Mazen Al-Amayreh Journal of Engineering Research and Application *www.ijera.com*
ISSN: 2248-9622 Vol. 10, Issue 01 (Series -II) January 2020, pp 62-68

RESEARCH ARTICLE OPEN ACCESS

Experimental Study of Thermal Conductivity of Ethylene Glycol Water Mixtures

Mazen Al-Amayreh
(Department of Natural Resources and Chemical Engineering. Tafila Technical University, Tafila, Jordan.

ABSTRACT
In this study, the thermal conductivities of ethylene glycol + water, diethylene glycol + water, and triethylene glycol + water mixtures were measured at temperatures ranging from 25 °C to 40 °C and concentrations ranging from 25 wt. % glycol to 75 wt.% glycol. At certain constant temperature level, the thermal conductivity decreases with increasing the mass percent of glycol in the solution from the 25 wt. % to 75 wt. %. On the hand, at certain constant solution composition, the thermal conductivity increases slightly with increasing the temperature. The results obtained were in good agreement with the published data in the literature

Keywords – Ethylene glycol, Thermal Conductivity, Triethylene glycol, variable composition

DATE OF SUBMISSION: 15-01-2020 DATE OF ACCEPTANCE: 31-01-2020

I. INTRODUCTION

Knowledge of thermal conductivity of liquids is very important to many industrial sectors. This parameter plays a crucial role in the development of heat transfer equipment. The estimation of the thermal conductivity of liquids is well treated in the literature (Parsons Jr and Mulligan, 1978;Lee et al., 1999). Heat transfer coefficients are calculated using correlations which require thermal conductivity data over a wide range of temperatures.

A Kusiak et al. (Kusiak et al., 2009) proposed a method by which thermal conductivity of liquids based on the front face-modulated photo thermal radiometry is evaluated. The study used a three-layer system, where the intermediate layer contains the investigated liquid. An experimental setup has been developed in order to avoid the drawbacks of the classical methods such as flash or hot wire measurement. Ramaswamy et al. (Ramaswamy et al., 2007) described a study of the thermal conductivity of selected liquid foods during high-pressure processing using a line heat source probe. The probe was calibrated using distilled water and probe specific calibration factors were developed by comparing experimental data against published data. Theoretical and semi-empirical models for estimating thermal conductivity of liquid foods are reviewed by Cuevas and Cheryan (CUEVAS and CHERYAN, 1978). Seven models were considered all containing temperature as an independent variable and were selected for their simplicity and apparent accuracy for further study and statistical evaluation. Zhang et al. (Zhang et al., 2005) used a hot probe for the measurement of liquid‘s thermal conductivity. According to experimental results on liquid samples, measurements time intervals were very short (5–20 s), and the measurement uncertainty was about 3%. The thermal conductivities of dimethyl sulfoxide (DMSO) and its aqueous solutions have been determined using the proposed technique.

Heyes and March (Heyes and March, 1996) concluded that a liquid‘s thermal conductivity can be calculated using approximate analytic theory, and also by molecular simulation which solves the many-body problem for molecules interacting through specific interactions. However, due to the many thousands of possible liquid combinations that can be used for heat transfer applications in a wide array of industries, it is not possible to specifically provide thermal conductivity data experimentally. Therefore, if measurement based thermal conductivity data is not available, the industry have used one of the following approaches: limited experimental data and theoretical or empirical data, or extrapolating experimental data for structurally similar chemicals.

Ethylene Glycol water mixtures are the most common antifreeze fluid for standard heating and cooling applications. They are common in heat-transfer applications where the temperature in the heat transfer fluid can be below 0oC. Glycol water solutions are also commonly used in heating applications that temporarily may not be operated in surroundings with freezing conditions, such as water cooled internal combustion engines.

Accurate knowledge of ethylene glycol water mixtures thermo physical properties is essential in process calculations involving these mixtures. Despite that, literature data on thermal conductivity of glycol + water mixtures are generally limited to ambient temperatures (Obermeier et al., 1985;Tsierkezos and Molinou, 1998). Sun and Teja (Sun and Teja, 2003), measured the thermal conductivity of ethylene glycol + water, diethylene glycol + water, and triethylene glycol + water mixtures using the relative transient hot-wire method at a temperature range between 290 K to 450 K, and concentrations between 25 to 100 mol % glycol. The data were correlated using simple empirical expressions.

In our work, we will study the thermal conductivity of aqueous glycol solutions which have found widespread application in the manufacture of solvents, hygroscopic agents, lubricants, and conditioning agents. The main objective of this study is to understand the factors influencing the thermal conductivity of liquids. The main factors to be studied are the composition and the temperature. The measurements will be conducted on a bench scale thermal conductivity measuring device. The thermal conductivity of different glycol water solutions over a wide range of temperature will be studied. Obtained data will be then compared to literature data which was measured using different more complicated techniques and over wider temperature ranges. Both experimental observations and theoretical models will be implemented to understand the role of solution composition and temperature on the thermal conductivity of glycol water solutions.

II. MATERIALS AND METHODS

2.1 Materials:

Reagent grade Monoethylene Glycol, Diethylene Glycol, and Triethylene Glycol were used in the experiments without further purification. The stated minimum purity of these reagents was around 99 wt. % and the rest is water. Glycol + water mixtures were prepared gravimetrically using distilled water. The thermal conductivities of ethylene glycol + water, diethylene glycol + water, and triethylene glycol + water mixtures were measured at temperatures ranging from 25 °C to 40 °C and concentrations ranging from 25 wt. % glycol to 75 wt.% glycol.

2.2 Equipment:

Equipment used for the measurement of thermal conductivity for glycol + water mixtures is a bench top thermal conductivity unit (model H471, P. A. Hilton, Ltd.). **Figure 1** shows a schematic diagram of the experimental setup.

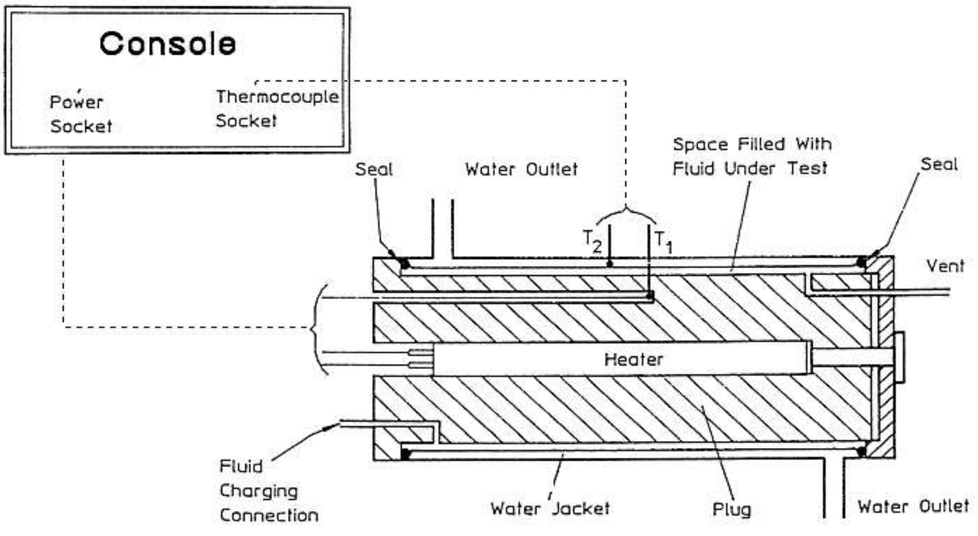

Figure 1: Schematic diagram of the experimental setup

Measurements are made by creating a temperature difference over a fluid sample that exists in a radial clearance. Fluid whose thermal conductivity is to be determined fills the small radial between a heated plug and water cooled jacket. The sample is subjected to heat, transferred from a resistance element from one side, and cooling from another side to create a temperature gradient. The clearance is small enough to prevent natural convection.

The plug is machined from aluminum and contains a cylindrical heating element whose resistance at the working temperature is accurately measured. A thermocouple is inserted into the plug close to its external surface, and the plug ports for the introduction and venting of the fluid under test. Due to the positioning of the thermocouples and the high thermal conductivities of the material involved, the temperatures measured are effectively the temperatures of the hot and cold faces of the fluid.

2.3. Data Analysis:

Average temperature of the fluid inside the cell can be calculated using the mean average approximation:

$$T^{AVG} = \frac{(T^2+T^1)}{2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

where T_2 and T_1 are the temperatures across the fluid (^oC).

Electrical heat input (Q_e, (W)) is calculated by dividing the square of the voltage (V, (Volts)) over the resistance (R, (Ohms)) of the heating element:

$$Qe = \frac{V^2}{R} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

The amount of heat transfered (Q_c, (W)) due to the conductivity of a fluid can be detrmined using Foriers law of thermal conduction:

$$Qc = K.A.(\Delta T/\Delta r) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3)$$

And the thermal conductivity at each average temperature (Equation 1) can be evaluated as:

$$K = \frac{Qc}{K.A.(\Delta T/\Delta r)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(4)$$

where K is the thermal conductivity of the fluid ($W/m^2.K$), A is the heat transfer surface area (m^2), $\Delta T = T_1 - T_2$ ($K = {}^oC$), and Δr is the distance over which heat is transferred (m).

In order to accurately estimate the amount of heat transferred (Q_c) from the amount of input electrical heat (Q_e), the lost heat (Q_i) is estimated through calibration. This is conducted using air in the radial space, where its thermal conductivity is known (also variable with temperature). T_1 and T_2 were calculated for an electrical input ranging from 20V to 35V. The resulting calibration carve is shown in **Figure 2**.

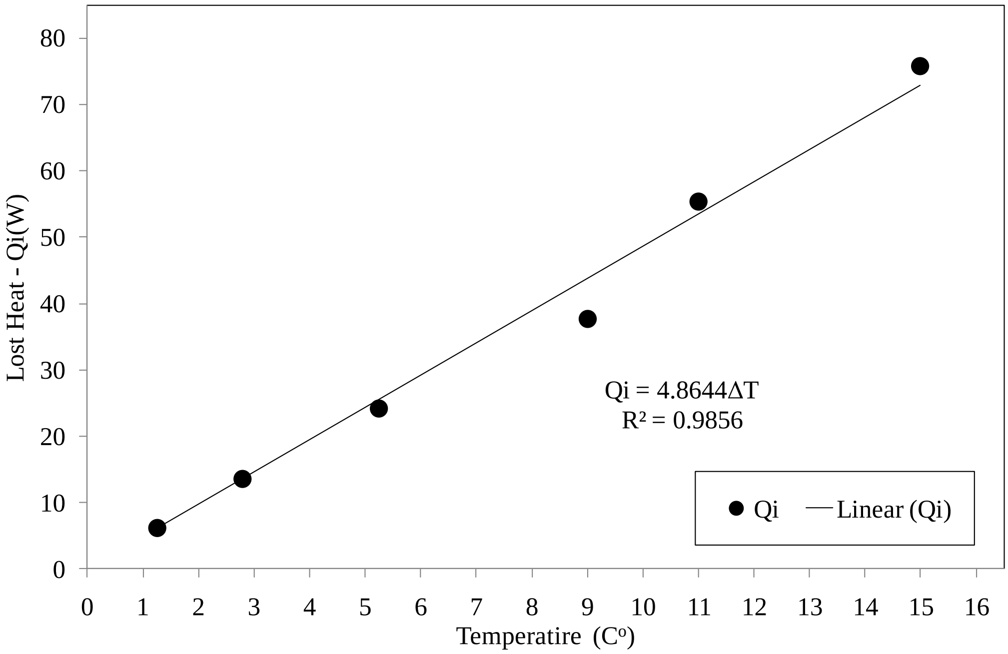

Figure 2: Calibration curve for lost heat estimation against temperature difference around the fluid.

III. RESULTS AND DISCUSSION

In this study, the effect of the composition of glycol+water solutions and temperature on the thermal conductivity was investigated. Different mono-, di- and tri- ethylene glycol+water solutions were subjected to experimental studies.

3.1 Monoethylene glycol+water solutions

Measured thermal conductivity of the different monoethylene glycol+water solutions as a function of temperature are given in **Figure 3**. As seen in **Figure 3**, at certain constant temperature level, the thermal conductivity decreases with increasing the mass percent of monoethylene glycol in the solution from the 25 wt. % to 75 wt. %; The average values of the thermal conductivity dropped from 0.381 ± 0.005, 0.320 ± 0.004, to 0.256 ± 0.006 ($W/m^2.K$) as the composition changed from 25%, 50%, 70% wt, respectively. Additionally, the thermal conductivity increased slightly with increasing the temperature at certain constant solution composition.

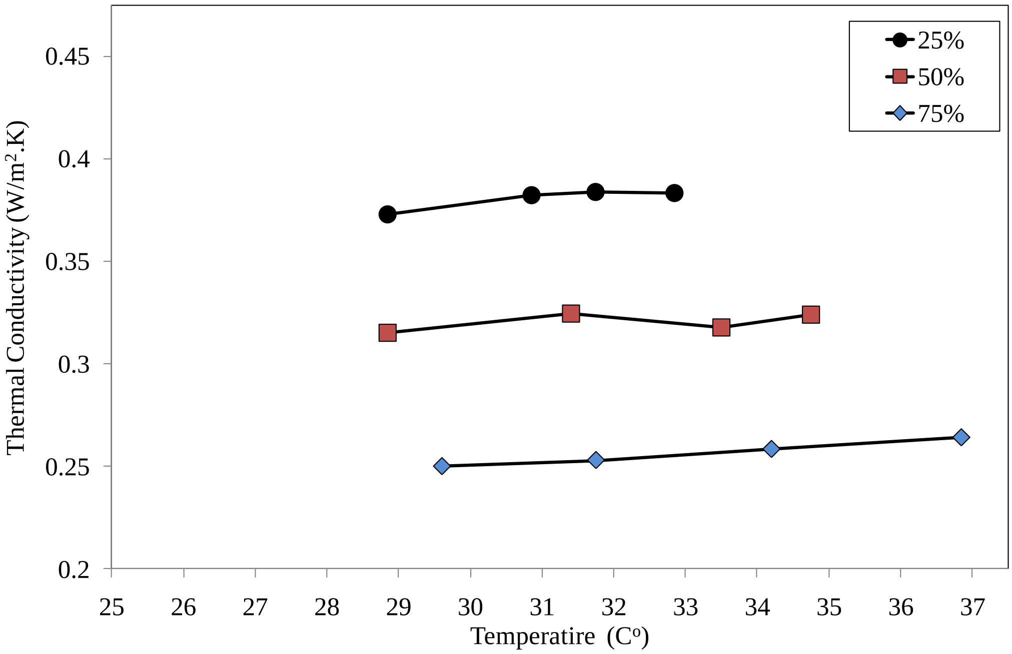

Figure 3: Measured thermal conductivity of the different monoethylene glycol+water solutions as a function of temperature.

These results compared well with previously published data by Sun and Tega (Sun and Teja, 2003), however at a higher range of temperatures (up to 75 °C). It was reported that the thermal conductivity for 25%, 50%, and 75% wt mixtures are 0.402 ± 0.012, 0.318 ± 0.013, to 0.272 ± 0.004 (W/m^2.K), respectively. Sun and Tega also reported that the thermal conductivity increases slightly with increasing the temperature over extended temperature range.

3.2 Diethylene glycol+water solutions

Measured thermal conductivity of the different diethylene glycol+water solutions as a function of temperature are given in **Figure 4**.

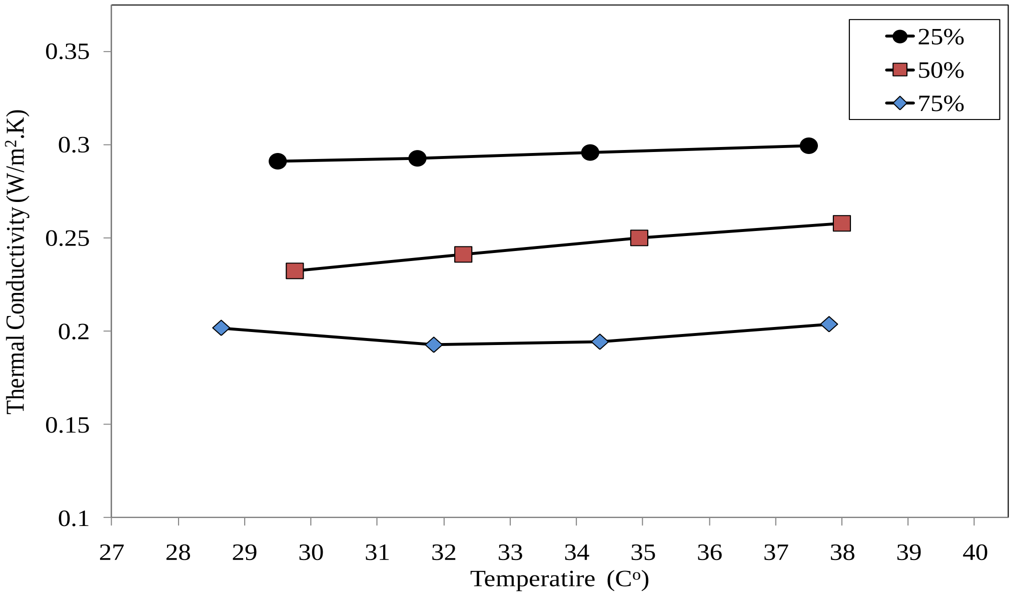

Figure 4: Measured thermal conductivity of the different diethylene glycol+water solutions as a function of temperature.

As shown in **Figure 4**, overall, thermal conductivity decreased compared to monoethylene glycol solutions. But similarly, the thermal conductivity decreases with increasing the mass percent of monoethylene glycol in the solution from the 25 wt. % to 75 wt. %; The average values of the thermal conductivity dropped from 0.294 ± 0.004, 0245 ± 0.011, to 0.198 ± 0.006 (W/m^2.K) as the composition changed from 25%, 50%, 70% wt, respectively.

Additionally, the thermal conductivity increased slightly with increasing the temperature at certain constant solution composition. These results also compared well with the previously published data (Sun and Teja, 2003) at the higher range of temperature. It was reported that the thermal conductivity for 25%, 50%, and 75% wt mixtures are 0.305 ± 0.013, 0.242 ± 0.007, to 0.213 ± 0.004 (W/m^2.K), respectively. The slight increase in thermal conductivity with increasing temperature was also reported over the extended temperature range was also reported.

3.3 Diethylene glycol+water solutions

Figure 5 shows the measured thermal conductivity of the different triethylene glycol+water solutions as a function of temperature.

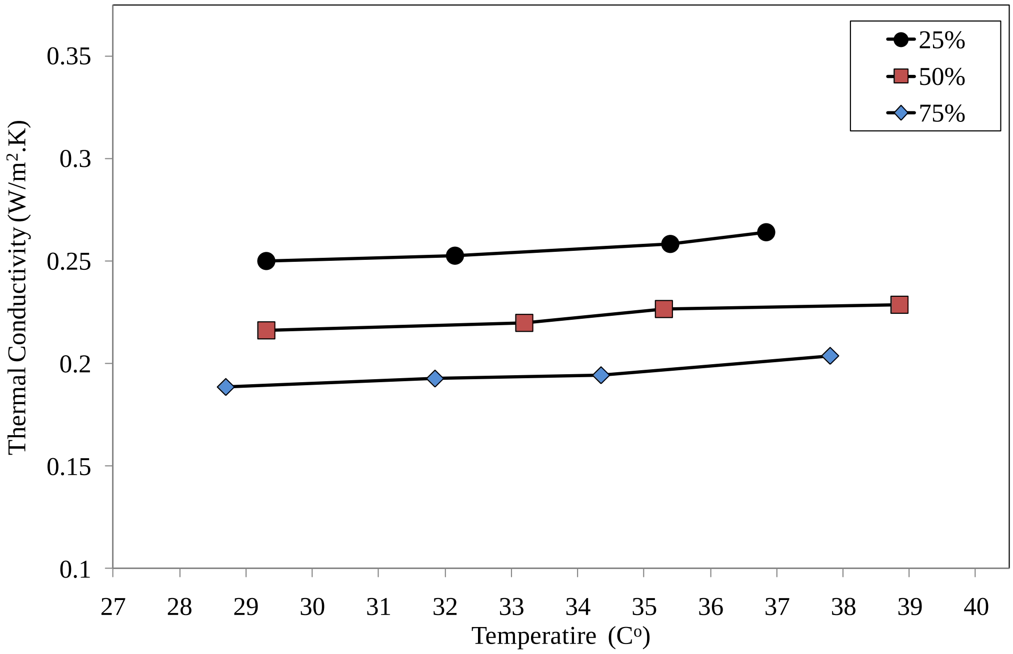

Figure 5: Measured thermal conductivity of the different triethylene glycol+water solutions as a function of temperature.

Similar to the behavior seen mono- and di-ethylene glycol+water solutions, the thermal conductivity decreases with increasing the mass percent of monoethylene glycol in the solution from the 25 wt. % to 75 wt. %; The average values of the thermal conductivity dropped from 0.256 ± 0.006, 0223 ± 0.006, to 0.194 ± 0.006 (W/m^2.K) as the composition changed from 25%, 50%, 70% wt, respectively. Also, the thermal conductivity decreased compared to diethylene glycol solutions. Additionally, the thermal conductivity increased slightly with increasing the temperature at certain constant solution composition.

These results were also comparable to the ones reported by Sun and Tega (Sun and Teja, 2003) at the higher range of temperature. Values of the thermal conductivity for the 25%, 50%, and 75% wt mixtures were reported as 0.267 ± 0.005, 0.215 ± 0.006, to 0.198 ± 0.003 (W/m^2.K), respectively. The slight increase in thermal conductivity with increasing temperature was also reported over the extended temperature range.

The observations mentioned above regarding mono-, di-, and tri ethylene glycol+water solutions indicated that in all the glycol+water solutions the thermal conductivity decreases with increasing the glycol content in the solution. The increase of glycol content in the solution leads to an increase in the molecular weight of the mixture as well as an increase in the density of the mixture. The change in the density in mono-, di-, and tri ethylene glycol+water solutions as a function of glycol content and temperature is shown in **Figure 6** (Sun and Teja, 2003).

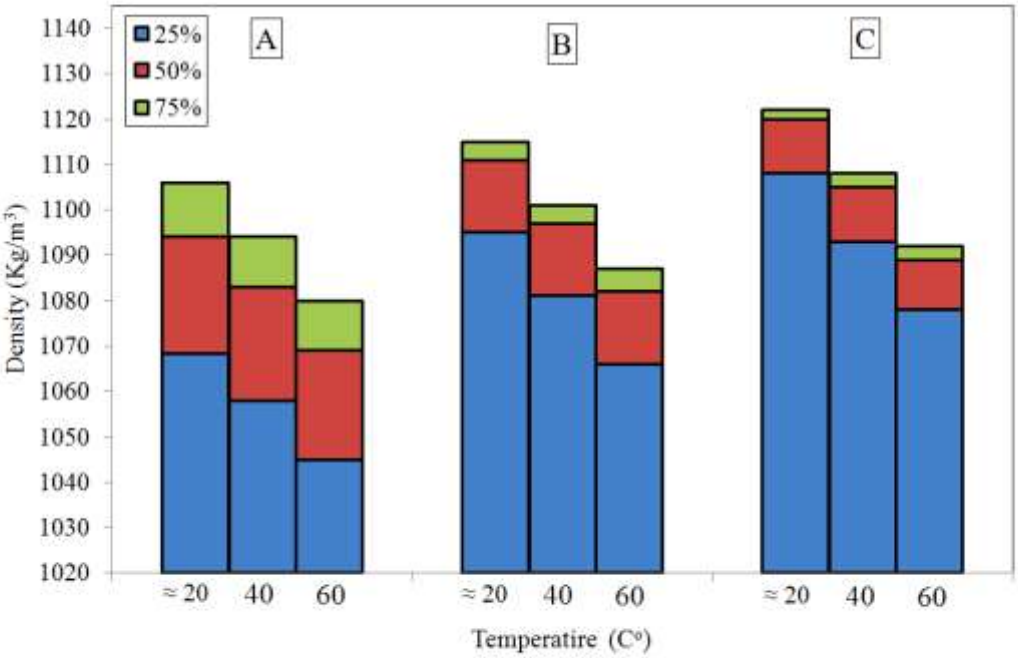

Figure 6: The change in the density of the different glycol solutions with concentration and temperature. A: Monoethylene glycol+water, B: Diethylene glycol+water, and C: Triethylene glycol+water. Adapted from (Sun and Teja, 2003).

The increase in density will lead to a decrease of the random translational motion of the liquid molecules as well as a decrease in their vibrational and rotational motion. This means the kinetic energy of a molecule will be reduced. The mechanism by which the liquid molecules transfer heat energy is a type of molecular collision and molecular diffusion. This mechanism is greatly depends upon the kinetic energy of the molecules. The molecules beside the hot side will gain a kinetic energy due to increasing their temperature, and then it will collide with the other molecules of lower kinetic energy level for from the hot surface. This will result in part of the kinetic energy of the more energetic (higher-temperature) molecule is transferred to the less energetic (lower temperature) molecule.

Based upon that, it can be said that a higher content of glycol in the solution will generate a stronger intermolecular forces, resulting in a solution with a higher density. This by its part will reduce the number of possible collisions between the molecules, thus lowering the chances for vibrational and rotational motion of the molecules themselves. This explains the decrease in the thermal conductivity with increasing the content of glycol in the solution. The measured slight increase in the thermal conductivity with temperature can be attributed to increasing the kinetic energy of the molecules and the weaker intermolecular forces between the molecules. This can result in increasing the number of collisions and thus increasing the rate of vibrational and rotational motions of the molecules.

It has been assumed that liquid molecules are arranged in a cubic lattice, and that energy is transferred from one lattice plane to the next at the speed at which sound travels through the fluid itself (Parker et al., 1961). Others have even obtained formulas which are characterized by the common property of direct proportionality between thermal conductivity and sound velocity in homogeneous liquids (Mustafaev and Abbasov, 1997). As mentioned above (Figure 6), higher glycol content will produce a denser solution. If a material is denser because its molecules are larger, it will transmit sound slower. Sound waves are made up of kinetic energy. It takes more energy to make large molecules vibrate than it does to make smaller molecules vibrate. Thus, sound will travel at a slower rate in the denser object if they have the same elastic properties. The decrease in sound velocity with increasing the density means a decrease in thermal conductivity of a liquid (Parker et al., 1961;Mustafaev and Abbasov, 1997). On the other hand, increasing the temperature can increase the sound velocity in the medium; therefore the thermal conductivity will increase. These arguments support the reported data.

IV. CONCLUSIONS

Thermal conductivities of Monoethylene glycol, Diethylene glycol, and Triethylene glycol + water mixtures were measured at temperatures ranging from 25 ˚C to 45 ˚C and glycol concentrations from 25 to 75 wt. %. Our data generally agreed with available literature data found at higher temperatures. Increasing the concentration of glycol leads to decrease of thermal conductivity, while increasing the temperature resulted in slight increase in thermal conductivity. The results were tested based on theoretical approaches and was in agreement with the theoretical observations.

REFERENCES

[1]. CUEVAS, R. and CHERYAN, M. "Thermal conductivity of liquid foods—a review", Journal of Food Process Engineering, **2**, 283-306.(1978).

[2]. Heyes, D. and March, N. "Theoretical approaches to thermal conductivity in liquids", Physics and Chemistry of Liquids, **33**, 65-83.(1996).

[3]. Kusiak, A., Pradere, C. and Battaglia, J.-L. "Measuring the thermal conductivity of liquids using photo-thermal radiometry", Measurement Science and Technology, **21**, 015403.(2009).

[4]. Lee, S., Choi, S.-S., Li, S., and and Eastman, J. "Measuring thermal conductivity of fluids containing oxide nanoparticles", Journal of Heat transfer, **121**, 280-289.(1999).

[5]. Mustafaev, R. and Abbasov, A. "A formula relating the thermal conductivity of liquids to the sound velocity in them", Journal of engineering physics and thermophysics, **70**, 27-29.(1997).

[6]. Obermeier, E., Fischer, S. and Bohne, D. "Thermal conductivity, density, viscosity, and prandtl-numbers of di-and triethylene glycol-water mixtures", Berichte der Bunsengesellschaft für physikalische Chemie, **89**, 805-809.(1985).

[7]. Parker, W., Jenkins, R., Butler, C. and Abbott, G. "Flash method of determining thermal diffusivity, heat capacity, and thermal conductivity", Journal of applied physics, **32**, 1679-1684.(1961).

[8]. Parsons Jr, J. and Mulligan, J. "Measurement of the properties of liquids and gases using a transient hot-wire technique", Review of scientific Instruments, **49**, 1460-1463.(1978).

[9]. Ramaswamy, R., Balasubramaniam, V. and Sastry, S. "Thermal conductivity of selected liquid foods at elevated pressures up to 700 mpa", Journal of Food Engineering, **83**, 444-451.(2007).

[10]. Sun, T. and Teja, A.S. "Density, viscosity, and thermal conductivity of aqueous ethylene, diethylene, and triethylene glycol mixtures between 290 k and 450 k", Journal of Chemical & Engineering Data, **48**, 198-202.(2003).

[11]. Tsierkezos, N.G. and Molinou, I.E. "Thermodynamic properties of water+ ethylene glycol at 283.15, 293.15, 303.15, and 313.15 k", Journal of Chemical & Engineering Data, **43**, 989-993.(1998).

[12]. Zhang, H., Zhao, G., Ye, H., Ge, X. and Cheng, S. "An improved hot probe for measuring thermal conductivity of liquids", Measurement Science and Technology, **16**, 1430.(2005).

Mazen Al-Amayreh, et.al. ”Experimental Study of Thermal Conductivity of Ethylene Glycol Water Mixtures” *International Journal of Engineering Research and Applications (IJERA*), vol.10 (01), 2020, pp 62-68.