.76	0.57
23	2.405	1.69	2.84	95	3.345	0.75	0.56
24	2.693	1.4	1.95	96	3.32	0.77	0.59
25	3.003	1.09	1.18	97	2.995	1.1	1.2
26	3.332	0.76	0.57	98	3.662	0.43	0.18
27	3.679	0.42	0.17	99	4.345	-0.25	0.07
28	4.043	0.05	0	100	5.116	-1.02	1.05
29	4.421	-0.33	0.11	101	5.914	-1.82	3.33
30	4.813	-0.72	0.52	102	6.846	-2.75	7.6
31	5.213	-1.12	1.26	103	3.332	0.76	0.57
32	5.624	-1.53	2.35	104	2.998	1.1	1.19
33	6.035	-1.94	3.78	105	3.303	0.79	0.62
34	6.447	-2.35	5.56	106	3.389	0.71	0.49
35	6.852	-2.76	7.63	107	3.547	0.55	0.29
36	7.252	-3.16	10	108	3.791	0.3	0.09
37	8.956	-4.86	23.68	109	2.68	1.41	1.99
38	1.908	2.19	4.76	110	3.009	1.09	1.17
39	3.375	0.72	0.51	111	3.33	0.76	0.58
40	5.353	-1.26	1.6	112	3.67	0.42	0.18
41	7.665	-3.57	12.78	113	4.02	0.07	0
42	10.027	-5.93	35.25	114	3.37	0.72	0.52
43	3.35	0.74	0.55	115	5.295	-1.2	1.45
44	3.355	0.74	0.54	116	10	-5.91	34.93
45	2.9	1.19	1.42	117	14.932	-10.84	117.55
46	2.904	1.19	1.41	118	19.113	-15.02	225.69
47	2.31	1.78	3.17	119	2.3331	1.76	3.09
48	3.504	0.59	0.34	120	2.9865	1.11	1.22
49	3.14	0.95	0.9	121	3.6383	0.46	0.2
50	4.18	-0.09	0.01	122	4.3856	-0.29	0.09
51	4.964	-0.87	0.76	123	5.0641	-0.97	0.95
52	5.878	-1.78	3.2	124	5.8068	-1.71	2.95
53	6.035	-1.94	3.78	125	6.7132	-2.62	6.88
54	2.615	1.48	2.18	126	3.333	0.76	0.57
55	2.619	1.48	2.16	127	2.72	1.37	1.88
56	2.888	1.21	1.44	128	3.06	1.03	1.06
57	3.143	0.95	0.9	129	3.34	0.75	0.56
58	3.338	0.76	0.57	130	3.72	0.37	0.14
59	2.692	1.4	1.95	131	4.06	0.03	0
60	3.336	0.76	0.57	132	2.7	1.39	1.93
61	4.023	0.07	0	133	3.045	1.05	1.09
62	3.333	0.76	0.57	134	3.339	0.76	0.56
63	2.752	1.34	1.79	135	3.68	0.41	0.17

64	2.857	1.24	1.52	136	4.042	0.05	0
65	2.744	1.35	1.81	137	3.32	0.77	0.59
66	4.964	-0.87	0.76	138	2.749	1.35	1.8
67	2.777	1.32	1.72	139	3.048	1.05	1.09
68	2.899	1.2	1.42	140	3.339	0.76	0.56
69	2.977	1.12	1.24	141	3.68	0.41	0.17
70	3.086	1.01	1.01	142	4.046	0.05	0
71	3.218	0.88	0.76	143	3.332	0.76	0.57
72	3.341	0.75	0.56	144	4.082	0.01	0
				n=144	Mean = 4.09	Sum/(n-1) = 623.3/143 = 4.36 s.d = sqrt(4.36) = 2.09	

the linear regression model to find the true solubility. The true solubility of glycine in water at 298.15 K is likely in between 3.125 to 3.389 molal, with the most likely value of 3.318 molal. The change in glycine solubility in water with temperature is approximately 0.0866 molal/K.

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CONFLICT OF INTEREST

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

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