

## Thermo Physical Properties of Some Physical and Chemical Solvents at Atmospheric Pressure

M. Shokouhi\*, A. H. Jalili, M. Hosseini-Jenab

Gas Science Department, Gas Research Division, Research Institute of Petroleum Industry (RIPI),  
National Iranian Oil Company (NIOC), West Blvd., Azadi Sport Complex, Tehran, Iran

### Abstract

In this paper, the thermal properties including molar heat capacity,  $C_p$ , thermal conductivity,  $\lambda$ , and thermal diffusivity,  $\alpha_D$ , of the pure physical solvents sulfolane (SFL), *N,N*-dimethylformamide (DMF), dimethylsulfoxide (DMSO), ethylene glycol (ETG), chloroform ( $CCL_3H$ ), acetonitrile ( $CH_3CN$ ), and pure chemical solvents monoethanolamine (MEA), diethanolamine (DEA), triethanolamine (TEA), methyldiethanolamine (MDEA), 2-amino-2-methyl-1-propanol (AMP) which all are extensively used in natural gas refinery processes were measured at temperatures ranging from (303.15 to 353.15) K and atmospheric pressure. All experimental measurements were carried out by using a PSL Systemtechnik instrument in which transient hot-wire method was employed to measure transport properties,  $\lambda$  and  $\alpha_D$ . All obtained data were correlated by using empirical linear temperature function with a very good correlation coefficient, better than  $R^2 = 0.99$ . Among the solvents tested in this paper, except for TEA, the thermal diffusivity decreased by increasing temperature and also except for TEA and ETG, thermal conductivity decreased with temperature.

**Keywords:** Thermal Property, Alkanolamine, Physical Solvents, Chemical Solvents, Heat Capacity, Thermal Conductivity, Thermal Diffusivity

### 1. Introduction

The transient hot-wire technique is extensively used for measurements of the thermal conductivity and thermal diffusivity of most fluids. However, for some special liquids like physical solvents and alkanolamines solutions commonly used in gas treatments, the thermal properties are important to know for industrial or security applications. Despite the great demand for knowledge of transport properties of physical

solvent and alkanolamines, only limited data exist in the literature.

A wide range of alkanolamines such as monoethanolamine (MEA), diglycolamine (DGA), diethanolamine (DEA), di-2-propanolamine (DIPA), triethanolamine (TEA), *N*-methyldiethanolamine (MDEA), 2-amino-2-methyl-1-propanol (AMP), Piperazine (PZ) and 2-piperidineethanol (2-PE) can be used as absorbents for acid gas removal processes [1]. Thermal properties data for alkanolamine

\* Corresponding author: shokouhim@ripi.ir

solutions are required for the design of the heat-exchanger equipment used in natural gas treating processes.

The  $C_p$  values of MEA, DEA, TEA, and MDEA are available in the literature [2-4]. Chiu *et al.* [5] recently measured the heat capacity of eight alkanolamines (MEA, DGA, DEA, DIPA, TEA, MDEA, AMP, 2-PE) at temperatures ranging from (303.15 to 353.15) K with a differential scanning calorimeter. Shin *et al.* [6] experimentally reported the heat capacities of aqueous solutions containing DEA and MDEA over the temperature range (303.2 to 353.2) K with a differential scanning calorimeter. Chen *et al.* reported the liquid heat capacity of some solvent systems containing PZ-MDEA-water [7], PZ-AMP-water [8] and SFL-AMP-water [9], all of which used the differential scanning calorimetry technique, over the temperature range (303.2 to 353.2) K. Maundha *et al.* [10] experimentally measured the heat capacity of some physical solvents of importance in natural gas sweetening: (1) sulfolane (SFL), (2) 4-formylmorpholine (NFM), (3) 1-methyl-2-pyrrolidinone (NMP), and (4) triethylene glycol dimethyl ether (TEGDME) with heat flow calorimeter at the temperature range of (303.15 to 353.15) K and for the entire range of mole fractions.

In the case of thermal conductivity, there is very little information in the open literature on liquids and further investigation is necessary for validity and reassurance of some important pure solvents.

Liquid thermal conductivity data were reported for alcohols [11,12], alkylamines [11], ethanolamines [13], glycols [14] and other organic compounds [11,15].

To the best of our knowledge, except for water [16] and Toluene [17-19] and some hydrocarbons [16], there is no information available in open literature concerning thermal diffusivity of liquids.

Shokouhi *et al.* experimentally measured heat capacity, thermal conductivity and thermal diffusivity of binary mixtures of SFL-water [20], and also DMF – water [21] solutions.

In this paper, the thermal properties including molar heat capacity,  $C_p$ , thermal conductivity,  $\lambda$ , and thermal diffusivity,  $\alpha_D$ , of some pure solvents containing Sulfolane (SFL), Dimethylformamid (DMF), Dimethylsulfoxide (DMSO), Ethylene Glycol (ETG), Chloroform ( $\text{CCL}_3\text{H}$ ), Acetonitril ( $\text{CH}_3\text{CN}$ ), Monoethanolamine (MEA), Diethanolamine (DEA), Triethanolamine (TEA), Methyl-diethanolamine (MDEA), 2-Amino-2-methyl-1-propanol (AMP), all of which are extensively used in natural gas refinery processes were measured at temperatures ranging from (303.15 to 353.15) K and atmospheric pressure. All experimental measurements were carried out using a PSL Systemtechnik instrument in which transient hot-wire method was employed to measure transport properties,  $\lambda$  and  $\alpha_D$  and will be explained in the following section. All obtained data are correlated using empirical linear temperature.

## **2. Experimental section**

### **2-1. Materials**

MEA, DEA, TEA and MDEA with a purity of ~ 99 % were obtained from the MERCK Company. AMP with purity of 95% was purchased from MERCK. Sulfolane (SFL) was obtained from the ACROS Company

with a purity of  $\sim 99\%$ . Dimethylformamide was obtained from Riedel-de Haen Company with a purity of  $\sim 99\%$ . Acetonitrile with a purity of  $\sim 99.5\%$  was purchased from Riedel-de Haen Company. Ethylene Glycol with a purity of  $\sim 99\%$  was purchased from MERCK Company. All substances were used as pure solvent without any further purification. Deionized water was used for a calibration of PSL Systemtechnik instrument, which was degassed in an ultrasonic bath (FUNGILAB, model UA10MFD) at temperatures from (303.15 to 353.15) K and wave frequency of 50 kHz about half an hour before use.

## 2-2. Apparatus and Procedure

The measurements of heat capacity, thermal conductivity and thermal diffusivity were carried out using a PSL Systemtechnik instrument equipped with a Lambda measuring and evaluation system. The operation of the instrument is based on the in-stationary hot-wire resistance technique [22,11]. The hot wire cell used in this work has been shown in Fig. 1. The hot-wire is made up of a thin platinum wire, which is soldered to the Lambda's sensor head. The sensor head contains a temperature sensor and they are inserted altogether into the liquid sample in the measurement cell. All wetted compartments of the apparatus (except hot wire) are constructed from 316L stainless steel. The hot-wire produces a constant heat stream to the surrounding liquid and at the same time it serves as the measuring sensor. A constant voltage is sent through the heat wire to heat it up. In dependent of the thermal conductivity of the

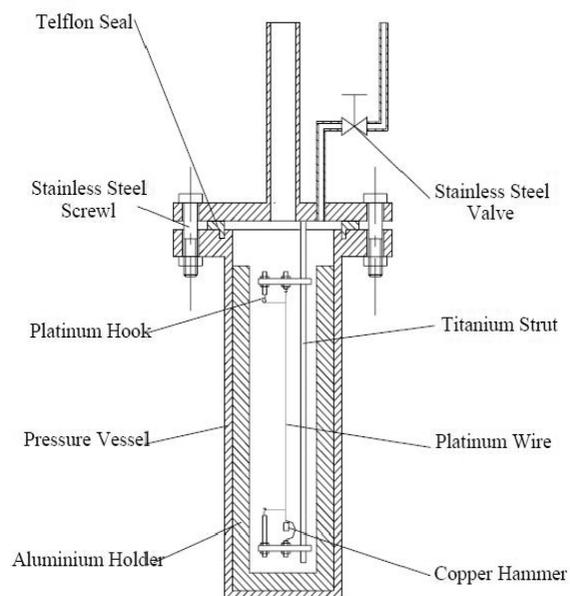


Figure 1

surrounding liquids, the resistance of the heat wire increases and a decrease of voltage can be attained. Due to these changes in voltage flow the thermal conductivity can be determined. The platinum wire served as a resistor in one arm of Wheatstone bridge, and the bridge circuit was used to obtain the resistance change of the wire during the measurement. To exclude convection influences, the temperature of the liquid sample was regulated to a very homogenous allocation by means of a precision thermostat unit (LabTemp model 300) and the measurements were carried out at minimum time intervals. The temperature stability of the precision thermostat was better than  $\pm 0.05$  K. To obtain precise measurements of the thermal properties of samples, the temperature scale of the PSL Systemtechnik instrument was first calibrated for the temperature range (298.15 to 353.15) K with the experimental data reported for water.

The heat capacity of the samples in the PSL Systemtechnik is measured on the basis of the operation of conventional calorimeters, which take advantage of the measurement of the voltage of a heating element of known or measurable resistance that a constant DC current passes through, followed by measurement of the increase in temperature of the sample,  $\Delta T$ . After calibration and evaluation of the heat capacity of the calorimeter, the heat capacity of the samples can be measured.

It must be emphasized that the volume of the measurement cell was filled completely with the liquid sample and capped tightly with the sensor head via stainless steel screw sealed by Teflon seal. Therefore there was no vapor-phase space for the liquid phase to vaporize. This resulted in constant composition of the solutions during the course of the measurements. Also, it must be mentioned that the PSL Systemtechnik instrument is not able to directly measure the thermal diffusivity, but calculates this property from simultaneous measurement of heat capacity, thermal conductivity and the density of liquid samples using the well-known relation,  $\lambda = \alpha \rho C_p$ , where  $\lambda$ ,  $\alpha$ ,  $\rho$ , and  $C_p$  stand for thermal conductivity, thermal diffusivity, density and heat capacity, respectively. In general, each reported data was an average of 5 to 10 measurements with the uncertainty of measurements being within  $\pm 0.20\%$  ( $0.20 \text{ J} \cdot \text{mol}^{-1} \cdot \text{K}^{-1}$ ) for heat capacity,  $\pm 0.69\%$  ( $1.1 \text{ mW} \cdot \text{m}^{-1} \cdot \text{K}^{-1}$ ) for thermal conductivity and  $\pm 0.26\%$  ( $0.03 \cdot 10^{-8} \text{ m}^2 \text{ s}^{-1}$ ) for thermal diffusivity. All measurements were carried out in the temperature range of (303.15 to 353.15) K with 10 K steps.

### **3. Results and discussion**

To validate the accuracy of our experimental data and the procedure applied for measurement, the heat capacity, thermal conductivity and thermal diffusivity of toluene, water and SFL were measured. Table 1 summarizes the results as well as corresponding values reported in literature. Comparison shows that the obtained experimental  $\lambda$ ,  $\alpha$ , and  $C_p$  values are in good agreement with literature data, being within 1% for thermal conductivities, within 1.8 % for thermal diffusivities, and within 1.2 % for molar heat capacities of the reported literature values for pure water [15], toluene [17,18], SFL [9], MDEA [12,23], and TEA [12,23], respectively.

All experimental thermal properties ( $C_p$ ,  $\lambda$ , and  $\alpha_D$ ) for (DMSO), (ETG), ( $\text{CCL}_3\text{H}$ ), ( $\text{CH}_3\text{CN}$ ), (MEA), (DEA), (TEA), (MDEA) and (AMP) in addition to (SFL) and (DMF) reported in previous works [20,21] are summarized in Table 2. As may be seen for all substances,  $C_p$  increases with rising temperature, but for the case of thermal conductivity and thermal diffusivity, except for TEA, the thermal diffusivity decreases by increasing temperature and also except for TEA and ETG, thermal conductivity decreases with temperature.

The measured  $\lambda$  and  $\alpha$  of all solvents studied are smaller than those of pure water, while  $C_p$  all solvents is greater than that of pure water. From molecular view points, the value of  $C_p$  is dependent on the number of translational, rotational and vibrational energy modes depending on atom numbers and intermolecular interaction. Owing to this fact, all pure solvents studied in the present work, have far more atom constituents than

water, their molar heat capacity being more than water and for the reason of the stability equilibrium condition arisen from the second law of thermodynamics the heat capacity of all solvents increases with temperature. Opposite to  $C_p$ , which is an equilibrium thermodynamic property,  $\lambda$  and  $\alpha$  are

transport or non-equilibrium properties, which strongly depend on intermolecular interaction, and regarding the fact that water construction is dominated by hydrogen bond network connections,  $\lambda$  and  $\alpha$  of pure water are greater than the corresponding quantities for solvents studied in this work.

**Table 1.** Review of the literature data for the molar heat capacity, thermal conductivity, and thermal diffusivity of pure water, toluene and sulfolane.

$T/$ (K)	$C_p$ (J/m. K)		$T/$ (K)	$\lambda$ (m.W/m.K)		$T/$ (K)	$\alpha \cdot 10^8$ (m <sup>2</sup> /s)	
	This Work	Lit. (Ref.)		This Work	Lit. (Ref.)		This Work	Lit. (Ref.)
Water [16]								
303.15	75.3	75.301	303.15	613.7	615.50	303.15	14.75	14.790
313.15	75.26	75.294	313.15	630.7	630.62	313.15	15.22	15.207
323.15	75.30	75.328	323.15	643.7	643.59	323.15	15.59	15.578
333.15	75.39	75.393	333.15	654.8	654.38	333.15	15.91	15.904
343.15	75.48	75.485	343.15	663.2	663.12	343.15	16.20	16.186
353.15	75.60	75.605	353.15	670.0	670.01	353.15	16.43	16.428
ARD%	0.017			0.067			0.095	
MRD%	0.045			0.29			0.27	
Toluene								
303.15	159.8	158.21	303.15	129.4	129.54[17]	303.15	8.598	8.592[18]
313.15	162.8	161.24	313.15	125.7	126.52[17]	313.15	8.349	8.317[18]
323.15	165.7	164.35	323.15	123.3	123.54[17]	323.15	8.066	8.051[18]
333.15	168.8	167.53	333.15	121.1	120.59[17]	333.15	7.905	7.796[18]
343.15	171.5	170.78	343.15	117.0	117.71[17]	343.15	7.669	7.551[18]
353.15	174.9	174.09	353.15	113.5	114.90[17]	353.15	7.382	7.316[18]
ARD%	0.69			0.48			0.86	
MRD%	1.0			1.2			1.8	
MDEA								
303.15	264.10	264[23]	297.7	182.5	168.5[13]			
313.15	271.05	271[23]	325.0	178.4	167.6[13]			
323.15	277.68	278[23]	353.9	174.3	166.3[13]			
333.15	284.40	284[23]						
343.15	291.48	291[23]						
353.15	298.20	298[23]						
ARD%	0.10			6.20				
MRD%	0.17			7.90				
TEA								
303.15	362.20	363[23]	296.8	190.4	188.4			
313.15	365.56	366[23]	327.3	194.4	194.1			
323.15	368.74	369[23]	356.3	198.2	195.6			
333.15	371.48	371[23]						
343.15	374.50	386[23]						
353.15	376.83	377[23]						
ARD%	0.05			0.85				
MRD%	0.12			1.33				
SFL								
303.15	181.5	182[9]						
308.15	183.0	184[9]						
313.15	185.1	185[9]						
318.15	186.5	186[9]						
323.15	188.7	188[9]						
328.15	189.6	189[9]						
333.15	192.3	191[9]						
338.15	192.6	193[9]						
343.15	194.3	194[9]						
348.15	195.6	197[9]						
353.15	197.8	199[9]						
ARD%	0.38							
MRD%	0.72							

**Table 2.** Experimental values measured in this work, Heat capacity, Thermal conductivity and Thermal diffusivity.

<i>T</i> / K	$\lambda$ (m.W/m.K)	$\alpha \cdot 10^8$ (m <sup>2</sup> /s)	<i>C<sub>p</sub></i> (J/m. K)
<b>DMF</b> ( <i>M<sub>w</sub></i> = 73.09 g.mole <sup>-1</sup> )			
303.15	186.3±1.2	9.57±0.10	151.35±0.20
313.15	183.6±1.2	9.43±0.10	152.88±0.20
323.15	181.0±1.2	9.30±0.10	154.40±0.20
333.15	178.3±1.2	9.17±0.10	155.93±0.20
343.15	175.7±1.2	9.04±0.10	157.46±0.20
353.15	173.0±1.2	8.91±0.10	158.98±0.20
<b>CH<sub>3</sub>CN</b> ( <i>M<sub>w</sub></i> = 41.05 g.mole <sup>-1</sup> )			
303.15	207.8±0.8	12.03±0.05	91.93±0.10
313.15	204.1±0.8	11.98±0.05	91.94±0.10
323.15	200.4±0.8	11.93±0.05	91.94±0.10
333.15	197.0±0.8	11.91±0.05	91.94±0.10
343.15	193.1±0.8	11.84±0.05	91.95±0.10
<b>CH<sub>3</sub>CL</b> ( <i>M<sub>w</sub></i> = 119.38 g.mole <sup>-1</sup> )			
303.15	114.0±0.9	8.01±0.05	115.50±0.11
313.15	111.6±0.9	7.84±0.05	116.97±0.12
323.15	109.3±1.0	7.67±0.05	118.45±0.12
333.15	106.9±1.0	7.50±0.05	119.91±0.12
343.15	104.6±1.0	7.34±0.05	121.45±0.12
<b>EthylenGlycol</b> ( <i>M<sub>w</sub></i> = 62.07 g.mole <sup>-1</sup> )			
303.15	251.9±1.5	9.48±0.07	149.00±0.15
313.15	254.5±1.5	9.39±0.07	152.99±0.15
323.15	257.2±1.5	9.28±0.07	157.55±0.15
333.15	259.7±1.4	9.17±0.06	161.95±0.14
343.15	262.3±1.3	9.08±0.06	166.43±0.14
<b>DMSO</b> ( <i>M<sub>w</sub></i> = 78.113 g.mole <sup>-1</sup> )			
303.15	223.0±1.1	10.36±0.10	154.39±0.20
313.15	218.5±1.1	10.16±0.10	155.70±0.20
323.15	213.5±1.1	9.93±0.10	157.01±0.20
333.15	208.1±1.1	9.69±0.10	158.32±0.20
343.15	203.6±1.1	9.50±0.09	159.63±0.20
353.15	199.0±1.1	9.29±0.09	160.94±0.20
<b>MEA</b> ( <i>M<sub>w</sub></i> = 61.084 g.mole <sup>-1</sup> )			
303.15	239.3±0.6	8.66±0.05	167.72±0.25
313.15	237.5±0.6	8.54±0.05	170.08±0.25
323.15	236.2±0.6	8.40±0.06	173.58±0.24
333.15	234.4±0.7	8.30±0.06	175.89±0.24
343.15	232.6±0.7	8.16±0.06	178.86±0.23
353.15	230.9±0.7	8.02±0.07	182.21±0.23
<b>DEA</b> ( <i>M<sub>w</sub></i> = 105.137 g.mole <sup>-1</sup> )			
303.15	217.9±1.4	8.20±0.07	255.96±0.70
313.15	217.2±1.4	8.08±0.07	260.33±0.70
323.15	216.4±1.4	7.91±0.08	266.74±0.70

333.15	215.8±1.7	7.79±0.08	271.74±0.70
343.15	215.2±1.7	7.66±0.08	277.32±0.60
353.15	214.6±1.7	7.50±0.08	284.09±0.60
<b>TEA</b> ( $M_w = 149.19 \text{ g.mole}^{-1}$ )			
303.15	191.2±1.1	7.03±0.05	362.20±0.47
313.15	192.8±1.1	7.07±0.06	365.56±0.48
323.15	193.9±1.0	7.08±0.06	368.74±0.50
333.15	195.0±1.0	7.11±0.05	371.48±0.50
343.15	196.5±1.1	7.15±0.05	374.50±0.50
353.15	198.0±1.1	7.19±0.05	376.83±0.50
<b>MDEA</b> ( $M_w = 119.16 \text{ g.mole}^{-1}$ )			
303.15	182.0±0.7	7.95±0.05	264.10±0.20
313.15	180.6±0.7	7.74±0.05	271.05±0.20
323.15	179.1±0.7	7.55±0.06	277.68±0.19
333.15	177.8±0.8	7.38±0.06	284.40±0.19
343.15	175.6±0.8	7.16±0.06	291.48±0.20
353.15	174.5±0.8	7.01±0.07	298.20±0.20
<b>AMP</b> ( $M_w = 89.141 \text{ g.mole}^{-1}$ )			
303.15	217.8±0.7	8.75±0.05	239.41±0.19
313.15	215.8±0.7	8.57±0.05	244.54±0.19
323.15	214.1±0.7	8.41±0.04	249.60±0.20
333.15	212.2±0.7	8.24±0.04	254.84±0.20
343.15	210.5±0.6	8.09±0.05	259.71±0.21
353.15	208.5±0.6	7.94±0.05	264.91±0.21

Except for some liquids like water and those containing multi-hydroxy and multi-amine groups, the thermal conductivity of organic liquids decreases with temperature. To investigate the effect of temperature on thermal conductivity and why some liquids with multi-hydroxy groups have opposite behavior in comparison with normal liquids, a theoretical-based model is necessary for thermal conductivity of liquids for a wide range of temperature. For this purpose, the ideas of Wang *et al.* [24] are used in which thermal conductivity of liquids may be expressed as a function of molar free volume and liquid lattice energy as in the form of equation 1:

$$\ln \lambda = K - n \ln V_f + \frac{kE_c}{RT} \quad (1)$$

in which,  $K$ ,  $k$  and  $n$  are constant, and  $R$ ,  $V_f$  and  $E_c$  are universal gas constant, molar free volume and liquid lattice energy, respectively.

As may be seen from equation 1, thermal conductivity of liquids increases with lattice energy and decreases with molar free volume, and also there is inverse explicit temperature dependence. Liquids with multi-hydroxy groups, because of hydrogen bonding, have large lattice energy and also their molar free volume reduces or smoothly increases with raising the temperature,

because of the breaking of the hydrogen bonds.

Below or near the normal boiling point over small temperature ranges, the functionality of temperature dependency of all three thermal properties,  $C_p$ ,  $\lambda$  and  $\alpha_D$  are linear and are presented over whole temperature range by

$$C_p = A_c + B_c \cdot T \quad (2)$$

$$\lambda = A_\lambda + B_\lambda \cdot T \quad (3)$$

$$\alpha_D = A_\alpha + B_\alpha \cdot T \quad (4)$$

All equations 2, 3 and 4 are related to liquids besides their correlation coefficients,  $R^2$ , average relative percent deviation, ARD%, and maximum relative percent deviation, MRD%, both of which are respectively defined in equations 4 and 5 are listed in Table 3.

$$ARD\% = \frac{100}{N} \sum_{i=0}^N \frac{|q_i^{cal} - q_i^{exp}|}{q_i^{exp}} \quad (5)$$

**Table 3.** Temperature linear equation of thermal properties obtained in this work.  $\lambda$  (m.W/m.K),  $\alpha \cdot 10^8$  ( $m^2/s$ ),  $C_p$  (J/m. K).

Substance	Linear Equation	ARD%	MRD%	$R^2$
DMF	$\lambda = -0.2648.T/K + 266.5288$	0.001%	0.005%	1.0000
	$\alpha \cdot 10^8 = -0.0132.T/K + 3.5617$	0.072%	0.116%	0.9999
	$C_p = 0.1527.T/K + 105.0460$	0.007%	0.01%	1.0000
SFL	$\lambda = -0.198451.T/K + 227.766$	0.114%	0.263%	0.9941
	$\alpha \cdot 10^8 = -0.0178171.T/K + 14.1727$	0.062%	0.445%	0.9963
	$C_p = 0.323091.T/K + 83.9095$	0.206%	0.391%	0.9940
CH <sub>3</sub> CN	$\lambda = -0.36173.T/K + 317.39679$	0.068%	0.174%	0.9994
	$\alpha \cdot 10^8 = -0.00426.T/K + 13.31257$	0.069%	0.165%	0.971
CH <sub>3</sub> CL	$\lambda = -0.23235.T/K + 184.38177$	0.047%	0.191%	0.9996
	$\alpha \cdot 10^8 = -0.01675.T/K + 13.08289$	0.038%	0.143%	0.9997
	$C_p = 0.14727.T/K + 70.86700$	0.038%	0.100%	0.9993
Ethylen Glycol	$\lambda = 0.2552.T/K + 174.7128$	0.034%	0.095%	0.9991
	$\alpha \cdot 10^8 = -0.0101.T/K + 12.5303$	0.137%	0.245%	0.9947
	$C_p = 0.4276.T/K + 19.4966$	0.158%	0.497%	0.9974
DMSO	$\lambda = -0.4925.T/K + 372.64$	0.159%	0.490%	0.9957
	$\alpha \cdot 10^8 = -0.0219.T/K + 17.01$	0.163%	0.483%	0.9949
	$C_p = 0.1314.T/K + 114.5252$	0.012%	0.020%	0.9999
MEA	$\lambda = -0.1711.T/K + 291.2846$	0.049%	0.106%	0.9976
	$\alpha \cdot 10^8 = -0.0131.T/K + 12.6565$	0.115%	0.310%	0.9973
	$C_p = 0.2935.T/K + 78.3283$	0.085%	0.235%	0.9982
DEA	$\lambda = -0.0677.T/K + 238.39$	0.035%	0.081%	0.9930
	$\alpha \cdot 10^8 = -0.0137.T/K + 12.371$	0.201%	0.458%	0.9977
	$C_p = 0.5452.T/K + 90.286$	0.179%	0.446%	0.9963
TEA	$\lambda = 0.131.T/K + 151.53$	0.053%	0.102%	0.9968
	$\alpha \cdot 10^8 = 0.0031.T/K + 6.1027$	0.217%	0.366%	0.9836
	$C_p = 0.2882.T/K + 275.26$	0.065%	0.129%	0.9959
MDEA	$\lambda = -0.1536.T/K + 228.66$	0.072%	0.189%	0.9955
	$\alpha \cdot 10^8 = -0.0189.T/K + 13.663$	0.093%	0.314%	0.9988
	$C_p = 0.6799.T/K + 58.078$	0.035%	0.067%	0.9999
AMP	$\lambda = -0.1792.T/K + 271.91$	0.036%	0.13%	0.9981
	$\alpha \cdot 10^8 = -0.0162.T/K + 13.629$	0.165%	0.341%	0.9989
	$C_p = 0.5131.T/K + 83.77$	0.037%	0.078%	0.9998

$$MRD\% = \text{Maximum} \left( \frac{|q_i^{cal} - q_i^{exp}|}{q_i^{exp}} \cdot 100 \right) \quad (6)$$

In equations 5 and 6,  $q$  is interest thermal property. Schematically linear behavior of

temperature dependency of three quantities has been shown in Figs. 1, 2 and 3 for  $C_p$ ,  $\lambda$  and  $\alpha_D$ , respectively. As can be seen, all three quantities have good linear correlation with correlation coefficient better than  $R^2=0.99$ .

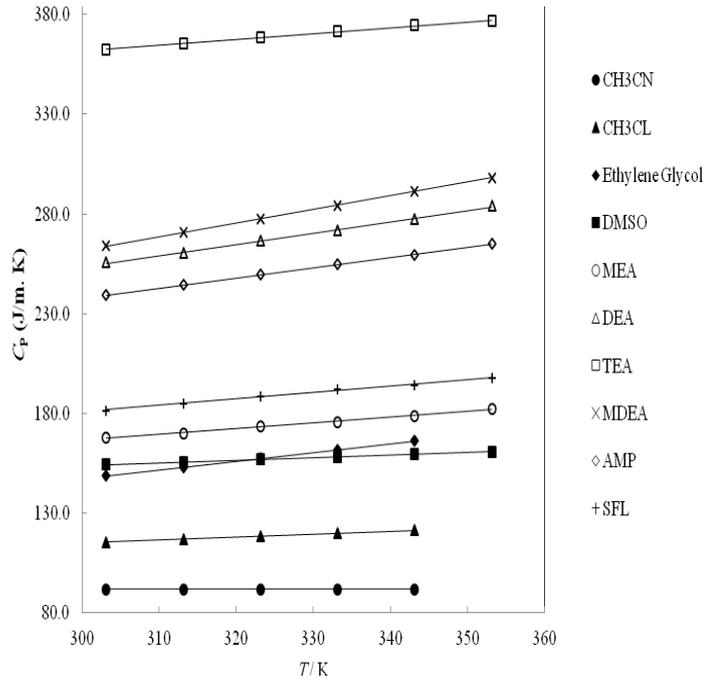


Figure 2. Temperature dependence of heat capacity for pure solvents.

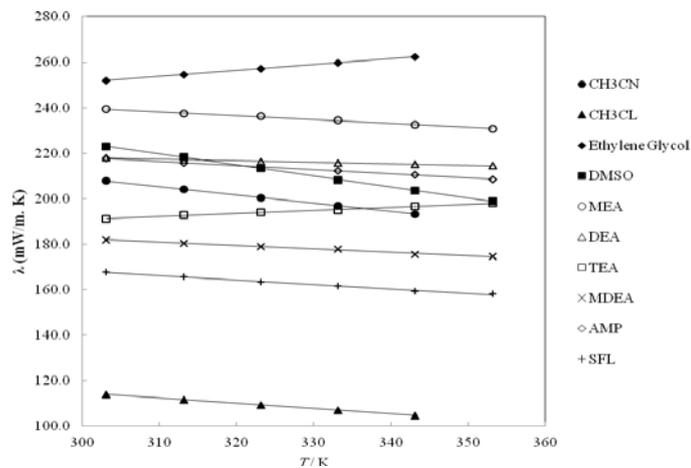


Figure 3. Temperature dependence of thermal conductivity for pure solvents.

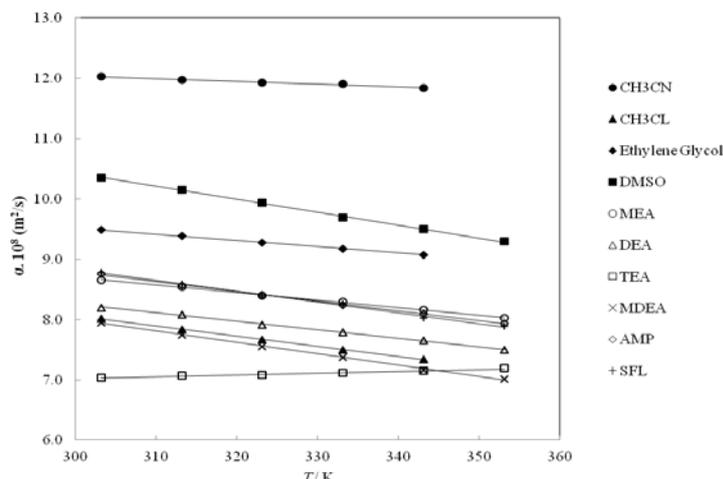


Figure 4. Temperature dependence of thermal diffusivity for pure solvents.

#### 4. Conclusions

The equilibrium thermal property, such as molar heat capacity, and transport thermal properties such as thermal conductivity, and thermal diffusivity of Sulfolane, Dimethylformamid, Dimethylsulfoxide, Ethylene Glycol, Chloroform, Acetonitril, Monoethanolamine, Diethanolamine, Triethanolamine, Methyl-diethanolamine, 2-Amino-2-methyl-1-propanol which are appropriate in the natural gas sweetening processes, were measured in this work.  $C_p$  increases with rising temperature, but for the case of thermal conductivity and thermal diffusivity, except for TEA, the thermal diffusivity decreased by increasing temperature and also except for TEA and ETG, thermal conductivity decreased with temperature.

#### Acknowledgement

We are thankful to the Research Council of the Research Institute of Petroleum Industry (RIPI) and the Research and Technology of the National Iranian Gas Company (NIGC) for their support of this work.

#### References

- [1] Karve, M., and Rajgor, R.V., "Amberlite XAD-2 impregnated organophosphinic acid extractant for separation of uranium (VI) from rare earth elements", *Desalination*, 232(1-3), 191, (2008).
- [2] Kohl, A.L. and Riesenfeld, F.C., *Gas purification*, 4<sup>th</sup> ed., Gulf, Houston, (1985).
- [3] Riddick, J.A., Bunger, W.B. and Sakano, T.K., *Organic solvents*, 4<sup>th</sup> ed., Wiley, New York, (1986).
- [4] Lee, L.L., *Thermodynamic models for natural gas sweetening fluids*, Annual report to the Gas Research Institute, University of Oklahoma, Norman, OK, (1994).
- [5] Lide, D.R., *Handbook of organic solvents*, CRC Press, Boca Raton, FL, (1995).
- [6] Chiu, L.F., Liu, H.F., and Li, M.H., "Heat capacity of alkanolamines by differential scanning calorimetry" *J. Chem. Eng. Data*, 44, 631, (1999).

- [7] Shin, T.W., Soriano, A.N. and Li, M.H., "Heat capacities of aqueous solutions containing diethanolamine and N-methyldiethanolamine", *J. Chem. Thermodynamics*, 41, 1259, (2009).
- [8] Chen, Y.R., Caparanga, A.R., Soriano, A.N. and Li, M.H., "Liquid heat capacity of the solvent system (piperazine + n-methyldiethanolamine + water)", *J. Chem. Thermodynamics*, 42, 54, (2010).
- [9] Chen, Y.R., Caparanga, A.R., Soriano, A.N. and Li, M.H., "Liquid heat capacity of the solvent system (piperazine + 2-amino-2-methyl-1-propanol + water)", *J. Chem. Thermodynamics*, 42, 518, (2010).
- [10] Ho, S.C., Chen, J.C. and Li, M.H., "Liquid heat capacity of aqueous sulfolane + 2-amino-2-methyl-1-propanol solutions", *J. Chin. Institute of Chem. Eng.*, 38, 349, (2007).
- [11] Mundhwa, M., Elmahmudi, S., Maham, Y. and Henni, A., "Molar heat capacity of aqueous sulfolane, 4-formylmorpholine, 1-methyl-2-pyrrolidinone and triethylene glycol dimethyl ether solutions from (303.15 to 353.15) K", *J. Chem. Eng. Data*, 54, 2895, (2009).
- [12] Cai, G., Zong, H., Yu, Q. and Lin R., "Thermal conductivity of alcohols with acetonitrile and N,N-dimethylformamid", *J. Chem. Eng. Data*, 38, 332, (1993).
- [13] Jamieson, D.T. and Cartwright, G., "Thermal conductivity of associated fluids", *J. Chem. Eng. Data*, 25, 199, (1980).
- [14] DiGuilio, R.M., McGregor, W.L. and Teja, A.S., "Thermal conductivity of the ethanolamines", *J. Chem. Eng. Data*, 37, 242, (1992).
- [15] DiGuilio, R.M. and Teja, A.S., "Thermal conductivity of poly(ethylene) glycols and their binary mixtures", *J. Chem. Eng. Data*, 35, 117, (1990).
- [16] Venart, J.E.S. and Prasade, R.C., "Thermal conductivity of water and oleum", *J. Chem. Eng. Data*, 25, 196, (1980).
- [17] NIST Scientific and Technical Database, Thermophysical Properties of Fluid Systems, <http://webbook.nist.gov/chemistry/fluid>, (Accessible on April, 2012).
- [18] Nieto de Castro, C.A, Li, S.F.Y., Nagashima, A., Trengove, R. D. and Wakeham, W. A., "Standard reference data for the thermal conductivity of liquid", *J. Phys. Chem. Ref. Data*, 15, 1073, (1986).
- [19] Ramires, M.L.V., Nieto de Castro, C.A., Perkins, R.A., Nagasaka, Y., Nagashima, A., Assael, M.J. and Wakeham, W.A., "Reference data for the thermal conductivity of saturated liquid toluene over a wide range of temperatures", *J. Phys. Chem. Ref. Data*, 29, 133, (2000).
- [20] Kraft, K., Lopes, M.M. and Leipertz, A., "Thermal diffusivity and thermal conductivity of toluene by photon correlation spectroscopy: A rest of the accuracy of the method", *Int. J. Thermophys*, 16, 423, (1995).
- [21] Shokouhi, M., Jalili, A.H., Mohammadian, A., Hosseini-Jenab, M.,

- and Sadraei-Nouri, S., "Heat capacity, thermal conductivity and thermal diffusivity of aqueous sulfolane solutions", *Thermochem. Acta*, 560, 63, (2013).
- [22] Shokouhi, M., Jalili, A.H., Vahidi, M., Hosseini-Jenab, M. and Taheri Mohammadabadi, A., "Thermo-physical properties of aqueous solution of N,N-dimethylformamide", *J. Mol. Liq.*, 186, 142, (2013).
- [23] Assael, M.J., Nieto de Castro, C.A., Roder, H.M. and Wakeham, W.A., "In measurements of the transport properties of fluids-experimental thermodynamics", Wakeham, W.A., Nagashima, A., Sengers, J.V., Eds., Blackwell Scientific, London, Vol. 3, (1991).
- [24] Osborne, N.S., Stimson, H.F. and Ginnings, D.C., "Measurements of heat capacity and heat of vaporization of water in the range 0°C to 100°C", *J. Res. Natl. Bur. Stand.*, 23, 197, (1939).
- [25] Wang, F.A., Zhu, J.Q., Chen, H.S., Wang, W.C. and Jiang, Y.L., "A new model of thermal conductivity for liquids", *Chem. Eng. J.*, 78, 187, (2000).