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*COMMUNICATIONS*

# THE HV ELECTRIC FIELD HEATING OF THE ETHYLENE GLYCOL

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The research on the electrical conductivity of the ethylene glycol under HV electric field operation was realized. Attempt was made to heat the ethylene 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 HV electric field heating method, seems very efficient while heating the ethylene glycol from temperature 250 K. It was compared that values of the conduction mechanisms activation energy, when ethylene glycol was by DC and HV electric field heated.

K e y w o r d s: conductivity, ethylene glycol, Joule heating

## 1 INTRODUCTION

The subject of this work is ethylene glycol, that is widely used in practice [1-3], heated in the HV electric field. 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.* This method could be an alternative one to those used nowadays to heating this type of liquids.

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. The ethylene glycol has a low conductivity. The density of electrical current $(j)$ depends on the electric field intensity $(E)$, electrical carrier concentration $(n_i)$, electric charge $(q_i)$, and charge mobility $(v_i)$ [4]:

$$j = E \sum_{i=1}^{m} n_i \, q_i \, v_i \tag{1}$$

The mobility of the charged particles in liquids, depends on the viscosity (Walden's rule). However the anomalous behavior with respect to Walden's rule for liquids low permittivities was observed. In low conductivity liquids, the conductivity mechanism is associated with the motion of slow-moving, singly-charged carriers with molecular dimensions [5]. It is clearly that when the carriers are larger and viscosity is higher, than the conductivity is lower [6].

The electric conductivity of glycol mixtures within the range of temperatures from 293K to 373K was investigated by different researchers and presented in their works concerning the ethylene and other glycols [7,8]. 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 and temperature from 250 K .

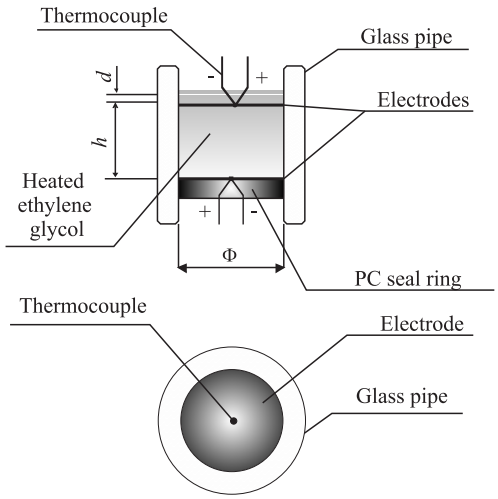


**Fig. 1.** The stationary heater $d \approx 5$ mm - thin liquid layer above the upper electrode, $h \approx 25$ mm - distance between electrodes, $\Phi \approx 58$ mm - diameter of both electrodes

## 1 EXPERIMENTAL

As a heating carrier it was used the pure ethylene glycol $C_2H_6O_2$. The volume of a glycol sample was $66 \times 10^{-6} m^3$. The 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 Fig. 1. The electrodes 0.6 mm in thickness were made of acid resistant steel and placed in a horizontal pipe.

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The lower electrode was immovable and mounted in a polycarbonate sealing ring. The movable upper electrode permitted one to regulate the distance h between both diameter electrodes from 0.0 m to 0.10 m. The thin liquid layer above the upper electrode was about $5 \times 10^{-3}$m in thickness. The $0.5 \times 10^{-6}\,\mathrm{m}^2$ thermocouple was placed at the middle of each electrode to control and measure temperature.

All the experiment were performed under normal air pressure and when laboratory temperature was kept almost constant (294 2 K).

The system for HV heating is shown on Fig. 2. The 50 Hz voltage $U$ was used during the experiments. The system was energized from a one-phase autotransformer, the HV transformer of a maximum of 10 kVA and the measuring system based on the resistive divider of a voltage ratio of 1000.

The voltage value $U$ was kept constant at values of 2.5; 5 and 7.5 kV. The relevant electric field intensity $E$ were 100 kV/m, 200 kV/m, and 300 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.

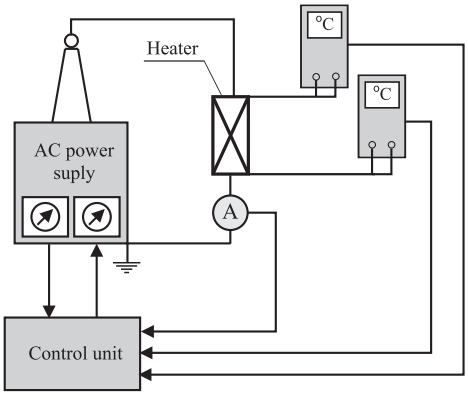


**Fig. 2.** Schematic view of the system for HV heating

Temperature readings were made without the voltage applied and thus the possible effect of an electromagnetic field on the measurement accuracy. 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 neglecting the capacitance of an electrode system. Therefore the sample conductivity was simply $\sigma = h/(RS)$, where $S$ was the active area of the electrodes and $h$ was a constant distance between the electrodes.

The ethylene glycol/water solution was prepared exactly before each filling of the heater. Then, the heater (with examined sample, electrodes and thermocouples) was placed into the refrigerator chamber, where the sample was cooled to 250 K and kept at such temperature by 6 hours. At 259K the sample of glycol was like liquid. The temperatures was controlling on both electrodes and chamber space. The temperature fluctuations were about 2K. Then the heater was quickly carried on experimental unit and immediately started to the test. This process was lasted about 30 s.

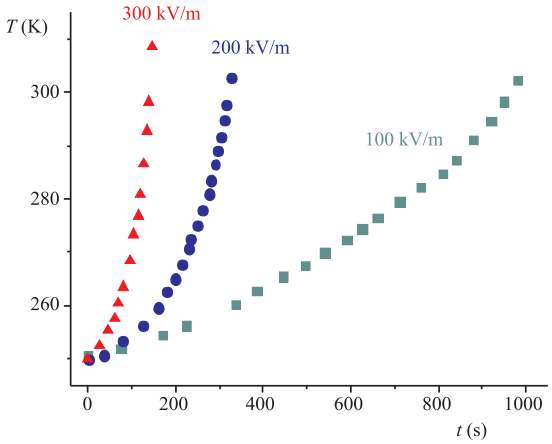


**Fig. 3.** The ethylene glycol temperature *v*stime

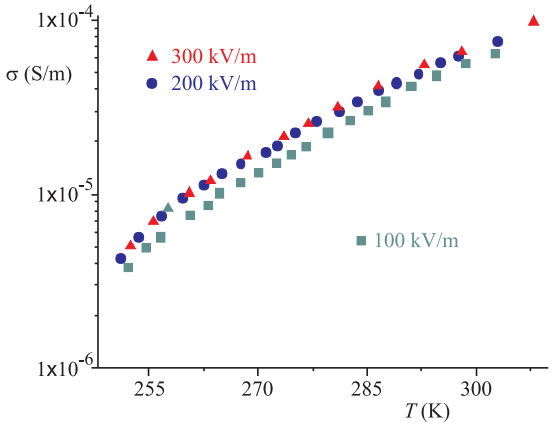


**Fig. 4.** The conductivity dependence on the ethylene glycol sample temperature

## 3 RESULTS AND DISCUSSION

The experimental data (temperature versus time of heating) are shown on Fig. 3. It is evident that the increasing of the electrical field strength (the increasing HV voltage applied to the electrodes) shortens the heating time.

The threefold electric field intensity increase shortens the heating time more than sevenfold up to the same temperature.

The electrical conductivity of the ethylene glycol versus temperature, for different electric field strength, is shown on figure 4.

The trends for all the electric field intensity 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 relationship between electric field applied and electric conductivity of the ethylene glycol while heating, is very weakly. The similar results are achieved by Galagher in simple dielectric liquids[6].

It is thought that the results obtained can be described best by the Arrhenius model similarly to the super ionic conductors [9,10]

$$\sigma = \frac{\sigma_0}{T} \exp(-\frac{W}{kT}) \tag{2}$$

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 $\ln(\sigma T) = f(1/T)$, Fig. 5, values of the activation energies of the conduction process were determined for temperature ranges 250-310 K, and are collected in Table 1.

**Table 1.** The activation energy of the conduction process while heating the ethylene glycol

| $E$ (kV/m) | $\Delta T$ (K) | $W$ (eV) |
|---|---|---|
| 100 | 250 - 310 | 0.42 |
| 200 | 250 - 310 | 0.42 |
| 300 | 250 - 310 | 0.40 |

One can suppose that in the ethylene glycol one mechanisms of the charge transfer occur. It is supposed that the electric conduction in ethylene glycol 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.

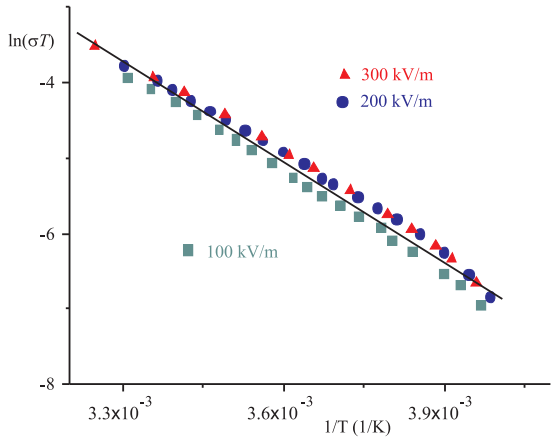


**Fig. 5.** The logarithmic dependence $\ln(\sigma T) = f(1/T)$ to enable the activation energy of the conduction process to be determined

For all the experiments performed the activation energy values calculated are, in temperature range 250 K - 310 K, practically the same and equal to about 0.4 eV.

## 4 CONCLUSION REMARKS

The conductivity changes with the glycol temperature one can describe with the Arrhenius type equation. It also permits the activation energy of the conduction process to be determined. The obtained values equal to about 0.4 eV suggests the diffusion controlled process such as pseudo-hopping of the OH- groups. Additionally, it should be said that the process of the stationary ohmic heating of the ethylene glycol from 250 K under the HV electric field is technically and technologically simple and easy to use.

## References

[1] BONCA, Z.—BUTRYMOWICZ, D.–TARGAŃSKI, W.—HAJDUK, T.: Nowe czynniki chłodnicze i nośniki ciepła. Właściwości cieplne, chemiczne i uzytkowe, IPPU MASTA, Gdańsk, 2004. (in Polish)

[2] SINGH, J.: Heat Transfer Fluids and Systems for Process and Energy Applications, Marcel Dekker, Inc, New York, 1985.

[3] HUNOLD, D.: Inżynieria i Aparatura Chemiczna, vol. 5, 2002, p. 23. (in Polish)

[4] MASNY, J.—TERESIAK, Z.: Przemiany energii elektrycznej, WNT, Warszawa, 1985. (in Polish)

[5] ANTONIEWICZ, J.: Właściwości dielektryków,Tablice i wykresy,, WNT, Warszawa, 1971. (in Polish)

[6] GALLAGHER, T. J.: Simple Dielectric Liquids, Mobility, Conduction and Breakdown, Clarendon Press, Oxford, 1975.

[7] LEE, Y. C.—RATNER, M. A.—SHRIVER, D. F.: Solid State Ionics, vol. 138, 2001, p. 273.

[8] IKEDA, Y.—HIRAOKA, T.—OHTA, S.: Solid State Ionics volume175, 2004, pp. 261.

[9] JAKUBOWSKI, J.: Przewodniki superjonowe, Właściwości fizyczne i zastosowanie, WNT), Warszawa, 1988. (in Polish)

[10] BOGUSZ, W—KROK, F.: Elektrolity stałe: właściwości elektryczne i sposoby ich pomiaru, WNT, Warszawa, 1995. (in Polish)

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