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ABSTRACT

The solubilities, densities and viscosities of lithium bromide (LiBr) + 1, 2-propanediol ($HO\text{-}CH_2\text{-}CHOH\text{-}CH_3$) aqueous solution (mass ratio of $LiBr/HO\text{-}CH_2\text{-}CHOH\text{-}CH_3$ = 3.5, 4.5 and 5.5) were measured in the mass fraction range from 0.30 to 0.75. Solubility measurements were performed by the visual method in the temperature range of (271.15 to 345.15) K. The density measurements were made using an automated vibrating tube density meter, and the viscosity measurements were carried out with an automated falling-ball viscometer in the temperature range of (293.15 to 363.15) K. The density and viscosity data were correlated with appropriate regression equations as a function of the mass fraction and temperature. The maximum average absolute deviations (AAD) between experimental and correlated data were 0.08% and 1.51% for densities and viscosities, respectively.

1. INTRODUCTION

The key technical barrier to using water/LiBr as the working fluid in air-cooled absorption chillers and absorption heat pump systems is the risk of crystallization when the absorber temperature rises at fixed evaporating pressure (Wang et al., 2011). Crystallization results in interruption of absorption chiller/heat pump operation and possible damage to the unit. One of the effective crystallization control strategies is using crystallization inhibitors. Biermann (1978) reviewed chemical inhibitors having the potential to sustain an air-cooled, solar-powered absorption refrigeration system. An aqueous chemical solution called "Carrol" was developed based on the review results (Reimann, 1981). It consists of LiBr, ethylene glycol, and 1-nonylamine (or phenylmethylcarbinol) as an absorbent mixture and water as the refrigerant. The ethylene glycol was used as a crystallization inhibitor. The major drawback of this fluid is the toxicity of ethylene glycol. Other potential working fluids evaluated for use in air-cooled water-based absorption systems are H_2O + LiBr + $LiNO_3$ (Iyoki et al., 1993c), H_2O + LiBr + LiI and H_2O + LiBr + $LiNO_3$ (Iyoki et al., 1993a, b), and H_2O + LiBr + $LiNO_3$ + LiI + LiCl (Koo et al., 1999). $LiNO_3$ behaves as a crystallization inhibitor and corrosion inhibitor. LiI is also selected as a crystallization inhibitor, and LiCl serves as a vapor pressure suppression agent. A company in Japan (Iizuka et al., 1992; Tongu S et al., 1993) patented a H_2O + LiBr + LiCl + LiI + $LiNO_3$ solution for an air-cooled, double-effect absorption chiller-heater which increases allowable absorber and condenser operating temperatures approximately 283.15 K and 4 K higher than for a water-cooled cycle. Ring et al. (2001) and Dirksen et al. (2001) tested the crystallization temperatures of 27 crystallization inhibitors (at concentrations of 250 to 1500 ppm) within industrial LiBr solutions cooled at a rate of 20 $K \cdot h^{-1}$. Some of these additives (such as Methylene diphosphonic acid, Pyrophosphoric acid, Amino Tri(methylene phosphonic acid), Diethylenetriamine pentamethylene phosphonic acid and 1-Hydroxyethylidene-1,1-diphosphonic Acid) further decreased the crystallization temperature by up to 13 K below the experimental crystallization temperature and up to 22 K below the equilibrium solubility of the same LiBr solution without additive. Park et al. (1997) carried out the experimental measurement of four physical properties (solubility, vapor pressure, density and viscosity) of LiBr + 1,3-propanediol (β-propylene glycol) + H_2O solution (LiBr/1,3-propanediol mass ratio = 3.5). The Dühring chart was generated using correlation results based on the experimental data and showed that the proposed solution could have a high absorber temperature, which is essential for the design of air-cooled absorption chillers. In this article, solubilities, densities and viscosities of LiBr + 1, 2-propanediol ($HO\text{-}CH_2\text{-}CHOH\text{-}CH_3$) aqueous solution (mass ratio of LiBr/$HO\text{-}CH_2\text{-}CHOH\text{-}CH_3$ = 3.5, 4.5 and 5.5) were measured in the mass fraction range from 0.30 to 0.75. The correlation equations of density and viscosity as functions of temperature and concentration mass fraction were presented as well.

2. EXPERIMENTAL SETUP

2.1 Materials

The reagents (as listed in Table 1), pure LiBr (mass fraction 0.999) and 1, 2-propanediol (mass fraction 0.995), were supplied by Aldrich Chemical Co. and Alfa Aesar Co., respectively, and were used without any purification. To avoid the presence of moisture traces, the LiBr was stored on molecular sieves. Distilled water was used to prepare the test samples.

Table 1: Description of the Chemical Samples

Chemical Name	Source	Initial Mass Fraction Purity	Purification Mehtod
Lithium Bromide	Aldrich	0.999	none
1, 2 - Propanediol	Alfa Aesar	0.995	none

2.2 Apparatus and Procedure

A high precision electric balance (Mettler, AE200) with measurement uncertainty of ±0.0001g was used to measure the weight of the chemicals and water to prepare the sample to the desired concentration ratio. The standard uncertainties of samples' concentrations were listed in Table 2, Table 3 and Table 5.

The solubility measurement setup consists of a supporting stand with a clamp, a hot plate stirrer, a crystallizing dish containing water and the test flask (closed with a rubber stopper) containing chemicals, water and a stir bar. The experimental setup is shown in Figure 1. The sample solution was prepared systematically to reduce sample concentration uncertainty. First the required amount of LiBr and 1, 2-propanediol were weighed in a closed flask to minimize moisture absorption from ambient air. Second, the required amount of water was weighed in another flask. Next the water was introduced into the test flask followed by the weighed LiBr and 1, 2-propanediol. A stir bar was introduced into the test flask and the flask was immediately closed with a rubber stopper and heated in a water bath to form a homogeneous solution. The exact amount of water and chemicals introduced into the test flask were noted by subtracting the trace amount of salt and water in the measurement flasks that could not be transferred. The water bath consists of a crystallizing dish containing water that was heated on a hot plate stirrer. Once the chemicals are dissolved and a homogeneous solution is formed, the test flask was removed from the hot water bath. The stir bar was also removed and the rubber stopper was replaced with a one-hole rubber stopper in order to insert the thermocouple (Type T, with accuracy of ±0.1 K) into the test solution. The hot homogeneous salt solution was then cooled in a cooling bath (with controlled temperature accuracy of ±0.01K) gradually and the solution was closely monitored for the appearance of the crystals. The crystallization temperature is determined when the first crystal forms. The temperature of the solution as a function of time was recorded by the data acquisition system and the graph was plotted to note the accurate crystallization temperature.

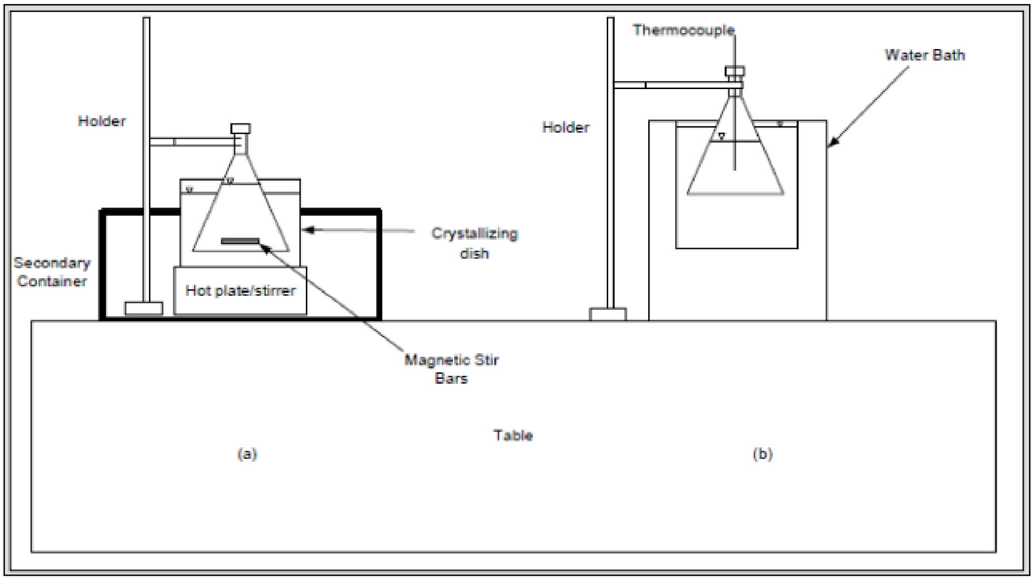

Figure 1: (a) Schematic diagram of salt solution preparation and (b) crystallization temperature measurement

The density measurements were carried out using an automated oscillating U-tube density meter (Anton Paar, DMA 4100 M). The instrument uncertainties of the density measurement were ±0.1 kg·m^{-3}.(Anton Paar, 2010) The test sample was introduced into a U-shape borosilicate glass tube which could oscillate at its characteristic frequency. This frequency would change depending on the density of the test sample. The density of sample was determined from precise measurement of the U-tube oscillating frequency (Anton Paar, 2010). The temperature sensors integrated in the density meter were two platinum resistance thermometers (Pt-100) with accuracy of 0.05 K. The density meter was calibrated with bi-distilled water (Anton Paar, Material No.26750) at 293.15 K, and the test result was compared with the data from published literature (Wagner and Pruß, 2002). The absolute deviation between them was 0.004 kg·m^{-3}. The measurement interval was 5 K throughout all of the tests.

The dynamic viscosity measurements were made with an automated falling-ball viscometer (Anton Paar, AMVn Micro Viscometer) which measured the rolling time of a steel ball through transparent liquid in a glass capillary tube according to Höppler's falling ball principle (Anton Paar, 2008). The dynamic viscosity of the test sample was calculated from the following equation:

$$\mu = K_1 \times (\rho_K - \rho_P) \times t \tag{1}$$

where μ is the dynamic viscosity of the test sample, K_1 is the calibration constant of measuring system, t is the steel ball rolling time, ρ_K is the density of steel ball, ρ_P is the density of the test sample. The calibration constant of measuring system (K_1) and the steel ball density (ρ_K) were supplied by the manufacturer (Anton Paar). The density of sample (ρ_P) could be measured using aforementioned oscillating U-tube density meter. The temperature sensor integrated in the viscosity meter is a platinum resistance thermometer (Pt-100) with accuracy of 0.05 K. The time measuring system has an accuracy of 0.002 second. The instrument uncertainties were ±0.5% for viscosity measurement (Anton Paar, 2008). The viscometer was calibrated with bi-distilled water (Anton Paar, Material No.26750) at 293.15 K, and the test result was compared with the results from published literature (Wagner and Pruß, 2002). The absolute deviation between them was 0.00001 mPa·s. The measurement interval was 5 K throughout all of the tests.

3. RESULTS AND DISCUSSION

3.1 Solubility

The solubilites of LiBr + 1, 2-propanediol aqueous solutions were measured in the temperature range from 271.24 K to 345.15 K, and the results are listed in Table 2. Figure 2 shows the experimental results of LiBr + 1, 2-propanediol (mass ratio of LiBr/1, 2-propanediol varies from 3.5 to 5.5). Compared to LiBr aqueous solution (Boryta, 1970) alone, a great extent of solubility enhancement occurred by adding 1,2-propanediol. Compared to LiBr + 1,3-propanediol (Park et al., 1997) with same mass ratio (3.5), there are at least 15 K of solubility enhancement for LiBr/1,2-propanediol in the mass fraction range from 0.70 to 0.74.

Table 2: Solubilities of the LiBr + 1, 2-propanediol Aqueous Solutions

***T* (K)**	**(LiBr + 1, 2-propanediol) concentration in mass fraction**
Mass ratio of LiBr/1, 2-propanediol=4.5	
285.31±0.1	0.7000±0.0001637
289.74±0.1	0.7095±0.0001876
294.00±0.1	0.7199±0.0001728
308.19±0.1	0.7298±0.0001654
319.55±0.1	0.7399±0.0001773
338.04±0.1	0.7497±0.0001658
Mass ratio of LiBr/1, 2-propanediol=3.5	
271.24±0.1	0.6999±0.0001638
285.38±0.1	0.7200±0.0001725
291.39±0.1	0.7397±0.0001775
Mass ratio of LiBr/1, 2-propanediol=5.5	
293.81±0.1	0.7001±0.0001635
317.15±0.1	0.7199±0.0001728
345.15±0.1	0.7399±0.0001773

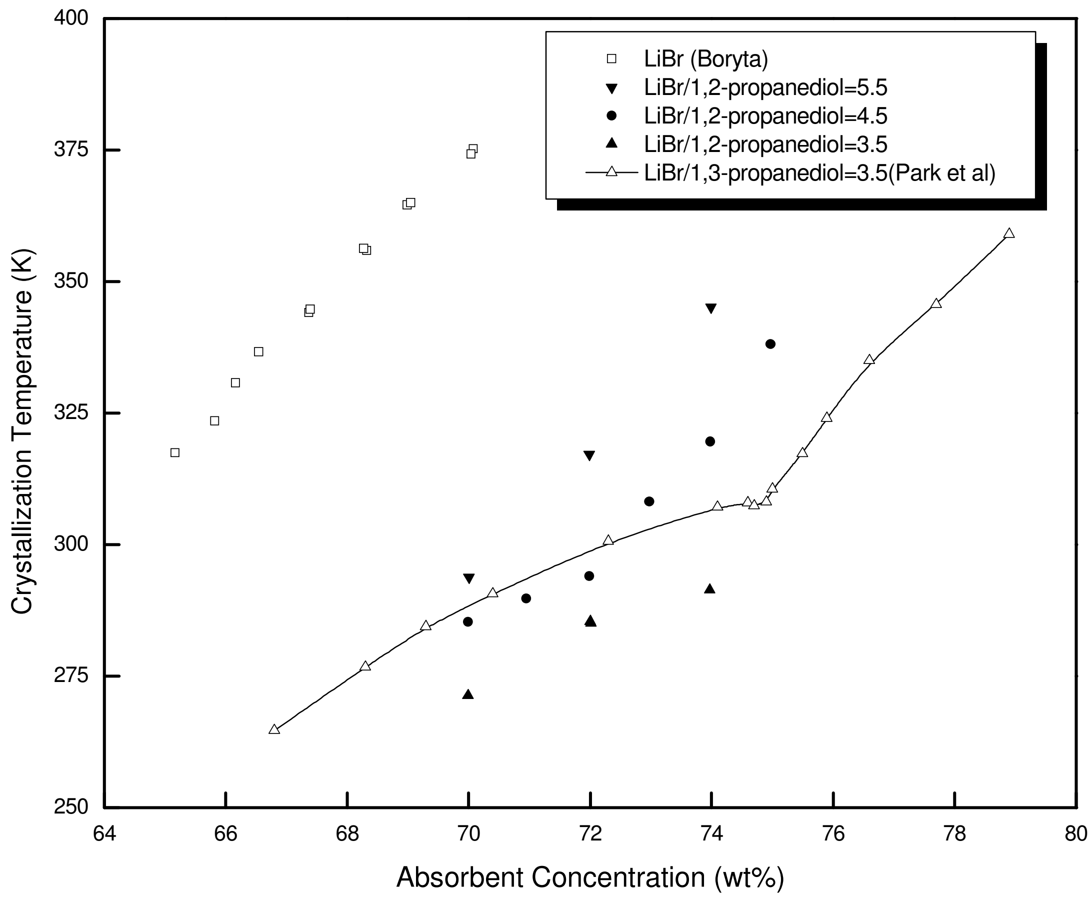

Figure 2: Solubilities of the LiBr (Boryta, 1970), LiBr + 1, 2-propanediol, LiBr + 1, 3-propanediol (Park et al., 1997) aqueous solutions

3.2 Density

The densities and viscosities of LiBr + 1, 2-propanediol aqueous solution (mass ratio of LiBr/1, 2-propanediol = 3.5, 4.5 and 5.5) were measured in the mass fraction range from 0.30 to 0.75 and in the temperature range from (293.15 to 363.15) K. The measured density values (as shown in Table 3) were regressed according to the following equation:

$$\rho = \sum_{i=0}^{3}[(A_i + B_i T + C_i T^2)X^i] \tag{2}$$

where ρ (kg·m^{-3}) is the density of LiBr + 1, 2-propanediol aqueous solution, T (K) is the absolute temperature of solution, X is the absorbent (LiBr + 1, 2-propanediol) concentration in mass fraction. $A_{\rm i}$, $B_{\rm i}$ and $C_{\rm i}$ are the coefficients for regression eq 2. The coefficients were determined using Engineering Equation Solver (EES) (Klein and Alvarado, 1992) and the values of coefficients are listed in Table 3. As listed in Table 4, the average absolute deviation (AAD) between the tested and the correlated densities were 0.08%, 0.05% and 0.04% for mass ratio of LiBr/1, 2-propanediol of 3.5, 4.5 and 5.5, respectively. Figure 3 showed the measured and calculated densities of aqueous solution with different concentrations.

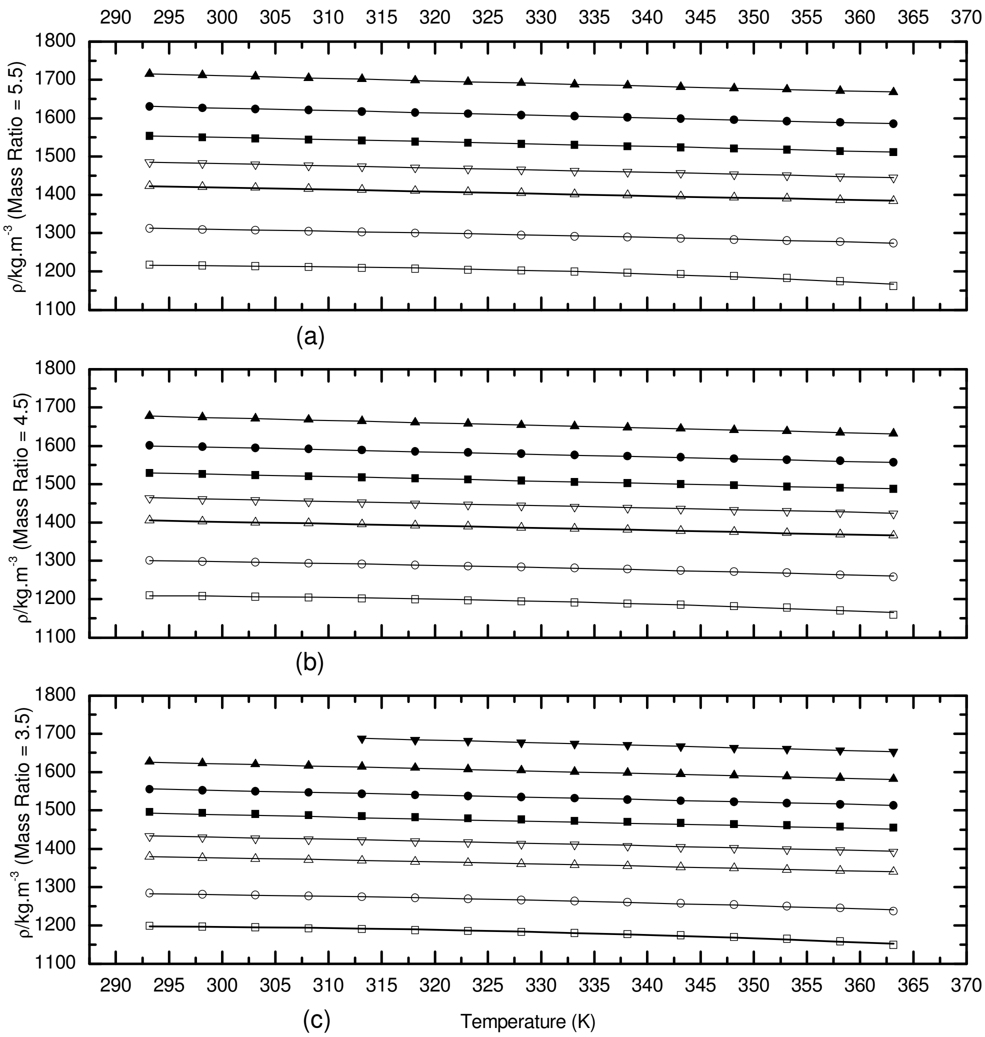

Figure 3: Densities of LiBr + 1, 2-propanediol aqueous solution at various mass ratios and mass fractions

(a) mass ratio of LiBr/1, 2-propanediol is 5.5; □, 0.3000; ○, 0.4000%; Δ, 0.5004;∇, 0.5498; ■, 0.5995; ●, 0.6498; ▲, 0.7003 ;—, data calculated by eq 2; (b) mass ratio of LiBr/1, 2-propanediol is 4.5; □, 0.3000; ○,0.4001; Δ, 0.4993;∇, 0.5498; ■, 0.6002; ●, 0.6503; ▲, 0.7998;—, data calculated by eq 2; (c) mass ratio of LiBr/1, 2-propanediol is 3.5; □, 0.2994; ○, 0.3970; Δ, 0.4983;∇, 0.5505; ■, 0.5989; ●, 0.6496; ▲, 0.7004; ▼, 0.7500; —, data calculated by eq 2.

3.3 Viscosity

The measured viscosities of LiBr + 1, 2-propanediol aqueous solution were listed in Table 5, and the test results were regressed to the following equation:

$$\log_{10}(\mu) = \sum_{n=0}^{4}\left[\left(A_n + \frac{B_n}{T} + \frac{C_n}{T^2}\right)X^n\right] \quad (3)$$

where μ is the dynamic viscosity (mPa·s), T is the absolute temperature of the solution (K), X is the absorbent (LiBr + 1, 2-propanediol) concentration in mass fraction. A_n, B_n and C_n are the coefficients for regression eq 3. The coefficients were determined using Engineering Equation Solver (EES)(Klein and Alvarado, 1992) and the values of coefficients were presented in Table 6. As shown in Table 5, the average absolute deviation (AAD) between the tested and the correlated densities were 1.51%, 0.87% and 0.65% for mass ratio of LiBr/1, 2-propanediol of 3.5, 4.5 and 5.5, respectively. Figure 4 depicted the measured and correlated dynamic viscosities of aqueous solution with different concentrations and mass ratios.

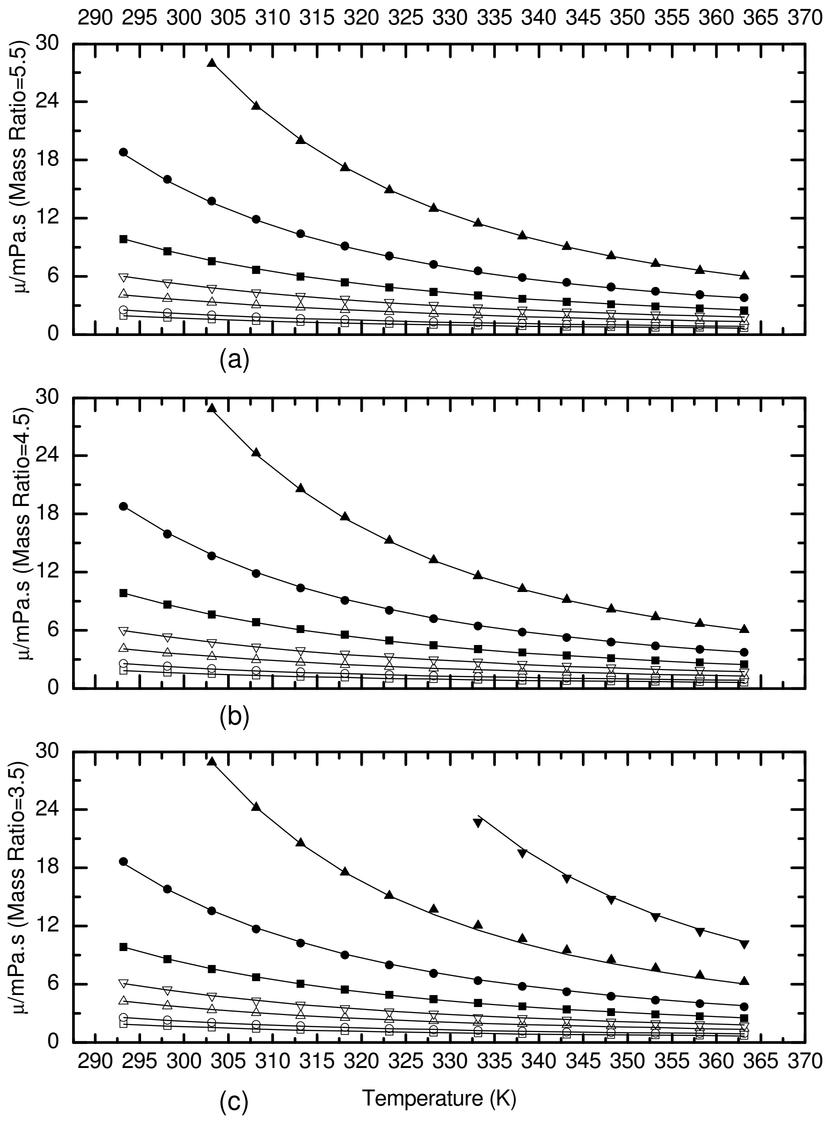

Figure 4: Viscosities of LiBr + 1, 2-propanediol aqueous solution at various mass ratios and mass fractions

(a) mass ratio of LiBr/1, 2-propanediol is 5.5; □, 0.3000; ○, 0.4000; Δ, 0.5004;∇, 0.5498; ■, 0.5995; ●, 0.6498; ▲, 0.7003 ;—, data calculated by eq 3; (b) mass ratio of LiBr/1, 2-propanediol is 4.5; □, 0.3000; ○, 0.4001; Δ, 0.4993;∇, 0.5498; ■, 0.6002; ●, 0.6503; ▲, 0.7998 ;—, data calculated by eq 3; (c) mass ratio of LiBr/1, 2-propanediol is 3.5; □, 0.2994; ○, 0.3970; Δ, 0.4983;∇, 0.5505; ■, 0.5989; ●, 0.6496; ▲, 0.7004 ;▼, 0.7500; —, data calculated by eq 3.

4. CONCLUSIONS

In this study, the solubilities, densities and viscosities of aqueous LiBr + 1, 2-propanediol solution, a possible new working fluid for air-cooled absorption chillers and absorption heat pump systems, were measured with different mass ratio (3.5, 4.5 and 5.5). The experiments covered the temperature ranging from 293.15 K to 363.15 K and mass fraction from 0.30 to 0.75. This working fluid has better crystallization inhibition performance than that of LiBr + 1,3-propanediol + H_2O solution reported by Park et al. (Park et al., 1997). Regression equations of density and viscosity were correlated using the experimental data sets, and the comparisons between experimental and correlated values showed good agreement with each other. These properties (density and viscosity) are essential to calculate the heat transfer coefficient of aqueous LiBr + 1, 2-propanediol solution in the absorption heat pump system.

Further investigations of aqueous LiBr + 1, 2-propanediol solution include: 1) generate the Dühring diagrams by measuring the solution vapor pressure at various absorbent mass fractions and solution temperatures, 2).measure the thermal conductivities and specific heat capacities using hot-wire method. The Dühring diagram of the LiBr + 1, 2-propanediol system will be used to evaluate if this solution could provide higher temperature lift at fixed evaporating temperature, which is crucial for the design of air-cooled absorption chiller and absorption heat pump systems. An in-depth discussion on the trade-off between thermal (thermal conductivities, specific heat capacities) and transport (densities and viscosities) properties and the crystallization issues will also be carried out for LiBr + 1, 2-propanediol aqueous solutions.

NOMENCLATURE

AAD	Average Absolute Deviation	*T*	Temperature (K)
A,B,C	Coefficients for regression equations	*X*	Concentration in mass fraction
K_1	Calibration constant	***Greek Letters***	
N	Number of data points	ρ	Density ($kg{\cdot}m^{-3}$)
RSME	Root-mean-square error	μ	Viscosity (mPa·s)
R^2	Coefficient of determination		

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Table 3: Densities (ρ, kg·m^{-3}) of LiBr + 1, 2-Propanediol Aqueous Solution at Various Mass Ratios and Mass Fractions[a]

Mass Ratio	X*100	*T*/K														
		293.16	298.14	303.14	308.14	313.14	318.14	323.14	328.14	333.14	338.14	343.14	348.14	353.14	358.14	363.14
3.5	29.94±0.0002044	1199.0	1197.1	1195.0	1192.8	1190.6	1188.2	1185.7	1183.1	1180.4	1177.6	1174.2	1169.9	1165.1	1158.4	1149.4
	39.70±0.0001886	1284.0	1281.8	1279.5	1277.1	1274.7	1272.1	1269.5	1266.8	1263.8	1261.1	1258.2	1253.9	1250.2	1246.0	1237.6
	49.83±0.0001728	1378.7	1376.2	1373.7	1371.1	1368.4	1365.7	1363.0	1360.2	1357.4	1354.5	1351.6	1348.7	1345.7	1342.6	1339.6
	55.05±0.0001680	1432.7	1430.0	1427.4	1424.6	1421.9	1419.1	1416.3	1413.4	1410.6	1407.7	1404.7	1401.7	1398.7	1395.7	1392.6
	59.89±0.0001654	1496.4	1493.6	1490.8	1487.9	1485.1	1482.2	1479.3	1476.3	1473.4	1470.4	1467.3	1464.3	1461.3	1458.3	1455.1
	64.96±0.0001636	1555.7	1552.8	1549.8	1546.8	1543.8	1540.7	1537.6	1534.7	1531.7	1528.6	1525.5	1522.4	1519.3	1516.2	1513.1
	70.04±0.0001635	1626.5	1623.3	1620.1	1616.9	1613.8	1610.6	1607.3	1604.1	1601.0	1597.8	1594.6	1591.4	1588.1	1584.9	1581.6
	75.00±0.0001658					1687.8	1684.3	1680.9	1677.5	1674.0	1670.6	1667.2	1663.8	1660.4	1657.0	1653.6
4.5	30.00±0.0002068	1210.4	1208.4	1206.4	1204.2	1201.9	1199.5	1197.1	1194.5	1191.9	1189.1	1186.0	1182.5	1178.5	1171.3	1159.6
	40.01±0.0001876	1301.2	1298.9	1296.6	1294.2	1291.8	1289.3	1286.7	1284.0	1281.3	1278.5	1275.3	1272.6	1269.0	1264.1	1257.8
	49.93±0.0001733	1405.1	1402.6	1400.0	1397.5	1394.9	1392.2	1389.4	1386.7	1383.9	1381.0	1378.1	1375.2	1372.2	1369.1	1366.0
	54.98±0.0001682	1463.5	1460.8	1458.1	1455.4	1452.6	1449.8	1447.0	1444.2	1441.3	1438.4	1435.5	1432.5	1429.5	1426.5	1423.4
	60.02±0.0001649	1529.6	1526.7	1523.9	1521.0	1518.1	1515.2	1512.2	1509.3	1506.3	1503.3	1500.2	1497.2	1494.1	1491.0	1487.9
	65.03±0.0001634	1601.2	1598.2	1595.1	1592.0	1589.0	1585.9	1582.8	1579.7	1576.6	1573.4	1570.3	1567.2	1564.0	1560.8	1557.6
	69.98±0.0001637	1677.7	1674.4	1671.1	1667.8	1664.5	1661.1	1657.8	1654.5	1651.2	1647.9	1644.6	1641.3	1637.9	1634.6	1631.2
5.5	30.00±0.0002069	1218.2	1216.2	1214.2	1212.0	1209.7	1207.4	1204.9	1202.4	1199.7	1196.9	1193.3	1188.3	1183.0	1174.2	1162.5
	40.00±0.0001876	1312.2	1309.9	1307.6	1305.2	1302.8	1300.3	1297.7	1295.1	1292.3	1289.6	1286.7	1283.9	1280.9	1277.9	1274.0
	50.04±0.0001731	1423.4	1420.8	1418.2	1415.6	1412.9	1410.2	1407.5	1404.7	1401.9	1399.1	1396.2	1393.2	1390.3	1387.1	1384.1
	54.98±0.0001683	1484.9	1482.2	1479.5	1476.7	1473.9	1471.1	1468.3	1465.4	1462.5	1459.6	1456.7	1453.7	1450.7	1447.7	1444.6
	59.95±0.0001650	1553.3	1550.4	1547.5	1544.6	1541.7	1538.7	1535.7	1532.8	1529.8	1526.8	1523.7	1520.7	1517.6	1514.5	1511.4
	64.98±0.0001634	1630.4	1627.3	1624.2	1621.0	1617.9	1614.7	1611.6	1608.4	1605.2	1602.1	1598.9	1595.7	1592.4	1589.2	1586.0
	70.03±0.0001637	1715.4	1711.9	1708.5	1705.1	1701.7	1698.3	1694.9	1691.5	1688.1	1684.7	1681.3	1677.9	1674.5	1671.1	1667.6

[a] The standard uncertainties u *are* u(T) = 0.01 K, $u(\rho)$ = 0.1 kg·m^{-3}, $u(X)$ are listed in the table

Table 4 Regression Coefficients of Correlation Eq 2 (Density)[a]

Mass Ratio	i	A_i	B_i	C_i	RMSE	R^2	AAD
3.5 (116 data point)	0	-1602.23807	16.4412713	-0.0262205085	2.0956	99.89%	0.08%
	1	10044.9965	-57.0243423	0.0870838742			
	2	-10061.2471	58.6244453	-0.0869014409			
	3	3818.76002	-17.1055301	0.0227764529			
4.5 (105 data point)	0	-2466.88000	21.9950545	-0.0350311176	1.0537	100%	0.05%
	1	15565.8324	-92.3866985	0.1433831820			
	2	-20653.1590	126.835973	-0.1956021170			
	3	10340.8144	-58.4268220	0.0885181206			
5.5 (105 data point)	0	-9040.87799	63.4099919	-0.1004288160	0.9329	100%	0.04%
	1	55959.7815	-346.395342	0.5442420430			
	2	-99497.1064	622.139100	-0.9767820710			
	3	59952.8467	-369.183666	0.5782738050			

[a]RSME: Root-Mean-Square Error, R^2: The Coefficient of Determination, AAD = Average Absolute Deviation = $\Sigma(|\rho_{test}-\rho_{predicted}|/\rho_{test})/N\times100\%$, N is the number of data points.

Table 5 Viscosities (μ, mPa·s) of LiBr + 1, 2-Propanediol Aqueous Solution at Various Mass Ratio and Mass Fraction[a]

Mass Ratio	X*100	*T*/K														
		293.15	298.15	303.15	308.15	313.15	318.15	323.15	328.15	333.15	338.15	343.15	348.15	353.15	358.15	363.15
3.5	29.94±0.0002044	1.8905	1.6889	1.5234	1.3841	1.2662	1.1603	1.0733	0.9952	0.9276	0.8684	0.8144	0.7665	0.7265	0.6925	0.6638
	39.70±0.0001886	2.5662	2.2822	2.0432	1.8462	1.6764	1.5292	1.4072	1.2983	1.2051	1.1236	1.0530	0.9951	0.9426	0.8952	0.8703
	49.83±0.0001728	4.2227	3.7453	3.3540	3.0323	2.7631	2.5360	2.3574	2.1931	2.0522	1.9342	1.8139	1.6976	1.5932	1.4899	1.3990
	55.05±0.0001680	6.1903	5.4413	4.8083	4.2866	3.8612	3.5080	3.2013	2.9264	2.5782	2.4739	2.2958	2.1222	1.9727	1.8344	1.7138
	59.89±0.0001654	9.8380	8.5740	7.5454	6.7036	6.0193	5.4353	4.8993	4.4423	4.0443	3.6908	3.3870	3.1217	2.8824	2.6772	2.4879
	64.96±0.0001636	18.6402	15.7935	13.5255	11.6916	10.2056	8.9775	7.9575	7.0891	6.3605	5.7370	5.1988	4.7314	4.3257	3.9747	3.6592
	70.04±0.0001635			28.8708	24.2129	20.5376	17.5126	15.1175	13.6993	12.0268	10.6507	9.5020	8.5098	7.6493	6.8841	6.2171
	75.00±0.0001658									22.7632	19.5858	16.9650	14.8061	13.0146	11.4995	10.2240
4.5	30.00±0.0002068	1.8538	1.6485	1.4796	1.3380	1.2176	1.1151	1.0263	0.9492	0.8822	0.8239	0.7727	0.7278	0.6878	0.6595	0.6276
	40.01±0.0001876	2.5394	2.2592	2.0253	1.8289	1.6624	1.5225	1.3988	1.2941	1.2024	1.1221	1.0529	0.9985	0.9459	0.9164	0.8712
	49.93±0.0001733	4.0970	3.6346	3.2475	2.9276	2.6644	2.4353	2.2341	2.0572	1.9038	1.7645	1.6400	1.5290	1.4322	1.3443	1.2653
	54.98±0.0001682	6.0366	5.3442	4.7700	4.3012	3.9196	3.5847	3.2815	3.0007	2.7463	2.5144	2.3116	2.1443	1.9986	1.8681	1.7385
	60.02±0.0001649	9.8368	8.6306	7.6241	6.8079	6.1126	5.4987	4.9389	4.4555	4.0386	3.6851	3.3830	3.1169	2.8828	2.6630	2.4629
	65.03±0.0001634	18.7674	15.9235	13.6758	11.8277	10.3403	9.0718	8.0336	7.1582	6.4177	5.7821	5.2435	4.7791	4.3749	4.0167	3.7023
	69.98±0.0001637			28.8406	24.2454	20.5646	17.6348	15.2245	13.2352	11.6198	10.2682	9.1329	8.1768	7.3557	6.652065	6.0428
5.5	30.00±0.0002069	1.9187	1.7136	1.5428	1.3971	1.2738	1.1650	1.0727	0.9900	0.9179	0.8545	0.7986	0.7643	0.7068	0.6840	0.6364
	40.00±0.0001876	2.4914	2.2240	2.0003	1.8118	1.6514	1.5136	1.3932	1.2898	1.1983	1.1185	1.0466	0.9856	0.9332	0.8858	0.8722
	50.04±0.0001731	4.1438	3.6905	3.3141	3.0188	2.8035	2.5369	2.3323	2.1599	1.9988	1.8489	1.7236	1.6102	1.5062	1.4131	1.3324
	54.98±0.0001683	6.0057	5.3388	4.7858	4.3404	3.9716	3.6435	3.3259	3.0358	2.7731	2.5409	2.3481	2.1885	2.0505	1.9250	1.8133
	59.95±0.0001650	9.8310	8.5516	7.5126	6.6646	5.9550	5.3539	4.8397	4.3866	3.9944	3.6542	3.3582	3.0974	2.8660	2.6623	2.4804
	64.98±0.0001634	18.7781	15.9698	13.7304	11.8968	10.3766	9.1073	8.0821	7.2229	6.5265	5.8860	5.3400	4.8661	4.4596	4.0970	3.7785
	70.03±0.0001637			27.9169	23.4951	19.9869	17.1663	14.8733	12.9923	11.4358	10.1296	9.0187	8.0826	7.2791	6.5897	5.9894

[a] The standard uncertainties *u are* u(T) = 0.01 K, $U_c(\mu)$ = 0.005μ (level of confidence =0.95), $u(X)$ are listed in the table

Table 6 Regression Coefficients of Correlation Eq 3 (Viscosity)[a]

Mass Ratio	*n*	A_n	B_n	C_n	RMSE	R^2	AAD
3.5 (110 data point)	0	-57.9808317	36044.5732	-5524306.37	0.0095494	99.95%	1.51%
	1	460.402587	-290467.671	45108631.4			
	2	-1276.88732	797927.160	-122266981			
	3	1476.10531	-904684.570	135289994			
	4	-600.634008	356541.960	-50704471.8			
4.5 (103 data point)	0	-153.318659	98060.1469	-15684292	0.0047119	99.99%	0.87%
	1	1298.05710	-836665.240	134771800			
	2	-3914.99709	2521669.06	-405789081			
	3	5020.74340	-3225475.21	517810662			
	4	-2326.80387	1489068.86	-237778366			
5.5 (103 data point)	0	-166.779619	109477.790	-17787787	0.0036774	99.99%	0.65%
	1	1433.81115	-948441.708	155200743			
	2	-4432.28796	2932795.45	-479983000			
	3	5858.60128	-3871936.07	633084538			
	4	-2807.42100	1851706.45	-301822214			

[a] RSME: Root-Mean-Square Error, R^2: The Coefficient of Determination, AAD = average absolute deviation = $\Sigma(|\mu_{test}-\mu_{predicted}|/\mu_{test})/M\times100\%$, M is the number of data.