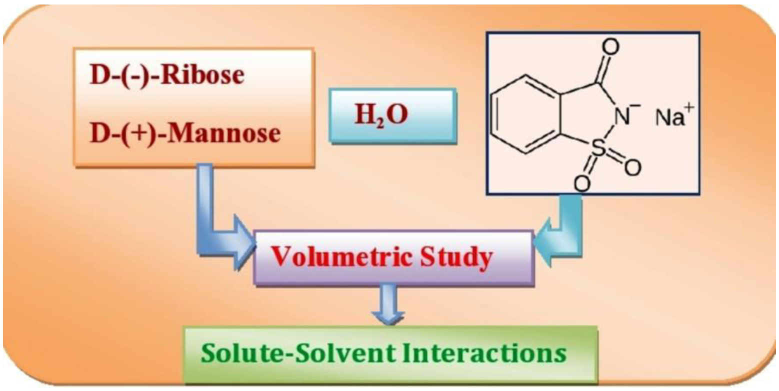
ISSN PRINT 2319 1775 Online 2320 7876

*Research paper*  UGC CARE Listed ( Group -I) Journal Volume 11, S Iss 3, Dec 2022

# Volumetric Study Of Monosaccharides (D-Ribose And D-Mannose)-Saccharin Sodium Salt In Aqueous Solutions At *T* = 298.15 K.

**Sanjeevan J. Kharat*[1], Valmik R. Jondhale[2]**
[1]Department of Chemistry, HPT Arts and RYK Science College, Nashik- 422 005, India.
[2]Department of Chemistry, GES Arts Commerce and Science College, Shreewardhan, Raigad-402 110, India.
*Corresponding author: sanjeevan.kharat@gmail.com

## Graphical abstract




**ABSTRACT:** Using a volumetric approach, monosaccharides were investigated in terms of temperature and different concentrations. At $T$ = 298.15 K, the densities of D(-)-ribose, D(+)-mannose in $H_2O$ and in aqueous saccharin Na salt with molality, $m$ = (0.05, 0.15, and 0.3) mol·kg$^{-1}$ were determined. The apparent molar volumes ($V_\phi$), partial molar volumes ($V_\phi^0$), and Masson's coefficient ($S_v$) were evaluated by means of experimental density ($\rho$) values. The data was further analysed in terms of transfer characteristics ($\Delta_{trs}V_\phi^0$), apparent specific volumes (ASV), and volumetric interaction coefficients ($V_{AB}$,$V_{ABB}$ using McMillan–Mayer theory). The significant interactions between the hydrophilic groups of solute (D-ribose and D-mannose) and the $Na^+$ ion of cosolute (saccharin sodium salt) at varied concentrations have been reported. Studied saccharide was found to have a sweet taste in mixed aqueous sodium saccharin.

**Keywords**: Apparent specific volume, Density, Monosaccharide, Partial molar volume, Sodium saccharin.

## INTRODUCTION

Recent work has examined the nature and degree of intermolecular interaction in aqueous solutions of combinations using thermophysical characteristics. Depending on the number of saccharide units present, sugars are divided into four different types. Simple sugars like glucose, fructose, galactose, mannose, ribose, xylose, arabinose, etc are called monosaccharides. Carbohydrates are the most prominent source of energy consumed by humans[1]. It also performs an important role in the regulation of living creatures throughout biologically based cycles[2,3]. The hydration abilities of saccharides are due to their hydrophilic hydroxyl groups (-OH)[4,5]. Sugar is important in confections and medicine because it not only adds sweetness but also improves the texture of foods, improves taste, exerts stability, and

ISSN PRINT 2319 1775 Online 2320 7876

Research paper © 2012 IJFANS. All Rights Reserved, UGC CARE Listed ( Group -I) Journal Volume 11, S Iss 3, Dec 2022

thus protects vitamins during processing and storage. Saccharides in $H_2O$ electrolyte arrangements play an important role in a number of scientific fields[6-10], including biology, pharmaceutical preparations, catalysis, climate, and food preparation. Recent data from the literature suggests that saccharide-metal ion blends have been extensively studied, further interpreted as interactions among solute-solute and solute-solvent [11-14].

Today, a range of new sweeteners are available as a substitute for natural sugars. Many man-made sweeteners[15-20] are available, of which Aspartame, Sucralose, Saccharin Na salt, and Acesulfame K are approved by the "Food and Drug Administration" (FDA) for use in the food and pharmaceutical industry. Blending sweeteners[21-23] with sugars is to reduce the amount used, reduce the cost, and improve the taste. Molecular interactions between sugar and the receptor form via $H_2O$ molecules that surround them. The conduct of metal ions with saccharides in aqueous solutions is useful to comprehend solute-solvent (sugar-$H_2O$) and solute-cosolute (sugar-saccharin) interactions along with taste.

The D-ribose and D-mannose (0.04-0.20) $m$ densities were evaluated at $T$ = 298.15 K in $H_2O$ and in aqueous saccharin Na salt with molalities of 0.05, 0.15, and 0.3 $m$. The interactions between saccharide (D-ribose and D-mannose)-saccharin sodium salt in an aqueous media were discovered through partial molar volumes, transfer characteristics, interaction coefficients, and apparent specific volumes.

## Materials and Methods

D(-)-ribose, D(+)-mannose, and saccharin Na salt were purchased with a purity of 99.0% from Sigma and used.

Aqueous solutions of solute and cosolute were prepared using triply distilled freshly prepared water and a stoppered airtight glass bottle. Similarly, measurements were done on a weight-by-weight (w/w) scale with an accuracy of ± 0.0001 g on a Dhona balance. $H_2O$ is used as a solvent and saccharide is used as a solute in both binary and ternary solutions with saccharin Na salt as a stock solution for subsequent usage.

The densities ($\rho$) of D(-)-ribose and D(+)-mannose in $H_2O$ and in aqueous saccharin Na salt were measured experimentally using a bi-capillary Pycnometer[24-29] at $T$ = 298.15 K. To submerge the pycnometer in a vertical position, a glass-walled water bath with a constant temperature of ± 0.01 K was utilized. At the studied temperature, the Pycnometer was calibrated by using organic solvents like ethyl acetate, carbon tetrachloride, and acetophenone. When the outcomes were compared to the reported results, it was revealed that they were in good agreement. Solvent density at the studied temperature was taken from published data[30,31]. The investigational variability in density determinations was 0.2 $kg\cdot m^{-3}$. The density of studied systems (saccharide with stock solution sodium saccharin) was investigated using the same method.

## Results and Discussion

### Volumetric study of D(-)-Ribose and D(+)-Mannose in aqueous solutions of saccharin sodium.

### Apparent molar volume

At $T$ = 298.15 K, the thermophysical characteristics and parameters of saccharides in aqueous sodium saccharin are studied. The apparent molar volumes ($V_\phi$) of the studied saccharide in $H_2O$ and in saccharin Na were calculated with the equation[5,32].

$$V_\phi = M/\rho - (\rho - \rho_o)/(m\rho\rho_o) \quad (1)$$

ISSN PRINT 2319 1775 Online 2320 7876

*Research paper* © 2012 IJFANS. All Rights Reserved, UGC CARE Listed ( Group -I) Journal Volume 11, S Iss 3, Dec 2022

In this equation, apparent molar volume is represented by $V_\phi$. Similarly, the density of a solution is denoted by $\rho$ and its molality is denoted by $m$. The molar mass of a solute is also indicated by M.

The $\rho$, and $V_\phi$ of D(-)-ribose, and D(+)-mannose in $H_2O$ and in aqueous saccharin Na salt, $m$ = (0.05, 0.15, and 0.3) mol·kg$^{-1}$ at $T$ = 298.15 K are shown in Table 1 and 2, respectively. The results show that, observed densities and apparent molar volumes depend on concentration and vary linearly with solute and cosolute concentrations.

By the least-square fit approach and Masson's equation[33,34], the $V_\phi$,values of binary and ternary mixtures are correlated with molality as shown below:

$$V_\phi = V_\phi^0 + S_v.m \qquad 2$$

The equation (2) is in the form y = mx + c, with an intercept, $V_\phi^0$(partial molar volume), and a slope, $S_v$(Masson's coefficient).

The results of $V_\phi^0$ are summarized in Table 3, while variations of $V_\phi$ of D-ribose, and D-mannose in $H_2O$, and in aqueous saccharin sodium with molalities, $m$ = (0.05, 0.15, and 0.3) mol·kg$^{-1}$ are represented in Fig. 1, and 2. The reported values of $V_\phi^0$(m$^3$·mol$^{-1}$) of D-mannose in $H_2O$ at $T$ = 298.15 K are (111.30[4], 111.7[35,36], and 111.72[37])·10$^{-6}$. Table 3 shows the $V_\phi^0$ estimated at $T$ = 298.15 K, from the present study is (111.7)·10$^{-6}$/(m$^3$·mol$^{-1}$). Similarly, for D-ribose the reported values at 298.15 K are (95.26[38], and 95.3[39,40])·10$^{-6}$ while the calculated value at the same temperature is (95.3)·10$^{-6}$/(m$^3$·mol$^{-1}$). The $V_\phi^0$ of D-ribose and D-mannose in $H_2O$ are in good accord with published figures in the literature at the investigated temperature.

The positive $V_\phi^0$ values offer significant solute-solvent interactions for molality, $m$ = (0.05, 0.15 and 0.3) of the saccharide-saccharin sodium salt system[41,42]. Additionally, the Masson's coefficients ($S_v$) are positive but less than the values of $V_\phi^0$. It shows that solute-solute interactions[43] are much lower than those between solute and solvent.

**Table 1: Densities ($\rho$/kg·m$^{-3}$), and apparent molar volumes ( $V_\phi$ /m$^3$·mol$^{-1}$) of monosaccharides in $H_2O$ at $T$ = 298.15 K.**

| **D(-)-Ribose** | | | **D(+)-Mannose** | | |
|---|---|---|---|---|---|
| ***m*** **(mol·kg$^{-1}$)** | **$\rho$ /(kg·m$^{-3}$)** | **$V_\phi$·10$^6$/(m$^3$·mol$^{-1}$)** | ***m*** **(mol·kg$^{-1}$)** | **$\rho$ /(kg·m$^{-3}$)** | **$V_\phi$·10$^6$/(m$^3$·mol$^{-1}$)** |
| 0.0000 | 997.1 | 95.3 | 0.0000 | 997.1 | |
| 0.0431 | 999.4 | 95.4 | 0.0372 | 999.6 | 111.8 |
| 0.0814 | 1002 | 95.4 | 0.0805 | 1002 | 111.9 |
| 0.1208 | 1004 | 95.5 | 0.1210 | 1005 | 112.0 |
| 0.1611 | 1006 | 95.5 | 0.1603 | 1008 | 112.1 |
| 0.2076 | 1008 | 95.3 | 0.2056 | 1011 | 112.3 |

**Table 2: Densities ($\rho$/kg·m$^{-3}$), and apparent molar volumes ( $V_\phi$ /m$^3$·mol$^{-1}$) of monosaccharides in aqueous saccharin Na salt at $T$ = 298.15 K.**

ISSN PRINT 2319 1775 Online 2320 7876

*Research paper*  UGC CARE Listed ( Group -I) Journal Volume 11, S Iss 3, Dec 2022

| *m* (mol.kg$^{-1}$) | $\rho$ /(kg·m$^{-3}$) | $V_\phi \cdot 10^6$/ (m$^3$·mol$^{-1}$) | *m* (mol·kg$^{-1}$) | $\rho$ /(kg·m$^{-3}$) | $V_\phi \cdot 10^6$/ (m$^3$·mol$^{-1}$) | *m* (mol·kg$^{-1}$) | $\rho$ /(kg·m$^{-3}$) | $V_\phi \cdot 10^6$/ (m$^3$·mol$^{-1}$) |
|---|---|---|---|---|---|---|---|---|
| | ***0.05*** | | | ***0.15*** | | | ***0.3*** | |
| D(-)-Ribose + Sodium saccharin | | | | | | | | |
| 0.0000 | 1001 | | 0.0000 | 1009 | | 0.0000 | 1022 | |
| 0.0370 | 1004 | 95.7 | 0.0399 | 1011 | 95.8 | 0.0385 | 1024 | 95.9 |
| 0.0798 | 1006 | 95.7 | 0.0798 | 1013 | 96.0 | 0.0809 | 1026 | 96.1 |
| 0.1199 | 1008 | 95.8 | 0.1287 | 1016 | 96.2 | 0.1236 | 1028 | 96.2 |
| 0.1598 | 1010 | 95.9 | 0.1663 | 1018 | 96.3 | 0.1674 | 1031 | 96.4 |
| 0.1998 | 1012 | 96.0 | 0.2079 | 1020 | 96.4 | 0.2013 | 1032 | 96.5 |
| D(+)-Mannose + Sodium saccharin | | | | | | | | |
| 0.0000 | 1002 | | 0.0000 | 1008 | | 0.0000 | 1022 | |
| 0.0395 | 1004 | 112.3 | 0.0421 | 1011 | 112.4 | 0.0409 | 1024 | 112.8 |
| 0.0790 | 1007 | 112.4 | 0.0810 | 1013 | 112.5 | 0.0812 | 1027 | 112.9 |
| 0.1190 | 1010 | 112.6 | 0.1237 | 1016 | 112.6 | 0.1199 | 1030 | 113.1 |
| 0.1597 | 1012 | 112.7 | 0.1662 | 1019 | 112.7 | 0.1632 | 1032 | 113.2 |
| 0.1901 | 1014 | 112.8 | 0.2133 | 1022 | 112.9 | 0.2010 | 1034 | 113.4 |

**Table 3: ($V_\phi^0$), ($S_v$), *ASV*, and ($\Delta_{trs}V_\phi^0$) of monosaccharides in $H_2O$, and in aqueous saccharin Na salt at *T* = 298.15 K.**

| **System** | **Parameters** | | | |
|---|---|---|---|---|
| | **$V_\phi^0 \cdot 10^6$/(m$^3$·mol$^{-1}$)** | **$S_v \cdot 10^6$ /(m$^3$·kg·mol$^{-2}$)** | **ASV $\cdot 10^6$/(m$^3$·kg$^{-1}$)** | **($\Delta_{trs}V_\phi^0$) $\cdot 10^6$/(m$^3$·mol$^{-1}$)** |
| D(-)-Ribose + $H_2O$ | 95.3 | 1.1 | 0.63 | |
| D(+)-Mannose + $H_2O$ | 111.7 | 2.78 | 0.62 | |
| D(-)-Ribose + 0.05 *m* Sodium saccharin | 95.6 | 2.09 | 0.64 | 0.28 |
| D(-)-Ribose + 0.15 *m* Sodium saccharin | 95.7 | 3.40 | 0.64 | 0.44 |
| D(-)-Ribose + 0.3 *m* Sodium saccharin | 95.8 | 3.21 | 0.64 | 0.53 |

ISSN PRINT 2319 1775 Online 2320 7876

Research paper © 2012 IJFANS. All Rights Reserved, UGC CARE Listed ( Group -I) Journal Volume 11, S Iss 3, Dec 2022

| | | | | |
|---|---|---|---|---|
| D(+)-Mannose + 0.05 *m* Sodium saccharin | 112.2 | 3.23 | 0.62 | 0.49 |
| D(+)-Mannose + 0.15 *m* Sodium saccharin | 112.4 | 2.41 | 0.62 | 0.64 |
| D(+)-Mannose + 0.3 *m* Sodium saccharin | 112.7 | 3.41 | 0.62 | 0.97 |

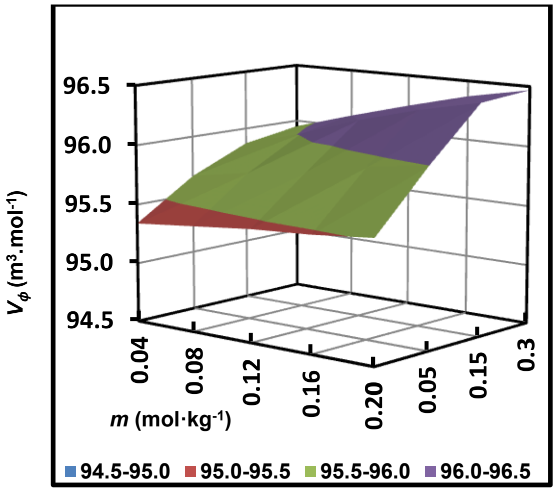
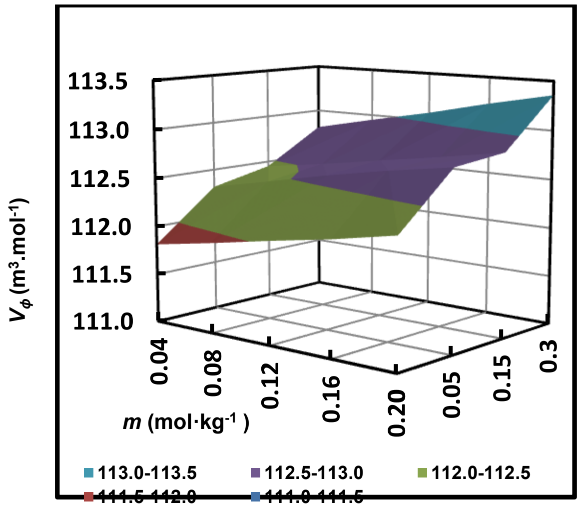



**Figure 1:** Graph of $V_\phi$ of D(-)-ribose in $H_2O$ and in saccharin Na salt with molality, $m$ = (0.05, 0.15, 0.3) mol·kg$^{-1}$ at 298.15 K.




.

**Figure 2:** Graph of $V_\phi$ of D(+)-mannose in $H_2O$ and in saccharin Na salt with molality, $m$ = (0.05, 0.15, 0.3) mol·kg$^{-1}$ at 298.15 K.

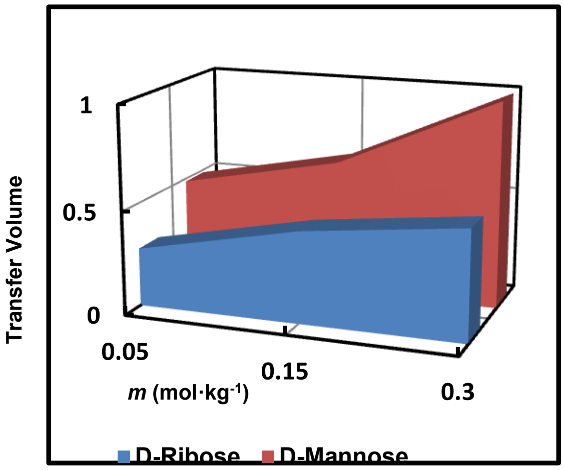



**Figure 3:** Partial molar volume of transfer, ($\Delta_{trs}V_{\phi}^{O}$) of D(-)-ribose and D(+)-mannose in saccharin Na salt with molality, $m$ = (0.05, 0.15, 0.3) mol·kg$^{-1}$ at 298.15 K.

**Transfer volume**

Using the following relation[40], the transfer volume of ($\Delta_{trs}V_{\phi}^{0}$) monosaccharides from $H_2O$ to aqueous saccharin Na Salt was obtained for the investigated systems at infinite dilution.

$$\Delta_{trs}V_{\phi}^{0} = V_{\phi}^{0}(\text{in sodium saccharin}) - V_{\phi}^{0}\ (\text{in H}_2\text{O}) \qquad 6$$

Table 3 shows the D-ribose and D-mannose $V_{\phi}^{0}$ values that can be used to determine ($\Delta_{trs}V_{\phi}^{0}$) from $H_2O$ to aqueous saccharin sodium with molality $m$. The $\Delta_{trs}V_{\phi}^{0}$ is positive at infinite dilution, often used to examine solute-cosolute interactions in aqueous medium[43] and increases with the concentration of cosolute[36]. Fig. 3 shows the variations in the transfer volume at infinite dilution ($\Delta_{trs}V_{\phi}^{0}$) with molalities, $m$ of saccharin Na at experimental temperature.

In the present study, two possible types of interaction happening among monosaccharide (D-ribose and D-mannose) and aqueous saccharin sodium in a ternary system could be categorized as follows[43]:

I) Hydrophilic-ionic interactions among monosaccharide hydrophilic groups (-C=O, -OH and -O-), and the $Na^+$ ion of saccharin Na salt.

II) Hydrophobic-ionic interactions among monosaccharide and cosolute ion.

In accordance with the "co-sphere overlap model[44]", type (I) interactions positively contribute to the $\Delta_{trs}V_{\phi}^{0}$ whereas type (II) interactions negatively contribute to the $\Delta_{trs}V_{\phi}^{0}$. Kumar et al.[45] reported similar results.

**Volumetric Interaction Coefficients**

Kozak et al[46,47] established the "McMillan-Mayer theory" of solutions in order to study volumetric interaction coefficients. On the basis of this, Krishnan et al.[48] explored the interactions of solutes and cosolutes in solvation spheres. Numerous researchers have investigated interactions in aqueous solutions using the theory[49-51].

The transfer volume is also related as:

$$\Delta_{trs}V_{\phi}^{0} = 2V_{AB}m_B + 3V_{ABB}m_B^2 + - - - - \qquad 7$$

D-ribose and D-mannose (solutes) are represented by A, while saccharin sodium (co-solute) is represented by B. These parameters were evaluated by analyzing investigational

*Research paper* © 2012 IJFANS. All Rights Reserved, UGC CARE Listed ( Group -I) Journal Volume 11, S Iss 3, Dec 2022

figures and using the least-squares approach to equation 7. The calculated values of $V_{AB}$for D-ribose and D-mannose are (2.34, and 3.38)·$10^{-6}$/($m^3$·$mol^{-2}$·kg), whereas those for $V_{ABB}$ are (-3.25, and -4.01)·$10^{-6}$/($m^3$·$mol^3$·$kg^2$), respectively, at $T$ = 298.15 K. Positive figures are contributed by the doublet interaction parameter ( $V_{AB}$) , whereas negative figures are contributed by the triplet interaction parameter[43] ($V_{ABB}$). Positive $V_{AB}$ figures illustrate that, monosaccharide (D-ribose and D-mannose), and saccharin Na have strong synergy. Negative figures of $V_{ABB}$ signify the nonexistence of D-ribose/mannose-saccharin-saccharin relations. Jiang and coworkers[52] noted a similar observation for ternary systems at 298.15 K.

The "Group Additivity Model" of Savage and Wood[53] examines the four forms of pair interactions involving saccharin Na (electrolyte), and D-ribose/mannose (non-electrolyte). The $Na^+$ – R (-R is an alkyl group) makes a small negative input (type I interaction) to $V_{AB}$ and Type II interaction of Anion – R contributes negatively to $V_{AB}$ also Type III interaction between $Na^+$– O is more dominant and contributes positively to $V_{AB}$(-O, hydrophilic groups in non-electrolyte) whereas type IV interaction of anion - O, contributes negatively to $V_{AB}$ but smaller than type I (hydrophobic groups).

In an aqueous medium, the complete dissociation of ions of saccharin Na takes place. The pair interaction coefficient of sodium ion with hydrophilic groups of monosaccharides (-OH, C=O, and -O-) is positive. Both theories anticipate that interactions linking solutes (D-ribose and D-mannose) and cosolute (saccharin sodium) are taking place.

**Apparent Specific Volume (ASV)**

It is helpful for getting data with respect to the taste conduct of sugars in blended aqueous sodium saccharin solutions. The aqueous solutions are classified as salty, sweet, bitter, and sour with respect to taste by Shamil and Birch[54]. The ASV range suggested by Parke et al[55], for sweet molecules is from (0.51 to 0.71)·$10^{-6}$/($m^3$·$kg^{-1}$) with an ideal value of (0.618)·$10^{-6}$/($m^3$·$kg^{-1}$) at the centre. The equation (8) is used to calculate the ASV of solutes in solvent and cosolute.

$$\text{ASV}=V_\phi^0/M \qquad 8$$

The solute's molar mass is denoted by M and its partial molar volume is denoted by $V_\phi^0$. Table 3 shows the ASV values of monosaccharide in $H_2O$, and saccharin sodium at the examined concentrations and temperature. At experimental temperature, the ASV values for ribose range from (0.635 to 0.638)·$10^{-6}$/($m^3$·$kg^{-1}$), while those for mannose range from (0.620 to 0.625)·$10^{-6}$/($m^3$·$kg^{-1}$). The saccharides examined in this study when incorporated into saccharin sodium stock solutions kept their sweetness.

**Conclusions**

Volumetric data of monosaccharides (D(-)-ribose, and D(+)-mannose) in $H_2O$ and aqueous saccharin sodium salt at $T$ = 298.15 K are included in this study. The investigational data were utilized to compute thermodynamic parameters such as $V_\phi$, $V_\phi{}^0$, $S_v$, $\Delta_{trs}V_\phi{}^0$, ASV, and ($V_{AB}$, and $V_{ABB}$). The corresponding $\Delta_{trs}V_\phi{}^0$ of ribose and mannose shift from $H_2O$ to saccharin Na salt is positive, and its degree rises as concentration increases. Positive values of $V_{AB}$ indicate the strong interactions between the solute (D-ribose and D-mannose) and the saccharin sodium. The ASV (0.623-0.638)·$10^{-6}$/($m^3$·$kg^{-1}$) figures suggested a sweet taste for studied saccharides in blended saccharin sodium.

**Acknowledgements**

The authors would like to express their thanks to the Principal, HPT Arts and RYK Science College, Nashik, for providing essential facilities.

ISSN PRINT 2319 1775 Online 2320 7876

*Research paper*  UGC CARE Listed ( Group -I) Journal Volume 11, S Iss 3, Dec 2022

## References


1. Caffall, K. H.; Mohnen, D. The structure, function, and biosynthesis of plant cell wall pectic polysaccharides. *Carbohydrate Res*. **2009**, *344*(14), 1879-1900.
2. Franks, F. Physical Chemistry of Small Carbohydrates - Equilibrium Solution Properties. *Pure Appl. Chem.* **1987**, *59* (9), 1189–1202.
3. Birch, G. G.; Pepper, T. Protection of vitamin C by sugars and their hydrogenated derivatives. *J. Agric. Food Chem*. **1983**, *31* (5), 980-985.
4. Høiland, H.; Holvik, H. Partial Molal Volumes and Compressibilities of Carbohydrates in Water. *J Solution Chem* **1978**, *7* (8), 587–596.
5. Galema, S. A.; Hoeiland, H. Stereochemical Aspects of Hydration of Carbohydrates in Aqueous Solutions. 3. Density and Ultrasound Measurements. *The Journal of Physical Chemistry* **1991**, *95* (13), 5321–5326.
6. Angyal, S. J. Complexes of Carbohydrates with Metal Cations. I. Determination of the Extent of Complexing by N.M.R. Spectroscopy. *Australian Journal of Chemistry* **1972**, *25* (9), 1957-1966.
7. Kaiwar, S. P.; Rao, C. P. Soluble Complexes of Early First-Row Transition-Metal Ions With D-Glucose. *Carbohydrate Res* **1992**, *237*, 203–210.
8. Tajmir-Riahi, H. A. Interaction of D-Glucose with Alkaline-Earth Metal Ions. Synthesis, Spectroscopic, and Structural Characterization of Mg(II)- and Ca(II)-D-Glucose Adducts and the Effect of Metal-Ion Binding on Anomeric Configuration of the Sugar. *Carbohydr Res* **1988**, *183* (1), 35–46.
9. Lichtenthaler, F. W. Towards Improving the Utility of Ketoses as Organic Raw Materials. *Carbohydrate Res* **1998**, *313* (2), 69–89.
10. Dey, S.; Rahman, M.; Islam, M.; Dutta, S.; Hossain, M.; Dhar, P. Studies on Volumetric and Viscometric Properties of L-Glutamic Acid in Aqueous Solution of Glucose over a Range of Temperatures (298K to 323K). *Letters in Applied NanoBioScience*. 2**020**, *9*, 1547-1561.
11. Kaur, K.; Arti, S.; Ghosh, T. K.; Banipal, T. S.; Banipal, P. K. To study the interactions between saccharide/their derivatives and bactericidal cefadroxil drug: Volumetric, acoustic and molecular docking studies. *The Journal of Chemical Thermodynamics*. **2021**, *159*, 106477.
12. Amirchand, K. D.; Kaur, S.; Banipal, T. S.; Singh, V. Volumetric and 1H NMR spectroscopic studies of saccharides-calcium lactate interactions in aqueous solutions. *Journal of Molecular Liquids*, **2021**, *334*, 116077.
13. Sharma, M.; Banipal, P. K.; Banipal, T. S. Hydration characteristics, structural effects and the taste quality of some polyhydroxy compounds in aqueous solutions of nicotinic acid (vitamin B3) at (288.15–318.15) K. *Food Chemistry*. **2020**, *310*, 125861.
14. Panda, S.; Das, K.; Singh, V.; Deenadayalu, N.; Gardas, R. L. Volumetric and compressibility studies of monosaccharides in aqueous cholinium propanoate [Chl][Pro] solutions at different temperatures. *Journal of Molecular Liquids*. **2020**. *298*, 111955.
15. Chattopadhyay, S.; Raychaudhuri, U.; Chakraborty, R. Artificial Sweeteners – a Review. *Journal of Food Science and Technology* **2011**, *51* (4), 611–621.
16. Harned, H. S.; Owen, B. B. *The Physical Chemistry of Electrolytic Solutions*, ACS Monograph No. 137, third ed., Reinhold Publishing Corp., New York, 1958.

ISSN PRINT 2319 1775 Online 2320 7876

*Research paper*  UGC CARE Listed ( Group -I) Journal Volume 11, S Iss 3, Dec 2022


17. Grenby, T. H.; Parker, K. J.; Lindley, M. G. *Developments in sweeteners-2*, Elsevier, 1983.
18. Poshala, K. *International Journal of Engineering Science and Computing,* **2020**, *10*, 27416.
19. Periyasamy, A. Artificial Sweeteners. *International Journal of Research and Review*. **2019**, *6*(1), 120-128.
20. Henin, N. Intake of Sweeteners, Physiological and Nutritional Aspects. *International Sugar Journal* **2001**, *103*, 346–351.
21. Nabors L-O'B.; Gelardi R. C. Alternative Sweeteners, 2nd ed. Marcel Dekker Inc., New York;1991.
22. Kretchmer, N.; Hollenbeck, C. Sugars and Sweeteners; CRC Press: Boca Raton, 1991.
23. Wani, M. M.; Bhat, T. A. Sugar substitutes and artificial sweeteners. *JMS SKIMS.* **2019**, *22*, 90.
24. Robertson, G. R. A Graduated Pycnometer. *Ind. Eng. Chem. Anal. Ed.* **1939**, *11* (8), 464.
25. Parker, H. C.; Parker, E. W. Chloride Solutions as Determined with a New Pycnometer. *J. Phys. Chem.* **1925**, *29* (2), 130-137.
26. Kharat, S. J.; Nikam, P. S. Density and Viscosity Studies of Binary Mixtures of Aniline+Benzene and Ternary Mixtures of (Aniline+Benzene+N,N-Dimethylformamide) at 298.15, 303.15, 308.15, and 313.15 K. *Journal of Molecular Liquids* **2007**, *131-132*, 81–86.
27. Kharat, S. J. Density and Viscosity Studies of Aqueous Solutions of Cesium Trifluoroacetate at Different Temperatures. *Journal of Chemical & Engineering Data*. **2008**, *53*(6), 1292-1294.
28. Kharat, S. J. Density, Viscosity and Ultrasonic Velocity Studies of Aqueous Solutions of Sodium Salycilate and Its Hydration Free Energy. *Physics and Chemistry of Liquids* **2014**, *52* (1), 7–16.
29. Kharat, S. J.; Munde, S. M. Volumetric Behavior of Sodium Saccharin in Water and (0.1, 0.3, and 0.5) m Fructose at (298.15, 303.15, 308.15, and 313.15) K. *Orbital: The Electronic Journal of Chemistry* **2017**, *9* (1), 36–42.
30. Lide, D. R. *CRC Handbook of Chemistry and Physics.* 73rd edn. CRC Press, Boca Raton, FL, 1992.
31. Engineering Tool Box, *$H_2O$ - Density, Specific Weight and Thermal Expansion Coefficient*.https://www.engineeringtoolbox.com/$H_2O$-density-specific-weight-d_595.html, 2003, [Accessed 12/05/2020].
32. Kupke, D. W. *Physical principles and techniques of physical chemistry, part-C*, New York: Academic press;1973.
33. Masson, D. *The London, Edinburgh, and Dublin Philosophical Magazine and Journal of Science*. **1929**, *8*, 218-235.
34. Ali, A.; Bidhuri, P.; Malik, N. A.; Uzair, S. Density, Viscosity, and Refractive Index of Mono-, Di-, and Tri-Saccharides in Aqueous Glycine Solutions at Different Temperatures. *Arabian Journal of Chemistry* **2019**, *12* (7), 1684–1694.
35. Banipal, P. K.; Banipal, T. S.; Ahluwalia, J. C.; Lark, B. S. Partial Molar Heat Capacities and Volumes of Transfer of Some Saccharides from Water to Aqueous Urea Solutions At T = 298.15 K. *The Journal of Chemical Thermodynamics* **2000**, *32* (10), 1409–1432

36. Shahidi, F.; Farrell, P. G.; Edward, J. T. Partial Molar Volumes Of Organic Compounds in Water. III. Carbohydrates. *J Solution Chem* **1976**, *5*(12), 807–816.
37. Fucaloro, A. F.; Pu, Y.; Cha, K.; Williams, A.; Conrad, K. Partial Molar Volumes and Refractions of Aqueous Solutions of Fructose, Glucose, Mannose, and Sucrose at 15.00, 20.00, and 25.00 °C. *J Solution Chem* **2007**, *36* (1), 61–80.
38. Banipal, P. K.; Banipal, T. S.; Lark, B. S.; Ahluwalia, J. C. Partial Molar Heat Capacities and Volumes of Some Mono-, Di- and Tri-Saccharides in Water at 298.15, 308.15 and 318.15 K. *Journal of the Chemical Society, Faraday Transactions* **1997**, *93* (1), 81–87.
39. Banipal, P. K.; Singh, V.; Aggarwal, N.; Banipal, T. S. Hydration Behaviour of Some Mono-, Di-, and Tri-Saccharides in Aqueous Sodium Gluconate Solutions at (288.15, 298.15, 308.15 and 318.15)K: Volumetric and Rheological Approach. *Food Chemistry* **2015**, *168*, 142–150.
40. Banipal, P. K.; Singh, V.; Banipal, T. S. Effect of Sodium Acetate on the Volumetric Behaviour of Some Mono-, Di-, and Tri-Saccharides in Aqueous Solutions over Temperature Range (288.15 to 318.15)K. *The Journal of Chemical Thermodynamics* **2010**, *42* (1), 90–103.
41. Franks, F. Water A Comprehensive Treatise: Volume 4: Aqueous Solutions of Amphiphiles and Macromolecules; Water; Springer US, **1975**.
42. Franks, F.; Quickenden, M. J.; Reid, D. S.; Watson, B. *Trans. Faraday Soc*. **1970**, *66*, 582-589.
43. Kharat, S. J.; Jondhale, V. R. Volumetric Study of Saccharide Interactions (D-Arabinose, D-Xylose, and D-Galactose) in Sodium Saccharin at 298.15 K. *J. Adv. Sci. Res.* **2021**, *3*, 152-159.
44. Gurney, R. W. Ionic Processes in Solution; McGraw-Hill Book Company, Inc, 1953.
45. Kumar, H.; Kumar, S.; Behal, I. Investigations on the temperature dependent volumetric and ultrasonic properties of structural isomers D(+)-glucose and D(−)-fructose in aqueous dipotassium oxalate solutions. *J. Chem. Thermodyn.* **2019,** *138*, 229-239.
46. McMillan, W. G.; Mayer, J. E. The Statistical Thermodynamics of Multicomponent Systems. *J. Chem. Phys.* **1945**, *13* (7), 276–305.
47. Kozak, J. J.; Knight, W. S.; Kauzmann, W. Solute-Solute Interactions in Aqueous Solutions. *J. Chem. Phys.* **1968**, *48* (2), 675–690.
48. Friedman, H. L.; Krishnan, C. V. Thermodynamics of Ionic Hydration. In *Aqueous Solutions of Simple Electrolytes*; Franks, F., Ed.; $H_2O$; Springer US: Boston, MA, 1973; pp 1–118.
49. Pal, A.; Kumar, S. Volumetric properties of L-alanine, and L-valine in aqueous sucrose solutions at $T = (288.15$ and $308.15)$ K. *The Journal of Chemical Thermodynamics*. **2005**, *37*(10), 1085-1092.
50. Hui X. J.; Han Y. C. Volumetric Properties of 1-Butyl-3-methylimidazolium Tetrafluoroborate–Glucose–Water Systems. *J. Chem. Eng. Data.* **2012**, *57*(4), 1134-1138.
51. Ali, A.; Hyder, S.; Sabir, S.; Chand, D.; Nain, A. K. Volumetric, Viscometric, and Refractive Index Behaviour of α-Amino Acids and Their Groups' Contribution in Aqueous d-Glucose Solution at Different Temperatures. *The Journal of Chemical Thermodynamics* **2006**, *38* (2), 136–143.
52. Jiang, Y.; Gao, S.; Xia, S.; Wang, J.; Zhuo, K.; Hu, M. Volumetric Properties and Volumetric Interaction Parameters of the CsCl-Saccharides (D-Glucose, D-

ISSN PRINT 2319 1775 Online 2320 7876

*Research paper* **© 2012 IJFANS. All Rights Reserved, UGC CARE Listed ( Group -I) Journal Volume 11, S Iss 3, Dec 2022**

Fructose)-Water Solutions at 298.15 K. *Journal of the Chinese Chemical Society* **2003**, *50* (5), 947–952.

53. Savage, J. J.; Wood, R. H. Enthalpy of Dilution of Aqueous Mixtures of Amides, Sugars, Urea, Ethylene Glycol, and Pentaerythritol at 25°C: Enthalpy of Interaction of the Hydrocarbon, Amide, and Hydroxyl Functional Groups in Dilute Aqueous Solutions. *J Solution Chem* **1976**, *5* (10), 733–750
54. Shamil, S.; Birch, G. G. A Conceptual Model of Taste Receptors, *Endeavour* **1990**, *14*, 191–193.
55. Parke, S. A.; Birch, G. G.; Portmann, M. O.; Kilcast, D. A Study of the Solution Properties of Selected Binary Mixtures of Bulk and Intense Sweeteners in Relation to Their Psychophysical Characteristics. *Food Chemistry* **1999**, *67* (3), 247–259.