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Relationships for thermodynamic evaluation of ammonia-water heat pump systems

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ABSTRACT

Thermodynamic property relations are relevant ingredients for the first and second simulation, analysis and optimization of ammonia-water heat pump systems. Many thermodynamic relations exist, many of which may be considered empirical, semi-empirical or in some case, derived with the use of some experimental data. The availability of experimental data especially the thermodynamic properties of the mixture over the whole operating range normally encountered in ammonia-water heat pump systems have allowed the formulation of unified and conceptually simple equations.

This paper presents relevant thermodynamic property relationships for liquid enthalpy, vapour enthalpy, vapour pressure, water concentration in vapour, and liquid entropy, all in terms of concentration and temperature for ammonia-water mixtures which are developed using Chebyshev series surface fits. The application of the Chebyshev polynomials increases the accuracy and enables wider operational range to be covered in a single final property equation. This therefore reduces the need for interpolation of extrapolation during the design or simulation of systems operating on ammonia-water working fluid. These equations are very useful in the computer-aided analysis of ammonia-water heat pump systems.

Keywords: *Thermodynamic relationships, heat pump systems, ammonia-water systems, Chebyshev surface fits*

INTRODUCTION

The mixture of ammonia and water has been a major working fluid in absorption heat pump systems for many years. The mathematical calculations and simulations models of components require the availability of simple and efficient mathematical methods for the determination of thermodynamic properties values of the working fluid. Many studies have been published on vapour-liquid equilibrium and the thermodynamic properties of ammonia-water mixtures, including p-t-x-y data and caloric properties. The availability of experimental data especially the thermodynamic properties of the mixture have allowed the formulation of unified and conceptually simple equations based upon the Helmoltz [1] or Gibbs free energies [2, 3].

Ammonia-water property data have been available for several years through the EES external library program called **AWMIX** [4]. The property routines in the library use the correlation described by Ibrahim and Klein [2] and those developed by Tillner-Roth and Friend [1]. **AWMIX** provides reliable information on the thermodynamic properties of ammonia-water for the entire composition range and in a wide range of temperature and pressure. Specifically, the **AWMIX** library program provides property data for all compositions from pure water to pure ammonia. VLE-properties between the solid-liquid-vapour boundary (195.5 K to 273.16 K) and the critical locus (405 K to 647 K), properties of liquid and vapour up to 40MPa and good predictions in the supercritical range.

For the correlations presented by Ibrahim and Klein [2], separate equations of state for liquid and gas phases were provided for pure ammonia and pure water. In the gas phase, the mixture was assumed to behave as an ideal solution, while in the liquid phase, the Gibbs excess energy was used to allow for departure from ideal solution behaviour. They also presented a modified correlation for the liquid Gibbs excess energy in which experimental data at higher temperatures and pressures were used. The new correlation covered vapour-liquid equilibrium pressures of 0.2110 bar and temperatures of 230 K to 600 K. The correlations compared satisfactorily with reported experimental data. When these equations are used in the simulation of a simple Kalina cycle, they give cycle efficiencies with a difference not larger than 3 % [5]. The same margin is expected for a heat pump system. M. Conde Engineering, Zurich [6] has compiled relevant procedures for calculating thermophysical properties of ammonia-water solutions.

Haj Taleb, Feidt and Lottin [7] presented a method that combines the Gibbs free energy method for mixture properties and bubble and dew point temperature equations for phase equilibrium. This method combines the advantages of the procedure used by Tillner-Roth and Friend [1], and Ibrahim and Klein [2], and avoids the need for iterations for phase equilibrium. The proposed correlations cover high vapour-liquid equilibrium pressures and temperatures. For accuracy, enthalpies and vapour-liquid equilibrium of the ammonia/water mixture are best calculated from the model proposed by Tillner-Roth and Friend [1]. The correlations presented by Conde [6] are best suitable for determining transport properties. The correlations reported by Tillner-Roth and Friend [1] are however mathematically very complicated and not suitable for simple calculations involving ammonia-water systems.

However, experimental data for the physical properties of ammonia-water mixtures over ranges normally encountered in ammonia-water heat pump system exist [8]. Attempts have been made to develop equations to fit these experimental data notably the works of Jain and Gamble [9]. However, these equations do not cover the full range of experimental data.

This paper presents a procedure for calculating the thermodynamic properties of ammonia-water mixture for the whole range of experimental data presented in the Macriss *et al* document. The procedure is based on the double Chebyshev Polynomial.

METHODS

The double Chebyshev series with argument X_{cap} and Y_{cap} can be represented as

$$H=\sum_{i=0}^{K}\sum_{j=0}^{L}A_{i,j}T_i(Y_{cap})(T_jX_{cap}) \tag{1}$$

Where $A_{i,j}$ = Chebyshev coefficients

T_i and T_j = Chebyshev transformations

X_{cap} = Chebyshev first argument, a variable dependent on X

$$x_{cap}=\frac{2x-(x_{\max}+x_{\min})}{(x_{\max}-x_{\min})} \tag{2}$$

Y_{cap} = Chebyshev second argument, a variable dependent on Y

$$y_{cap}=\frac{2y-(y_{\max}+y_{\min})}{(y_{\max}-y_{\min})} \tag{3}$$

and H = independent variable

For a single Chebyshev series, its expansion which is the Chebyshev polynomials is;

$$F(x) = 0.5+ a_0 + a_1T_1(x) + a_2T_2(x) + ... + a_nT_n(x) \tag{4}$$

$$= \sum_{r=0}^{n} a_r T_r(x) \tag{5}$$

Where a_r = Chebyshev coefficients.

For a double variable Chebyshev series, its expansion will yield a matrix of coefficients represented by;

$$\left|\begin{array}{ccccc} a_{0,0} & a_{0,1} & a_{0,2} & \cdots & a_{0,L-1} \\ a_{1,0} & a_{1,1} & a_{1,2} & \cdots & a_{1,L-1} \\ a_{2,0} & a_{2,1} & a_{2,2} & \cdots & a_{2,L-1..} \\ a_{k-1,0} & a_{k-1,1} & a_{k-1,2} & \cdots & a_{k-1,L-1} \end{array}\right|$$

A decision was taken to fix liquid enthalpy, vapour enthalpy, vapour pressure, water concentration in vapour, and liquid entropy as dependent variables and temperatures and liquid concentrations as independent variables; being represented by X_{cac} and Y_{cap} respectively. This is because these values are generally the properties required when simulating or designing ammonia-water heat pump systems. The Chebyshev coefficients were evaluated by appropriately fitting in, values of X_{cap} and Y_{cap} obtained from the data presented by Macriss *et al* [8]. The coefficients were then refitted into Equation (1) to obtain the independent variable – liquid concentration-temperature relationships. This was done for a range of operating temperatures (and by implications operating pressures) from -40 °C to 160 °C. A breakdown of the results are presented in Tables (I) to (V).

DISCUSSION OF RESULTS

Calculated values were very close to the tabulated properties and more accurate for ranges covered by the Jain and Gable relationships. The size of the data is directly proportional to the degree of fit. The Maximum absolute error between the experimental data and those generated by the use of the Equations is ±1.78 %. The maximum absolute errors for the various properties are indicated on the various tables. Because they are generated from experimental data, they are therefore more reliable than those generated from empirical or semi-empirical procedures.

CONCLUSION

Appropriate thermodynamic property relationship in terms of concentration and temperature for ammonia-water mixtures have been developed using Chebyshev series surface fits. The double Chebyshev polynomial of the first kind, which was used to formulate the properties produced good results and justify the use of Chebyshev polynomial in handling empirical data (10). They are more accurate and cover a wider operational range than those developed by Jain and Gamble [9]. Efforts have been made to cover all the experimental data in the Macriss *et al* Report. The equations are very handy for computer-aided analysis of ammonia-water heat pump systems.

TABLE I: LIQUID ENTHALPY OF AMMONIA-WATER SOLUTION(kJ/kg)

Temperature(T) range: 233.15K – 272.03889K Concentration (X) range 10wt% -100wt% $U = (2T - (272.03889+233.15))/(272.03889-233.15)$ $V = (2X - (100+10))/(100-10)$ $x_1 = \cos(\mathrm{acos}(U))$ $y_1 = \cos(\mathrm{acos}(V))$ $x_2 = \cos(2\mathrm{acos}(U))$ $y_2 = \cos(2\mathrm{acos}(V))$ $x_3 = \cos(3\mathrm{acos}(U))$ $y_3 = \cos(3\mathrm{acos}(V))$ $x_4 = \cos(4\mathrm{acos}(U))$ $y_4 = \cos(4\mathrm{acos}(V))$ $y_5 = \cos(5\mathrm{acos}(V))$	The coefficients are -9.1303E+02 1.6526E+02 2.3290E+00 -7.1415E-01 8.6908E-01 8.1098E+01 8.4783E+00 -1.5322E+00 3.9225E-01 -5.1072E-01 2.1503E+02 -4.1738E+00 1.3162E+00 -2.2661E-01 3.2467E-01 -2.5040E+01 3.9042E+00 -1.3482E+00 4.2061E-01 -4.0873E-01 -4.2814E+00 -3.2019E+00 1.0509E+00 -4.7134E-01 4.4445E-01 1.5513E+00 2.0490E+00 -5.6347E-01 2.5490E-01 4.3315E-01 which can be represented by Z_{11} Z_{12} Z_{13} Z_{14} Z_{15} Z_{21} Z_{22} Z_{23} Z_{24} Z_{21} Z_{31} Z_{32} Z_{33} Z_{34} Z_{34} Z_{41} Z_{42} Z_{43} Z_{44} Z_{44} Z_{51} Z_{52} Z_{53} Z_{54} Z_{54} Z_{61} Z_{62} Z_{63} Z_{64} Z_{64} The value for the enthalpy H(kJ/kg) is given as $H = A + B + C + D + E + F$ Where $A = 0.25\,Z_{11} + 0.5Z_{12}x_1 + 0.5Z_{13}x_2 + 0.5Z_{14}x_3 + 0.5Z_{15}x_4$ $B = y_1(0.5\,Z_{21} + Z_{22}x_1 + Z_{23}x_2 + Z_{24}x_3 + Z_{25}x_4)$ $C = y_2(0.5\,Z_{31} + Z_{32}x_1 + Z_{33}x_2 + Z_{34}x_3 + Z_{35}x_4)$ $D = y_3(0.5\,Z_{41} + Z_{42}x_1 + Z_{43}x_2 + Z_{44}x_3 + Z_{45}x_4)$ $E = y_4(0.5\,Z_{51} + Z_{52}x_1 + Z_{53}x_2 + Z_{54}x_3 + Z_{55}x_4)$ $F = y_5(0.5\,Z_{61} + Z_{62}x_1 + Z_{63}x_2 + Z_{64}x_3 + Z_{65}x_4)$
Temperature(T) range: 272.03889K – 360.927778K Concentration (X) range 0wt% -100wt% $U = (2T - (360.92778+233.15)) / (360.927778-233.15)$ $V = (2X - (100+0)) / (100-0)$ $x_1 = \cos(\mathrm{acos}(U))$ $y_1 = \cos(\mathrm{acos}(V))$ $x_2 = \cos(2\mathrm{acos}(U))$ $y_2 = \cos(2\mathrm{acos}(V))$ $x_3 = \cos(3\mathrm{acos}(U))$ $y_3 = \cos(3\mathrm{acos}(V))$ $x_4 = \cos(4\mathrm{acos}(U))$ $y_4 = \cos(4\mathrm{acos}(V))$ $x_5 = \cos(5\mathrm{acos}(U))$ $y_5 = \cos(5\mathrm{acos}(V))$ $y_6 = \cos(5\mathrm{acos}(V))$	The coefficients are 3.2796E+02 4.1765E+02 7.2486E+00 1.4096E+00 1.3842E+00 8.0727E-01 3.6984E+01 1.8083E+01 3.7172E+00 1.3878E+00 5.7801E-01 2.6093E-01 2.5064E+02 -1.4995E+00 1.4144E+00 1.2629E+00 4.5639E-01 1.2939E-01 -6.7469E+00 3.2120E+00 1.3634E+00 4.7048E-01 4.8789E-01 3.9950E-01 -1.7843E+01 -2.8775E-01 2.9878E-01 2.9766E-01 2.1430E-01 2.3201E-01 6.2351E+00 9.4842E-01 4.9746E-01 5.2922E-01 5.8257E-01 3.2683E-01 2.4057E+00 1.4490E+00 6.9218E-01 4.1905E-01 4.7021E-01 2.9575E-01 which can be represented by Z_{11} Z_{12} Z_{13} Z_{14} Z_{15} Z_{16} Z_{21} Z_{22} Z_{23} Z_{24} Z_{25} Z_{26} Z_{31} Z_{32} Z_{33} Z_{34} Z_{35} Z_{36} Z_{41} Z_{42} Z_{43} Z_{44} Z_{45} Z_{46} Z_{51} Z_{52} Z_{53} Z_{54} Z_{55} Z_{56} Z_{61} Z_{62} Z_{63} Z_{64} Z_{65} Z_{66} Z_{71} Z_{72} Z_{73} Z_{74} Z_{75} Z_{76} The value for the enthalpy H(kJ/kg) is given as $H = A + B + C + D + E + F + G$ Where $A = 0.25\,Z_{11} + 0.5Z_{12}x_1 + 0.5Z_{13}x_2 + 0.5Z_{14}x_3 + 0.5Z_{15}x_4 + 0.5Z_{16}x_5$ $B = y_1(0.5\,Z_{21} + Z_{22}x_1 + Z_{23}x_2 + Z_{24}x_3 + Z_{25}x_4 + Z_{26}x_5)$ $C = y_2(0.5\,Z_{31} + Z_{32}x_1 + Z_{33}x_2 + Z_{34}x_3 + Z_{35}x_4 + Z_{36}x_5)$ $D = y_3(0.5\,Z_{41} + Z_{42}x_1 + Z_{43}x_2 + Z_{44}x_3 + Z_{45}x_4 + Z_{46}x_5)$ $E = y_4(0.5\,Z_{51} + Z_{52}x_1 + Z_{53}x_2 + Z_{54}x_3 + Z_{55}x_4 + Z_{56}x_5)$ $F = y_5(0.5\,Z_{61} + Z_{62}x_1 + Z_{63}x_2 + Z_{64}x_3 + Z_{65}x_4 + Z_{66}x_5)$ $G = y_6(0.5\,Z_{71} + Z_{72}x_1 + Z_{73}x_2 + Z_{74}x_3 + Z_{75}x_4 + Z_{76}x_5)$

Temperature(T) range 360.927778 - 394.261K Concentration (X) range 0wt% -70wt% $U = (2T - (394.261 + 360.92778)) / (394.261 - 360.92778)$ $V = (2X - (70+0)) / (70-0)$ $x_1 = \cos(a\cos(U))$ $y_1 = \cos(a\cos(V))$ $x_2 = \cos(2a\cos(U))$ $y_2 = \cos(2a\cos(V))$ $x_3 = \cos(3a\cos(U))$ $y_3 = \cos(3a\cos(V))$ $x_4 = \cos(4a\cos(U))$ $y_4 = \cos(4a\cos(V))$ $y_5 = \cos(5a\cos(V))$	The coefficients are: 1.3482E+03 2.2938E+02 4.3591E+01 1.6064E+00 -1.0313E+01 -6.8124E+01 7.4008E+01 4.0490E+01 2.5050E+00 -8.8966E+00 1.8529E+02 5.3601E+01 3.1462E+01 6.8986E-01 -9.0761E+00 6.1008E+01 3.5848E+01 1.9875E+01 -2.0659E+00 -7.1557E+00 1.3216E+01 1.7882E+01 1.0206E+01 -2.3241E+00 -4.9086E+00 2.8951E+00 5.0705E+00 3.5591E+00 -1.2141E+00 -2.1912E+00 which can be represented by Z_{11} Z_{12} Z_{13} Z_{14} Z_{15} Z_{21} Z_{22} Z_{23} Z_{24} Z_{25} Z_{31} Z_{32} Z_{33} Z_{34} Z_{35} Z_{41} Z_{42} Z_{43} Z_{44} Z_{45} Z_{51} Z_{52} Z_{53} Z_{54} Z_{55} Z_{61} Z_{62} Z_{63} Z_{64} Z_{65} The value for the enthalpy H(kJ/kg) is given as $H = A + B + C + D + E + F$ Where $A = 0.25 Z_{11} + 0.5 Z_{12} x_1 + 0.5 Z_{13} x_2 + 0.5 Z_{14} x_3 + 0.5 Z_{15} x_4$ $B = y_1(0.5 Z_{21} + Z_{22} x_1 + Z_{23} x_2 + Z_{24} x_3 + Z_{25} x_4)$ $C = y_2(0.5 Z_{31} + Z_{32} x_1 + Z_{33} x_2 + Z_{34} x_3 + Z_{35} x_4)$ $D = y_3(0.5 Z_{41} + Z_{42} x_1 + Z_{43} x_2 + Z_{44} x_3 + Z_{45} x_4)$ $E = y_4(0.5 Z_{51} + Z_{52} x_1 + Z_{53} x_2 + Z_{54} x_3 + Z_{55} x_4)$ $F = y_5(0.5 Z_{61} + Z_{62} x_1 + Z_{63} x_2 + Z_{64} x_3 + Z_{65} x_4)$
Temperature(T) range 394.261K – 433.15K Concentration (X) range 0wt% -50wt% $U = (2T - (433.15 + 394.261)) / (433.15 - 394.261)$ $V = (2X - (70+0)) / (70-0)$ $x_1 = \cos(a\cos(U))$ $y_1 = \cos(a\cos(V))$ $x_2 = \cos(2a\cos(U))$ $y_2 = \cos(2a\cos(V))$ $y_3 = \cos(3a\cos(V))$	The coefficients are: 1.9078E+03 1.7700E+02 3.6988E+00 -2.0514E+02 3.5113E+00 3.0889E+00 3.1418E+01 -2.8672E+00 2.4401E+00 7.9652E+00 -1.3708E+00 1.1788E+00 which can be represented by Z_{11} Z_{12} Z_{13} Z_{21} Z_{22} Z_{23} Z_{31} Z_{32} Z_{33} Z_{41} Z_{42} Z_{43} The value for the enthalpy H(kJ/kg) is given as $H = A + B + C + D$ Where $A = 0.25 Z_{11} + 0.5 Z_{12} x_1 + 0.5 Z_{13} x_2$ $B = y_1(0.5 Z_{21} + Z_{22} x_1 + Z_{23} x_2)$ $C = y_2(0.5 Z_{31} + Z_{32} x_1 + Z_{33} x_2)$ $D = y_3(0.5 Z_{41} + Z_{42} x_1 + Z_{43} x_2)$
Maximum absolute error between the experimental data and those generated = ±1.65%	

TABLE II: VAPOUR ENTHALPY OF AMMONIA-WATER SOLUTION (kJ/kg)

Temperature(T) range 233.15K - 272.03889K Concentration (X) range 10wt% -100wt% $U = (2T -(272.03889+233.15))/(272.03889-233.15)$ $V = (2X -(100+10))/(100-10)$ $x_1 = \cos(\mathrm{acos}(U))$ $y_1 = \cos(\mathrm{acos}(V))$ $x_2 = \cos(2\mathrm{acos}(U))$ $y_2 = \cos(2\mathrm{acos}(V))$ $x_3 = \cos(3\mathrm{acos}(U))$ $y_3 = \cos(3\mathrm{acos}(V))$ $x_4 = \cos(4\mathrm{acos}(U))$ $y_4 = \cos(4\mathrm{acos}(V))$ $y_5 = \cos(5\mathrm{acos}(V))$	The coefficients are 5.0722E+03 8.6271E+01 2.0373E+00 2.1750E+00 1.9510E-01 -8.6667E+01 -2.3583E+01 -2.2498E+00 9.7238E-01 6.9894E-01 4.2873E+01 1.3137E+01 1.5338E+00 -9.4574E-01 -2.9239E-01 -2.5459E+01 -8.3678E+00 -1.0347E+00 1.2421E+00 -1.0012EE-01 1.4819E+01 5.8819E+00 8.0059E-01 -8.9299E-01 -8.9632E-02 -6.1504E+00 -3.0295E+00 -7.6234E-01 3.6674E-01 -1.6957E-01 which can be represented by Z_{11} Z_{12} Z_{13} Z_{14} Z_{15} Z_{21} Z_{22} Z_{23} Z_{24} Z_{24} Z_{31} Z_{32} Z_{33} Z_{34} Z_{34} Z_{41} Z_{42} Z_{43} Z_{44} Z_{44} Z_{51} Z_{52} Z_{53} Z_{54} Z_{54} Z_{61} Z_{62} Z_{63} Z_{64} Z_{64} The value for the enthalpy H(kJ/kg) is given as $H = A + B + C + D + E + F$ Where $A = 0.25\,Z_{11} + 0.5Z_{12}x_1 + 0.5Z_{13}x_2 + 0.5Z_{14}x_3 + 0.5Z_{15}x_4$ $B = y_1(0.5\,Z_{21} + Z_{22}x_1 + Z_{23}x_2 + Z_{24}x_3 + Z_{25}x_4)$ $C = y_2(0.5\,Z_{31} + Z_{32}x_1 + Z_{33}x_2 + Z_{34}x_3 + Z_{35}x_4)$ $D = y_3(0.5\,Z_{41} + Z_{42}x_1 + Z_{43}x_2 + Z_{44}x_3 + Z_{45}x_4)$ $E = y_4(0.5\,Z_{51} + Z_{52}x_1 + Z_{53}x_2 + Z_{54}x_3 + Z_{55}x_4)$ $F = y_5(0.5\,Z_{61} + Z_{62}x_1 + Z_{63}x_2 + Z_{64}x_3 + Z_{65}x_4)$
Temperature(T) range 272.03889K - 360.927778K Concentration (X) range 0wt% -100wt% $U = (2T -(360.92778+233.15)) / (360.927778-233.15)$ $V = (2X -(100+0)) / (100-0)$ $x_1 = \cos(\mathrm{acos}(U))$ $y_1 = \cos(\mathrm{acos}(V))$ $x_2 = \cos(2\mathrm{acos}(U))$ $y_2 = \cos(2\mathrm{acos}(V))$ $x_3 = \cos(3\mathrm{acos}(U))$ $y_3 = \cos(3\mathrm{acos}(V))$ $x_4 = \cos(4\mathrm{acos}(U))$ $y_4 = \cos(4\mathrm{acos}(V))$ $x_5 = \cos(5\mathrm{acos}(U))$ $y_5 = \cos(5\mathrm{acos}(V))$ $y_6 = \cos(5\mathrm{acos}(V))$	The coefficients are 6.1550E+03 2.0995E+02 3.4432E+00 3.2670E+01 5.3165E+00 1.6198E+01 -7.8540E+02 -8.0272E+01 -1.2773E+00 -6.7427E+00 4.7341E+00 -5.3236E+00 5.0954E+02 2.2547E+01 4.6424E+00 2.1336E+01 2.7418E+00 1.0491E+01 -3.5716E+02 1.0388E+01 6.8376E+00 -6.7143E+00 2.8007E+00 -3.9867E+00 2.3151E+02 8.6627E-01 7.2526E+00 1.7469E+01 2.4523E+00 9.7139E+00 -1.2528E+02 1.3289E+01 9.1136E+00 -4.4525E+00 5.8272E+00 -3.0551E+00 7.2356E+01 3.8791E+00 1.8614E+00 1.2283E+01 3.3641E-01 6.8522E+00 which can be represented by Z_{11} Z_{12} Z_{13} Z_{14} Z_{15} Z_{16} Z_{21} Z_{22} Z_{23} Z_{24} Z_{25} Z_{26} Z_{31} Z_{32} Z_{33} Z_{34} Z_{35} Z_{36} Z_{41} Z_{42} Z_{43} Z_{44} Z_{45} Z_{46} Z_{51} Z_{52} Z_{53} Z_{54} Z_{55} Z_{56} Z_{61} Z_{62} Z_{63} Z_{64} Z_{65} Z_{66} Z_{71} Z_{72} Z_{73} Z_{74} Z_{75} Z_{76} The value for the enthalpy H(kJ/kg) is given as $H = A + B + C + D + E + F + G$ Where $A = 0.25\,Z_{11} + 0.5Z_{12}x_1 + 0.5Z_{13}x_2 + 0.5Z_{14}x_3 + 0.5Z_{15}x_4 + 0.5Z_{16}x_5$ $B = y_1(0.5\,Z_{21} + Z_{22}x_1 + Z_{23}x_2 + Z_{24}x_3 + Z_{25}x_4 + Z_{26}x_5)$ $C = y_2(0.5\,Z_{31} + Z_{32}x_1 + Z_{33}x_2 + Z_{34}x_3 + Z_{35}x_4 + Z_{36}x_5)$ $D = y_3(0.5\,Z_{41} + Z_{42}x_1 + Z_{43}x_2 + Z_{44}x_3 + Z_{45}x_4 + Z_{46}x_5)$ $E = y_4(0.5\,Z_{51} + Z_{52}x_1 + Z_{53}x_2 + Z_{54}x_3 + Z_{55}x_4 + Z_{56}x_5)$ $F = y_5(0.5\,Z_{61} + Z_{62}x_1 + Z_{63}x_2 + Z_{64}x_3 + Z_{65}x_4 + Z_{66}x_5)$ $G = y_6(0.5\,Z_{71} + Z_{72}x_1 + Z_{73}x_2 + Z_{74}x_3 + Z_{75}x_4 + Z_{76}x_5)$

Temperature(T) range: 360.927778 - 394.261K
Concentration (X) range: 0wt% -70wt%

$U = (2T - (394.261+360.92778)) / (394.261 - 360.92778)$
$V = (2X - (70+0)) / (70-0)$

$x_1 = \cos(a\cos(U))$ $y_1 = \cos(a\cos(V))$
$x_2 = \cos(2a\cos(U))$ $y_2 = \cos(2a\cos(V))$
$x_3 = \cos(3a\cos(U))$ $y_3 = \cos(3a\cos(V))$
$x_4 = \cos(4a\cos(U))$ $y_4 = \cos(4a\cos(V))$
$y_5 = \cos(5a\cos(V))$

The coefficients are:

6.6870E+03	-1.2110E+02	-8.9959E+01	-5.8089E+01	-3.5814E+01
-1.2241E+03	1.9933E+02	-8.2280E+01	-5.4365E+01	-3.3459E+01
2.8358E+02	-1.5587E+02	6.0581E+01	-3.9450E+01	2.6886E+01
3.8503E+02	-8.7217E+01	-3.4585E+01	-2.0894E+01	-1.6217E+01
4.0012E+01	-6.3288E+01	-1.2328E+01	-5.7870E+00	-7.6109E+00
-8.8595E+01	-1.9785E+01	2.8056E-02	1.7153E+00	2.1435E+00

which can be represented by

Z_{11}	Z_{12}	Z_{13}	Z_{14}	Z_{15}
Z_{21}	Z_{22}	Z_{23}	Z_{24}	Z_{25}
Z_{31}	Z_{32}	Z_{33}	Z_{34}	Z_{35}
Z_{41}	Z_{42}	Z_{43}	Z_{44}	Z_{45}
Z_{51}	Z_{52}	Z_{53}	Z_{54}	Z_{55}
Z_{61}	Z_{62}	Z_{63}	Z_{64}	Z_{65}

The value for the enthalpy H(kJ/kg) is given as

$$H = A + B + C + D + E + F$$

Where

$$A = 0.25\,Z_{11} + 0.5Z_{12}x_1 + 0.5Z_{13}x_2 + 0.5Z_{14}x_3 + 0.5Z_{15}x_4$$
$$B = y_1(0.5\,Z_{21} + Z_{22}x_1 + Z_{23}x_2 + Z_{24}x_3 + Z_{25}x_4)$$
$$C = y_2(0.5\,Z_{31} + Z_{32}x_1 + Z_{33}x_2 + Z_{34}x_3 + Z_{35}x_4)$$
$$D = y_3(0.5\,Z_{41} + Z_{42}x_1 + Z_{43}x_2 + Z_{44}x_3 + Z_{45}x_4)$$
$$E = y_4(0.5\,Z_{51} + Z_{52}x_1 + Z_{53}x_2 + Z_{54}x_3 + Z_{55}x_4)$$
$$F = y_5(0.5\,Z_{61} + Z_{62}x_1 + Z_{63}x_2 + Z_{64}x_3 + Z_{65}x_4)$$

Temperature(T) range: 394.261K - 433.15K
Concentration (X) range: 0wt% - 50wt%

$U = (2T - (433.15 + 394.261)) / (433.15 - 394.261)$
$V = (2X - (70+0)) / (70-0)$

$x_1 = \cos(a\cos(U))$ $y_1 = \cos(a\cos(V))$
$x_2 = \cos(2a\cos(U))$ $y_2 = \cos(2a\cos(V))$
$y_3 = \cos(3a\cos(V))$

The coefficients are:

7.3973E+03	-4.8097E+01	-9.3117E+00
-1.3005E+03	1.3704E+02	-5.7844E+00
2.0557E+02	-1.1116E+02	2.2069E+00
-2.5230E+02	-2.5318E+01	8.5748E+00

which can be represented by

Z_{11}	Z_{12}	Z_{13}
Z_{21}	Z_{22}	Z_{23}
Z_{31}	Z_{32}	Z_{33}
Z_{41}	Z_{42}	Z_{43}

The value for the enthalpy H(kJ/kg) is given as

$$H = A + B + C + D$$

Where

$$A = 0.25\,Z_{11} + 0.5Z_{12}x_1 + 0.5Z_{13}x_2$$
$$B = y_1(0.5\,Z_{21} + Z_{22}x_1 + Z_{23}x_2)$$
$$C = y_2(0.5\,Z_{31} + Z_{32}x_1 + Z_{33}x_2)$$
$$D = y_3(0.5\,Z_{41} + Z_{42}x_1 + Z_{43}x_2)$$

Maximum absolute error between the experimental data and those generated = ±1.28%

TABLE III: VAPOUR PRESSURE (BARS)

Température(T) range 233.15K – 272.03889K

Concentration (X) range: 10wt% - 100wt%

$U = (2T - (272.03889+233.15))/(272.03889-233.15)$

$V = (2X - (100+10))/(100-10)$

$x_1 = \cos(\mathrm{acos}(U))$
$x_2 = \cos(2\mathrm{acos}(U))$
$x_3 = \cos(3\mathrm{acos}(U))$
$x_4 = \cos(4\mathrm{acos}(U))$

$y_1 = \cos(\mathrm{acos}(V))$
$y_2 = \cos(2\mathrm{acos}(V))$
$y_3 = \cos(3\mathrm{acos}(V))$
$y_4 = \cos(4\mathrm{acos}(V))$
$y_5 = \cos(5\mathrm{acos}(V))$

The coefficients are:

3.6808E+00	1.4653E+00	2.6908E-01	6.1717E-03	3.7519E-03
2.2835E+00	8.8168E-01	1.2951E-01	2.4266E-02	-2.6143E-03
2.7893E-01	9.9338E-02	2.6932E-02	-1.3214E-02	3.8809E-03
-2.5774E-01	-9.5328E-02	-2.3879E-02	1.1666E-02	-3.6895E-03
-4.3672E-02	-4.3636E-03	8.7169E-03	9.2548E-03	3.4843E-03
6.5733E-02	1.9132E-02	-1.2631E-03	5.1231E-03	-1.1155E-03

which can be represented by

Z_{11}	Z_{12}	Z_{13}	Z_{14}	Z_{15}
Z_{21}	Z_{22}	Z_{23}	Z_{24}	Z_{24}
Z_{31}	Z_{32}	Z_{33}	Z_{34}	Z_{34}
Z_{41}	Z_{42}	Z_{43}	Z_{44}	Z_{44}
Z_{51}	Z_{52}	Z_{53}	Z_{54}	Z_{54}
Z_{61}	Z_{62}	Z_{63}	Z_{64}	Z_{64}

The value for the Pressure P(bars) is given as

$P = A + B + C + D + E + F$

Where

$A = 0.25 Z_{11} + 0.5Z_{12}x_1 + 0.5Z_{13}x_2 + 0.5Z_{14}x_3 + 0.5Z_{15}x_4$
$B = y_1(0.5 Z_{21} + Z_{22}x_1 + Z_{23}x_2 + Z_{24}x_3 + Z_{25}x_4)$
$C = y_2(0.5 Z_{31} + Z_{32}x_1 + Z_{33}x_2 + Z_{34}x_3 + Z_{35}x_4)$
$D = y_3(0.5 Z_{41} + Z_{42}x_1 + Z_{43}x_2 + Z_{44}x_3 + Z_{45}x_4)$
$E = y_4(0.5 Z_{51} + Z_{52}x_1 + Z_{53}x_2 + Z_{54}x_3 + Z_{55}x_4)$
$F = y_5(0.5 Z_{61} + Z_{62}x_1 + Z_{63}x_2 + Z_{64}x_3 + Z_{65}x_4)$

Température(T) range: 272.03889K – 360.927778K
Concentration (X) range 0wt% -100wt%

$U = (2T - (360.92778+233.15)) / (360.927778-233.15)$
$V = (2X - (100+0)) / (100-0)$

$x_1 = \cos(\mathrm{acos}(U))$
$x_2 = \cos(2\mathrm{acos}(U))$
$x_3 = \cos(3\mathrm{acos}(U))$
$x_4 = \cos(4\mathrm{acos}(U))$
$x_5 = \cos(5\mathrm{acos}(U))$

$y_1 = \cos(\mathrm{acos}(V))$
$y_2 = \cos(2\mathrm{acos}(V))$
$y_3 = \cos(3\mathrm{acos}(V))$
$y_4 = \cos(4\mathrm{acos}(V))$
$y_5 = \cos(5\mathrm{acos}(V))$
$y_6 = \cos(5\mathrm{acos}(V))$

The coefficients are:

3.7173E+01	1.9211E+01	4.3453E+00	5.7224E-01	7.0691E-02	9.0808E-02
2.2473E+01	1.1212E+01	2.3399E+00	2.4366E-01	2.0406E-02	4.4588E-02
3.1567E+00	1.4732E+00	2.7733E-01	1.1513E-01	4.8693E-02	6.7805E-02
-1.7614E+00	-6.3199E-01	3.2855E-02	1.6148E-01	8.6963E-02	7.5052E-02
-7.4369E-03	2.5397E-01	2.3136E-01	2.1380E-01	1.0714E-01	8.7518E-02
7.0209E-01	4.4647E-01	2.1997E-01	1.6861E-01	9.9284E-02	6.3939E-02
1.9149E-01	1.5159E-01	1.2422E-00	1.1215E-01	6.3871E-02	3.8718E-02

which can be represented by

Z_{11}	Z_{12}	Z_{13}	Z_{14}	Z_{15}	Z_{16}
Z_{21}	Z_{22}	Z_{23}	Z_{24}	Z_{25}	Z_{26}
Z_{31}	Z_{32}	Z_{33}	Z_{34}	Z_{35}	Z_{36}
Z_{41}	Z_{42}	Z_{43}	Z_{44}	Z_{45}	Z_{46}
Z_{51}	Z_{52}	Z_{53}	Z_{54}	Z_{55}	Z_{56}
Z_{61}	Z_{62}	Z_{63}	Z_{64}	Z_{65}	Z_{66}
Z_{71}	Z_{72}	Z_{73}	Z_{74}	Z_{75}	Z_{76}

The value for the Pressure P(bars) is given as

$H = A + B + C + D + E + F + G$

Where

$A = 0.25 Z_{11} + 0.5Z_{12}x_1 + 0.5Z_{13}x_2 + 0.5Z_{14}x_3 + 0.5Z_{15}x_4 + 0.5Z_{16}x_5$
$B = y_1(0.5 Z_{21} + Z_{22}x_1 + Z_{23}x_2 + Z_{24}x_3 + Z_{25}x_4 + Z_{26}x_5)$
$C = y_2(0.5 Z_{31} + Z_{32}x_1 + Z_{33}x_2 + Z_{34}x_3 + Z_{35}x_4 + Z_{36}x_5)$
$D = y_3(0.5 Z_{41} + Z_{42}x_1 + Z_{43}x_2 + Z_{44}x_3 + Z_{45}x_4 + Z_{46}x_5)$
$E = y_4(0.5 Z_{51} + Z_{52}x_1 + Z_{53}x_2 + Z_{54}x_3 + Z_{55}x_4 + Z_{56}x_5)$
$F = y_5(0.5 Z_{61} + Z_{62}x_1 + Z_{63}x_2 + Z_{64}x_3 + Z_{65}x_4 + Z_{66}x_5)$
$G = y_6(0.5 Z_{71} + Z_{72}x_1 + Z_{73}x_2 + Z_{74}x_3 + Z_{75}x_4 + Z_{76}x_5)$

Température(T) range 360.927778 – 394.261K Concentration (X) range 0wt% -70wt% $U = (2T-(394.261+360.92778)) / (394.261-360.92778)$ $V = (2X-(70+0)) / (70-0)$ $x_1 = \cos(\text{acos}(U))$ $y_1 = \cos(\text{acos}(V))$ $x_2 = \cos(2\text{acos}(U))$ $y_2 = \cos(2\text{acos}(V))$ $x_3 = \cos(3\text{acos}(U))$ $y_3 = \cos(3\text{acos}(V))$ $x_4 = \cos(4\text{acos}(U))$ $y_4 = \cos(4\text{acos}(V))$ $y_5 = \cos(5\text{acos}(V))$	The coefficients are 7.3384E+01 1.1359E+01 6.2687E-01 4.9686E-01 3.3870E-01 4.2393E+01 5.5444E+00 1.8673E-01 4.5359E-01 3.1916E-01 7.3008E+01 8.7205E-02 -9.2569E-02 3.4546E-01 2.5449E-01 -2.1280E+00 -7.5911E-01 -4.8995E-02 2.4011E-01 1.6482E-01 -1.3488E+00 -3.0746E-01 -1.6250E-02 1.2821E-01 7.4950E-02 -9.7287E-02 -1.5769E-02 -1.0766E-02 3.3634E-02 1.9762E-02 which can be represented by Z_{11} Z_{12} Z_{13} Z_{14} Z_{15} Z_{21} Z_{22} Z_{23} Z_{24} Z_{25} Z_{31} Z_{32} Z_{33} Z_{34} Z_{35} Z_{41} Z_{42} Z_{43} Z_{44} Z_{45} Z_{51} Z_{52} Z_{53} Z_{54} Z_{55} Z_{61} Z_{62} Z_{63} Z_{64} Z_{65} The value for the Pressure P (bars)enthalpy is given as $P = A + B + C + D + E + F$ Where $A = 0.25 Z_{11} + 0.5Z_{12}x_1 + 0.5Z_{13}x_2 + 0.5Z_{14}x_3 + 0.5Z_{15}x_4$ $B = y_1(0.5 Z_{21} + Z_{22}x_1 + Z_{23}x_2 + Z_{24}x_3 + Z_{25}x_4)$ $C = y_2(0.5 Z_{31} + Z_{32}x_1 + Z_{33}x_2 + Z_{34}x_3 + Z_{35}x_4)$ $D = y_3(0.5 Z_{41} + Z_{42}x_1 + Z_{43}x_2 + Z_{44}x_3 + Z_{45}x_4)$ $E = y_4(0.5 Z_{51} + Z_{52}x_1 + Z_{53}x_2 + Z_{54}x_3 + Z_{55}x_4)$ $F = y_5(0.5 Z_{61} + Z_{62}x_1 + Z_{63}x_2 + Z_{64}x_3 + Z_{65}x_4)$
Température(T) range 394.261K – 433.15K Concentration (X) range 0wt% -50wt% $U = (2T-(433.15+394.261)) / (433.15-394.261)$ $V = (2X-(70+0)) / (70-0)$ $x_1 = \cos(\text{acos}(U))$ $y_1 = \cos(\text{acos}(V))$ $x_2 = \cos(2\text{acos}(U))$ $y_2 = \cos(2\text{acos}(V))$ $y_3 = \cos(3\text{acos}(V))$	The coefficients are 9.4406E+01 1.7359E+01 1.0749E+00 4.8685E+01 7.9703E+00 2.8306E-01 9.6482E+00 1.3284E+00 -9.9955E-02 5.4273E-01 5.9780E-02 -8.7505E-02 which can be represented by Z_{11} Z_{12} Z_{13} Z_{21} Z_{22} Z_{23} Z_{31} Z_{32} Z_{33} Z_{41} Z_{42} Z_{43} The value for the Pressure P (bars) is given as $P = A + B + C + D$ Where $A = 0.25 Z_{11} + 0.5Z_{12}x_1 + 0.5Z_{13}x_2$ $B = y_1(0.5 Z_{21} + Z_{22}x_1 + Z_{23}x_2)$ $C = y_2(0.5 Z_{31} + Z_{32}x_1 + Z_{33}x_2)$ $D = y_3(0.5 Z_{41} + Z_{42}x_1 + Z_{43}x_2)$
Maximum absolute error between the experimental data and those generated = $\underline{+}1.11\%$	

TABLE IV: WATER CONCENTRATIONS IN VAPOUR(Wt%)

Temperature(T) range 272.03889K- 360.92778K Concentration (X) range: 10wt% - 90wt% U = (2T -(360.92778+272.03889))/(360.92778 - 272.03889) V= (2X -(90+10))/ (90-10) x_1 = cos(acos(U)) y_1 = cos(acos(V)) x_2 = cos(2acos(U)) y_2 = cos(2acos(V)) x_3 = cos(3acos(U)) y_3 = cos(3acos(V)) x_4 = cos(4acos(U)) y_4 = cos(4acos(V)) x_5 = cos(5acos(U)) y_5 = cos(5acos(V)) y_6 = cos(5acos(V))	The coefficients are 1.9507E+01 5.2662E+00 3.9637E-01 9.6148E-03 -3.7783E-02 4.0555E-04 -1.6128E+01 -3.8655E+00 -1.6934E-01 1.5437E-02 1.5209E-02 -1.3840E-02 1.0106E+01 1.8633E+00 8.6565E-02 -1.3690E-02 -1.8607E-02 -1.0906E-03 -5.3371E+00 7.2286E-01 8.3665E-02 -1.2892E-02 8.2066E-03 1.0207E-02 2.3701E+00 2.2687E-01 4.7359E-02 1.0697E-02 9.1521E-03 -9.9061E-03 -9.8228E-01 -1.1650E-01 -1.1465E-02 -1.6531E-02 -1.2643E-02 -2.0615E-03 2.8156E-01 -2.2572E-02 4.6726E-02 1.9661E-02 -1.2824E-02 -1.6304E-02 which can be represented by $\begin{matrix} Z_{11} & Z_{12} & Z_{13} & Z_{14} & Z_{15} & Z_{16} \\ Z_{21} & Z_{22} & Z_{23} & Z_{24} & Z_{25} & Z_{26} \\ Z_{31} & Z_{32} & Z_{33} & Z_{34} & Z_{35} & Z_{36} \\ Z_{41} & Z_{42} & Z_{43} & Z_{44} & Z_{45} & Z_{46} \\ Z_{51} & Z_{52} & Z_{53} & Z_{54} & Z_{55} & Z_{56} \\ Z_{61} & Z_{62} & Z_{63} & Z_{64} & Z_{65} & Z_{66} \\ Z_{71} & Z_{72} & Z_{73} & Z_{74} & Z_{75} & Z_{76} \end{matrix}$ The value for the water Con W (wt %) is given as $W = A + B + C + D + E + F + G$ Where $A = 0.25 Z_{11} + 0.5Z_{12}x_1 + 0.5Z_{13}x_2 + 0.5Z_{14}x_3 + 0.5Z_{15}x_4 + 0.5Z_{16}x_5$ $B = y_1(0.5 Z_{21} + Z_{22}x_1 + Z_{23}x_2 + Z_{24}x_3 + Z_{25}x_4 + Z_{26}x_5)$ $C = y_2(0.5 Z_{31} + Z_{32}x_1 + Z_{33}x_2 + Z_{34}x_3 + Z_{35}x_4 + Z_{36}x_5)$ $D = y_3(0.5 Z_{41} + Z_{42}x_1 + Z_{43}x_2 + Z_{44}x_3 + Z_{45}x_4 + Z_{46}x_5)$ $E = y_4(0.5 Z_{51} + Z_{52}x_1 + Z_{53}x_2 + Z_{54}x_3 + Z_{55}x_4 + Z_{56}x_5)$ $F = y_5(0.5 Z_{61} + Z_{62}x_1 + Z_{63}x_2 + Z_{64}x_3 + Z_{65}x_4 + Z_{66}x_5)$ $G = y_6(0.5 Z_{71} + Z_{72}x_1 + Z_{73}x_2 + Z_{74}x_3 + Z_{75}x_4 + Z_{76}x_5)$
Temperature(T) range 360.927778K – 394.261K Concentration (X) range 10wt% - 70wt% U = (2T -(394.261 +360.92778)) / (394.261 - 360.92778) V = (2X -(10+70)) / (70-10) x_1 = cos(acos(U)) y_1 = cos(acos(V)) x_2 = cos(2acos(U)) y_2 = cos(2acos(V)) y_3 = cos(3acos(V))	The coefficients are 3.6840E+01 1.6020E+00 -1.1460E+00 -3.5807E+01 -6.1256E+00 -1.0895E+00 8.6294E+00 -3.0641E+00 -7.3772E-01 -8.3204E+00 -1.8361E+00 -1.6027E-01 which can be represented by $\begin{matrix} Z_{11} & Z_{12} & Z_{13} \\ Z_{21} & Z_{22} & Z_{23} \\ Z_{31} & Z_{32} & Z_{33} \\ Z_{41} & Z_{42} & Z_{43} \end{matrix}$ The value for the water Con W (wt %) is given as $W = A + B + C + D$ Where $A = 0.25 Z_{11} + 0.5Z_{12}x_1 + 0.5Z_{13}x_2$ $B = y_1(0.5 Z_{21} + Z_{22}x_1 + Z_{23}x_2)$ $C = y_2(0.5 Z_{31} + Z_{32}x_1 + Z_{33}x_2)$ $D = y_3(0.5 Z_{41} + Z_{42}x_1 + Z_{43}x_2)$

<table>
<tr>
<td>Température(T) range: 394.261K- 433.15K
Concentration (X) range: 10wt% -50wt%

U = (2T -(433.15-394.261)) / (433.15-394.261)
V = (2X -(50+10)) / (50-10)

x_1 = cos(acos(U)) y_1 = cos(acos(V))
x_2 = cos(2acos(U)) y_2 = cos(2acos(V))
y_3 = cos(3acos(V))</td>
<td>The coefficients are
7.5949E+01 6.0156E+00 3.4364E-01
-3.6416E+01 -1.8080E+00 2.5615E-01
1.1760E+01 1.6974E-01 1.3220E-01
3.2166E+00 1.1466E-01 7.3459E-02

which can be represented by:
Z_{11} Z_{12} Z_{13}
Z_{21} Z_{22} Z_{23}
Z_{31} Z_{32} Z_{33}
Z_{41} Z_{42} Z_{43}

The value for the water Con W (wt %) is given as
$W = A + B + C + D$
Where
$A = 0.25 Z_{11} + 0.5Z_{12}x_1 + 0.5Z_{13}x_2$
$B = y_1(0.5 Z_{21} + Z_{22}x_1 + Z_{23}x_2)$
$C = y_2(0.5 Z_{31} + Z_{32}x_1 + Z_{33}x_2)$
$D = y_3(0.5 Z_{41} + Z_{42}x_1 + Z_{43}x_2)$</td>
</tr>
<tr>
<td colspan="2">Maximum absolute error between the experimental data and those generated = ±1.41%</td>
</tr>
</table>

TABLE V: LIQUID ENTROPIES VALUES

Temperature(T) range 233.15K – 272.03889K

Concentration (X) range 10wt% -100wt%

$U = (2T - (272.03889+233.15))/(272.03889-233.15)$

$V = (2X - (100+10))/(100-10)$

$x_1 = \cos(\mathrm{acos}(U))$ $y_1 = \cos(\mathrm{acos}(V))$
$x_2 = \cos(2\mathrm{acos}(U))$ $y_2 = \cos(2\mathrm{acos}(V))$
$x_3 = \cos(3\mathrm{acos}(U))$ $y_3 = \cos(3\mathrm{acos}(V))$
$x_4 = \cos(4\mathrm{acos}(U))$ $y_4 = \cos(4\mathrm{acos}(V))$
$y_5 = \cos(5\mathrm{acos}(V))$

The coefficients are

-3.4482E+00	6.6703E-01	-4.6207E-03	2.7994E-03	3.7956E-03
2.9553E-01	3.1802E-02	-6.8849E-03	1.7226E-03	-1.5735E-03
7.9982E-01	-2.2327E-02	5.6871E-03	-1.0581E-03	1.1831E-03
-9.4909E-02	1.6384E-02	-58785E-03	1.8218E-03	-1.7062E-03
-1.4208E-02	-1.2749E-02	4.6680E-03	-1.9818E-03	1.8848E-03
4.2094E-03	7.7552E-03	-2.9285E-03	8.4612E-04	2.0575E-03

which can be represented by

Z_{11}	Z_{12}	Z_{13}	Z_{14}	Z_{15}
Z_{21}	Z_{22}	Z_{23}	Z_{24}	Z_{25}
Z_{31}	Z_{32}	Z_{33}	Z_{34}	Z_{35}
Z_{41}	Z_{42}	Z_{43}	Z_{44}	Z_{45}
Z_{51}	Z_{52}	Z_{53}	Z_{54}	Z_{55}
Z_{61}	Z_{62}	Z_{63}	Z_{64}	Z_{65}

The value for the Liquid Entropies S (kJ/kg K) is given as

$S = A + B + C + D + E + F$

Where

$A = 0.25 Z_{11} + 0.5Z_{12}x_1 + 0.5Z_{13}x_2 + 0.5Z_{14}x_3 + 0.5Z_{15}x_4$
$B = y_1(0.5 Z_{21} + Z_{22}x_1 + Z_{23}x_2 + Z_{24}x_3 + Z_{25}x_4)$
$C = y_2(0.5 Z_{31} + Z_{32}x_1 + Z_{33}x_2 + Z_{34}x_3 + Z_{35}x_4)$
$D = y_3(0.5 Z_{41} + Z_{42}x_1 + Z_{43}x_2 + Z_{44}x_3 + Z_{45}x_4)$
$E = y_4(0.5 Z_{51} + Z_{52}x_1 + Z_{53}x_2 + Z_{54}x_3 + Z_{55}x_4)$
$F = y_5(0.5 Z_{61} + Z_{62}x_1 + Z_{63}x_2 + Z_{64}x_3 + Z_{65}x_4)$

Temperature(T) range 272.03889K – 360.927778K
Concentration (X) range 0wt% 100wt%

$U = (2T - (360.92778+233.15)) / (360.927778-233.15)$
$V = (2X - (100+0)) / (100-0)$

$x_1 = \cos(\mathrm{acos}(U))$ $y_1 = \cos(\mathrm{acos}(V))$
$x_2 = \cos(2\mathrm{acos}(U))$ $y_2 = \cos(2\mathrm{acos}(V))$
$x_3 = \cos(3\mathrm{acos}(U))$ $y_3 = \cos(3\mathrm{acos}(V))$
$x_4 = \cos(4\mathrm{acos}(U))$ $y_4 = \cos(4\mathrm{acos}(V))$
$x_5 = \cos(5\mathrm{acos}(U))$ $y_5 = \cos(5\mathrm{acos}(V))$
$y_6 = \cos(5\mathrm{acos}(V))$

The coefficients are

9.5496E-01	1.3619E+00	6.2029E-03	1.4255E-02	1.2319E-02	-1.2831E-03
1.2900E-01	7.0346E-02	1.9712E-02	1.0447E-02	1.0139E-03	3.1844E-03
8.9737E-01	-1.3377E-02	5.2104E-03	4.3935E-03	-1.9954E-04	1.6921E-03
-2.2549E-02	6.9899E-03	3.5255E-03	-5.1398E-04	4.6963E-03	-1.7948E-03
-6.7774E-02	2.3083E-03	1.4876E-03	2.2480E-03	-2.7057E-03	3.6447E-03
2.2562E-02	2.2743E-03	1.2281E-03	1.3606E-03	2.4436E-03	4.1706E-04
1.0077E-02	3.6354E-03	7.3776E-04	1.2873E-03	3.6169E-03	-6.9773E-04

which can be represented by

Z_{11}	Z_{12}	Z_{13}	Z_{14}	Z_{15}	Z_{16}
Z_{21}	Z_{22}	Z_{23}	Z_{24}	Z_{25}	Z_{26}
Z_{31}	Z_{32}	Z_{33}	Z_{34}	Z_{35}	Z_{36}
Z_{41}	Z_{42}	Z_{43}	Z_{44}	Z_{45}	Z_{46}
Z_{51}	Z_{52}	Z_{53}	Z_{54}	Z_{55}	Z_{56}
Z_{61}	Z_{62}	Z_{63}	Z_{64}	Z_{65}	Z_{66}
Z_{71}	Z_{72}	Z_{73}	Z_{74}	Z_{75}	Z_{76}

The value for the Liquid Entropies S (kJ/kg K) is given as

$S = A + B + C + D + E + F + G$

Where

$A = 0.25 Z_{11} + 0.5Z_{12}x_1 + 0.5Z_{13}x_2 + 0.5Z_{14}x_3 + 0.5Z_{15}x_4 + 0.5Z_{16}x_5$
$B = y_1(0.5 Z_{21} + Z_{22}x_1 + Z_{23}x_2 + Z_{24}x_3 + Z_{25}x_4 + Z_{26}x_5)$
$C = y_2(0.5 Z_{31} + Z_{32}x_1 + Z_{33}x_2 + Z_{34}x_3 + Z_{35}x_4 + Z_{36}x_5)$
$D = y_3(0.5 Z_{41} + Z_{42}x_1 + Z_{43}x_2 + Z_{44}x_3 + Z_{45}x_4 + Z_{46}x_5)$
$E = y_4(0.5 Z_{51} + Z_{52}x_1 + Z_{53}x_2 + Z_{54}x_3 + Z_{55}x_4 + Z_{56}x_5)$
$F = y_5(0.5 Z_{61} + Z_{62}x_1 + Z_{63}x_2 + Z_{64}x_3 + Z_{65}x_4 + Z_{66}x_5)$
$G = y_6(0.5 Z_{71} + Z_{72}x_1 + Z_{73}x_2 + Z_{74}x_3 + Z_{75}x_4 + Z_{76}x_5)$

Température(T) range: 360.927778 – 394.261K
Concentration (X) range: 0wt% -70wt%

U = (2T -(394.261+360.92778)) / (394.261-360.92778)
V = (2X -(70+0)) / (70-0)

x_1 = cos(acos(U))
x_2 = cos(2acos(U))
x_3 = cos(3acos(U))
x_4 = cos(4acos(U))

y_1 = cos(acos(V))
y_2 = cos(2acos(V))
y_3 = cos(3acos(V))
y_4 = cos(4acos(V))
y_5 = cos(5acos(V))

The coefficients are:

2.9753E+00	-2.7729E-01	-5.5085E-01	-3.8062E-01	-1.5296E-01
-1.1765E+00	-6.1557E-01	-5.0648E-01	-3.5171E-01	-1.4224E-01
-6.3253E-02	-4.9197E-01	-4.1028E-01	-3.0184E-01	1.2687E-01
-2.4511E-01	-3.0765E-01	-2.6126E-01	-2.0087E-01	-8.6777E-02
-1.7128E-01	1.5194E-01	-1.4450E-01	-1.2011E-01	-5.5143E-02
-5.5391E-02	-5.3141E-02	-5.5635E-02	-4.7043E-02	-2.1680E-02

which can be represented by

Z_{11}	Z_{12}	Z_{13}	Z_{14}	Z_{15}
Z_{21}	Z_{22}	Z_{23}	Z_{24}	Z_{25}
Z_{31}	Z_{32}	Z_{33}	Z_{34}	Z_{35}
Z_{41}	Z_{42}	Z_{43}	Z_{44}	Z_{45}
Z_{51}	Z_{52}	Z_{53}	Z_{54}	Z_{55}
Z_{61}	Z_{62}	Z_{63}	Z_{64}	Z_{65}

The value for the Liquid Entropies S (kJ/kg K) is given as

$S = A + B + C + D + F + F$

Where

$A = 0.25 Z_{11} + 0.5Z_{12}x_1 + 0.5Z_{13}x_2 + 0.5Z_{14}x_3 + 0.5Z_{15}x_4$
$B = y_1(0.5 Z_{21} + Z_{22}x_1 + Z_{23}x_2 + Z_{24}x_3 + Z_{25}x_4)$
$C = y_2(0.5 Z_{31} + Z_{32}x_1 + Z_{33}x_2 + Z_{34}x_3 + Z_{35}x_4)$
$D = y_3(0.5 Z_{41} + Z_{42}x_1 + Z_{43}x_2 + Z_{44}x_3 + Z_{45}x_4)$
$E = y_4(0.5 Z_{51} + Z_{52}x_1 + Z_{53}x_2 + Z_{54}x_3 + Z_{55}x_4)$
$F = y_5(0.5 Z_{61} + Z_{62}x_1 + Z_{63}x_2 + Z_{64}x_3 + Z_{65}x_4)$

Température(T) range 394.261K – 433.15
Concentration (X) range 0wt% -50wt%

U = (2T -(433.15 +394.261)) / (433.15 - 394.261)
V = (2X -(70+0)) / (70-0)

x_1 = cos(acos(U))
x_2 = cos(2acos(U))

y_1 = cos(acos(V))
y_2 = cos(2acos(V))
y_3 = cos(3acos(V))

The coefficients are

5.3522E+00	4.3540E-01	7.8090E-03
-7.2272E-01	1.2796E-02	2.5150E-03
1.2821E-01	-5.1678E-03	2.9983E-03
3.7860E-02	-5.9225E-03	7.6739E-03

which can be represented by

Z_{11}	Z_{12}	Z_{13}
Z_{21}	Z_{22}	Z_{23}
Z_{31}	Z_{32}	Z_{33}
Z_{41}	Z_{42}	Z_{43}

The value for the Liquid Entropies S (kJ/kg K) is given as

$S = A + B + C + D$

Where

$A = 0.25 Z_{11} + 0.5Z_{12}x_1 + 0.5Z_{13}x_2$
$B = y_1(0.5 Z_{21} + Z_{22}x_1 + Z_{23}x_2)$
$C = y_2(0.5 Z_{31} + Z_{32}x_1 + Z_{33}x_2)$
$D = y_3(0.5 Z_{41} + Z_{42}x_1 + Z_{43}x_2)$

Maximum absolute error between the experimental data and those generated = ±1.78%

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