Electrical conduction of the ethylene glycol when heated in the HV electric field

Tadeusz J Mączka¹, Juliusz B Gajewski, Dorota Nowak-Woźny

Institute of Heat Engineering and Fluid Mechanics, Wrocław University of Technology, Wybrzeże Wyspiańskiego 27, 50-370 Wrocław, Poland

Email: tadeusz.maczka@pwr.wroc.pl

Abstract. In this paper the results of research on the electrical conductivity of ethylene glycol during the Joule heating (or ohmic heating) based on Joule’s law under the HV electric field. Attempts were made to heat the glycol without its flow in a stationary heater with plane parallel electrodes oriented horizontally. On the basis of an analysis of the experimental results obtained it was found that the method employed to the Joule heating in the electric field generated by the high 50 Hz voltage applied to the electrodes seems very efficient while heating ethylene glycol.

1. Introduction

The heat carriers on the basis of ethylene glycol have the widespread application to the different branches of technology, especially to the air-conditioning and the motorization technique. A good price, good anticorrosion features, a relatively wide range of temperatures (from −40 to +150°C), low viscosity, a relatively high specific heat and thermal conductivity, as well as good mixing with water and alcohols cause the ethylene glycol to be widely used in practice [1–3].

The electrical conductivity of glycol mixtures within the range of temperatures from 20 to 100°C was investigated by different researchers and presented in their works concerning the ethylene and other glycols [4, 5]. The experiments were performed mostly under the DC electric fields or AC electric fields of the frequency higher than 50 Hz—power frequency in most of the European countries. There is still a lack of data about the research on the conductivity of the ethylene glycol and its water solutions at a frequency of 50 Hz.

From the technical point of view the conductivity values obtained for that frequency are of importance because the glycol is often used as a heat carrier in the systems energized with the voltage of power frequency. The glycol works both as a heating medium and as a refrigerant, and therefore the wide temperature range is so crucial in this consideration.

On the basis of an analysis of the experimental results obtained it was found that the method we have employed to the Joule heating in the electric field generated by the high voltage applied to the electrodes seems very efficient while heating the ethylene glycol.

This method of the glycol heating is a novel one, as supposed, the more so as there is a lack of any news about such a method used for the ohmic heating of the ethylene glycol, as well as other organic liquids including other glycols, glycerines, resins, etc. The method proposed could be an alternative one to those used nowadays to heating this type of liquids.

¹ To whom any correspondence should be addressed.
2. Experimental

2.1. Material tested, experimental setup and procedures
The pure ethylene glycol C\textsubscript{2}H\textsubscript{6}O\textsubscript{2} was used. The volume of a heated glycol sample was 264-10\textsuperscript{-6} m\textsuperscript{3} during the experiments performed. The glycol heating under the HV electric field was carried out without any flow of the liquid in the heater with plane parallel electrodes oriented horizontally. The schematic diagram of a stationary heater is shown in figure 1.

The electrodes 0.6-10\textsuperscript{-3} m in thickness were made of acid resistant steel and placed in a horizontal pipe. The lower electrode was immovable and mounted on a polycarbonate (PC) sealing ring. The movable upper electrode permitted one to regulate the distance \( h \) between both 58-10\textsuperscript{-3} m in diameter electrodes from 0 to 0.12 m.

The thin liquid layer above the upper electrode was about 5-10\textsuperscript{-3} m in thickness.

The 0.5-10\textsuperscript{-6} m\textsuperscript{2} thermocouples were placed at the middle of each electrode to control and measure temperature.

The 50 Hz voltage \( U \) was used throughout the experiments. The power supply was made up of a one-phase autotransformer, the HV transformer of a maximum output voltage of 10 kVA, and a measuring system based on the resistive voltage divider of a voltage ratio of 1000.

The values of the voltage applied to the system, as given at the beginning of each heating process, were kept constant at 5, 10, 15, 20, and 25 kV. The relevant electric field strengths \( E \) were 50, 100, 150, 200, and 250 kV/m, respectively. The current flowing through a sample was measured with an ammeter connected directly to and in series with the heater current circuit. The value of the supply voltage, the time variations of the current flowing through a heated sample and its temperature were recorded.

Temperature readings were made without the voltage applied and thus the possible effect of an electromagnetic field on the measurement accuracy could be estimated. The temperature values were obtained as averages of the temperatures of the upper and lower electrodes.

The sample resistance was obtained directly from Ohm’s law \((R = U/I)\) neglecting the capacitance of an electrode system. Therefore the sample conductivity was simply \( \sigma = 1/\rho = h/(RS) \), where \( S \) was the active area of the electrodes and \( h \) was a constant distance of 0.1 m between the electrodes.

Each heating was carried out with a fresh glycol sample. All the experiment were performed under practically normal air pressure and the temperature in the laboratory was controlled and kept almost constant at 21±2°C (294±2 K).

The ethylene glycol was exactly mixed before each filling of the heater. No thermal insulation of the heater was used since that could not permit one to visually observe the liquid during the experiments. We tried to keep up the identical environmental conditions and experimental procedure for each trial.

3. Results and discussion
An analysis of the experimental data obtained shows that an increase in the electric field strength through the increasing HV voltage applied to the electrodes shortens the heating time to 1637, 490, 217, 125, and 70 s for electric field strengths of 50, 100, 150, 200, and 250 kV/m, respectively. The five-fold increase of the electric field strength in the heater shortens the heating time more than twenty-three-fold up to the same temperature.
Figure 2 shows the dependence of the electrical conductivity of ethylene glycol on the temperature. The trends for all the electric field strengths applied are similar and any differences between the curves can be neglected. It seems that the conductivity is here activated thermally.

It was found that the electric field applied had practically no effect on the conductivity of the ethylene glycol while heating. This proves the results presented by Galagher [7].

It is thought that the results obtained can be described best by the Arrhenius model similarly to the super ionic conductors [10,11]

\[
\sigma = \sigma_0 \cdot \exp\left(-\frac{W}{kT}\right),
\]

where: \(k\) is the Boltzmann constant, \(T\) is the liquid temperature, \(W\) is the activation energy, and \(\sigma_0\) is a constant.

On the basis of the expression \(\ln(\sigma T) = f(1/T)\) (figure 3) two values of the activation energies of the conduction process were determined for two temperature ranges and collected in table 1. One can suppose that in the ethylene glycol two different mechanisms of the charge transfer occur. It is supposed that the conduction is related to the transport of the glycol molecules, which have no hydroxyl groups OH, as a result of elevated temperature, and to the hydroxyl groups displacement itself. The transport “routes” of the hydroxyl groups are likely the glycol molecules which have no such groups because of the action of temperature. As a result, each hydroxyl group “jumps” from one molecule to another one.

In the range of lower temperatures we observed the thermally activated process of hydroxyl groups thermal dissociation. At higher temperatures the additional process of hydroxyl groups dislocation could take place on the basis of glycol, i.e. the thermally activated „jumps” of hydroxyl groups OH over the glycol molecules.

For all the experiments performed the activation energy values calculated are distinctly different and higher for the lower range of temperatures of 293–308 K than for the range of higher temperatures of 309–375 K regardless of the external electric field strengths. The activation energy values were 0.45–0.49 eV and 0.23–0.24 eV, respectively.

4. Concluding remarks

The electrical conductivity of the ethylene glycol does not depend on the electric field strength of the

![Figure 2. The conductivity dependence on the ethylene glycol sample temperature.](image)

![Figure 3. The logarithmic dependence \(\ln(\sigma T) = f(1/T)\) to enable the activation energy of the conduction process to be determined.](image)

| \(E\) (kV/m) | \(\Delta T\) (K) | \(W\) (eV) |
|------------|----------------|---------|
| 50         | 293–308        | 0.45    |
|            | 309–375        | 0.24    |
| 100        | 293–308        | 0.49    |
|            | 309–375        | 0.23    |
| 150        | 293–308        | 0.53    |
|            | 309–375        | 0.24    |
| 200        | 309–375        | 0.23    |
|            | 293–308        | 0.46    |
| 250        | 309–375        | 0.24    |
HV 50 Hz voltage applied within the range of temperatures considered. The conductivity changes with the glycol temperature one can describe with the Arrhenius model. It also permits the activation energy of the conduction process to be determined. Additionally, it should be said that the process of the stationary ohmic heating of ethylene glycol under the HV electric field is technically and technologically simple and easy to use.

5. References

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