Electrical conductivity of aqueous solution of KOH at atmospheric pressure

K I Kuznetsov¹, S V Skorodumov¹ and P P Granchenko¹

¹National Research University “Moscow Power Engineering Institute”, Moscow, 111250 Russia

granchenkop@gmail.com; kikuznlyc@mail.ru

Abstract. Measurements of the electrical conductivity ratio of a 20% aqueous solution of KOH depending on temperature, intensity of electric field and frequency of changing direction of current are being studied. To ensure and conduct the measurements a conductivity meter was made with a current that changed the direction by means of a “meander” voltage. The measurement results of the study are processed in the form of analytical dependencies.

1. Introduction

The development of modern nuclear power requires the introduction of new energy technologies without reducing the level of safety of facilities.

One of the ways to achieve such opportunities is to search for new coolants of the core, allowing a good conversion of all types of energy released into heat, operating at a higher temperature than water-water power plants and less sensitive to possible overheating. Such coolants can be liquid metal ligatures [1,2], as well as melts of salts, which are ionic conductors. To study the processes of heat exchange in ionic conductors, the properties in substances simulating real coolants at experimental temperatures from 10°C to 90°C were studied. The purpose of this paper was to measure the electrical conductivity of a working sample of a solution of KOH in the above-mentioned temperature range at atmospheric pressure.

2. Experimental base and results of measurements

To carry out the experiments, an experimental unit has been constructed, including a contact type conductivity meter, a liquid thermostat using water as the coolant and a number of devices providing conditions for measuring the electrical conductivity ratio, as well as measuring the assignment parameters.

Based on Debye and Gückel theory [3,4] can be concluded the dependence of the conductivity of KOH (strong electrolyte) to be studied on:
• Solution temperatures
• Intensity of the applied electric field
• Frequency of change of current direction
• The concentration of the solution (the effect was not taken into account as a specific sample of the solution was investigated).

Since a conductometer based on the contact method of measurements was used in the work, as a result of the leakage of charges into the electrode area, their screening occurs [5], which was revealed...
during preliminary measurements at a direct current. In some cases, this problem is solved using alternating current in conductometers.

However, this technique eliminates the measurement of the dependence of electrical conductivity on the intensity of the applied electric field. In the present work, the authors have solved this problem by using a meander-type voltage as a current source (meander is a voltage varying abruptly from +U to -U). This provides a measurement of electrical conductivity, with a precisely set level of electric field strength applied to a calibrated section of a channel filled with electrolyte. According to the Wien effect, for strong electrolytes, there is a dependence of the electrical conductivity of the electrolyte solution on the electric field strength. With an increase in the intensity of the electrical conductivity of the electrolyte tends to the limit value. With an abrupt change in the magnitude of the voltage, charge leakage that shields the current electrodes characteristic of contact-type conductometers is excluded. A general view of the research facility as well as the experimental unit layout are shown in Fig. 1 and Fig. 2.

The experimental facility includes a measuring cell of a conductivity meter placed in a liquid thermostat with a temperature keeping accuracy of ±0.1 C, a power supply of a matching amplifier B-5-47a, a signal generator of a special form GFG-8219a with an integrated frequency meter operating in the "meander voltage" mode, a universal digital 6-digit voltmeter V-7-65/2, switchable with a two-position switch P1, alternately connected to the reference resistance box MCR-60 and to the potential electrodes of the investigated y ASTK conductivity meter. To control the shape of the electrical signal, an electron-beam oscilloscope S-1-68, operating in a standby mode with internal synchronization, is connected to the output of the matching amplifier. The main element of the experimental unit is the measuring cell of the conductivity meter. A schematic drawing of the measuring cell is shown in Fig. 3.
Figure 3. Measuring cell.

The measuring cell of the conductivity meter is made of PTFE F-4 (a material inert to alkalis at any concentration). From the ends of the cylindrical body 1, graphite current electrodes 3 are introduced with a deposited copper plating of the outer end, compacted with a silicone sealant. Current conductors soldered to the coppered surface are led out through fluoroplastic tubes 7 fixed with an epoxy compound to the cover of the thermostat 8. Potential electrodes 4 are made of graphite rods 0.5 mm in diameter, practically non-perturbing in the ion conductor channel. To the coppered ends of the rods, conductors are soldered to the dry zone through the fluoroplastic rods 5, which are also fastenings of the cell body to the thermostat cover. To fill the channel with electrolyte solution, tubes 6 are inserted into the body of the measuring cell. In connection with the necessity of matching the load resistance with the current source, the authors developed and manufactured a bipolar amplifier. A schematic diagram of the amplifier is shown in Fig. 4.

Figure 4. Matching amplifier circuit.
The amplifier is assembled on composite transistors T1, T2 with a high gain (β ≥ 750) in a balanced two-arm system with a common collector.

The amplifier is powered by a stabilized voltage source BPS-12/10 with an output voltage of 12 V and a maximum load current of 5 A. The amplifier provides a load connection ≥ 2 Ω at an amplitude of up to 5 V.

In the absence of signal mode, both transistors are closed by a constant offset through resistors R3, R4. To ensure the temperature mode of the transistors installed on the radiators, and the resistors R1, R2 providing the middle point (common bus), the blower fan is included in the amplifier.

3. Description of measurements

Measurements of electrical conductivity were carried out at constant temperatures. At each isotherm, measurements are made with different signal amplitudes, that is, for different electric field intensity, and for different frequencies of current direction change. The measured conductivity ratio calculated as:

\[ \sigma = \frac{4 \pi d^2}{\pi d^2} \cdot \frac{U_N}{U_X \cdot R_N} \]  

where \( d \) is the diameter of the channel; \( x \) is the distance between the potential electrodes, \( U_N \) is the voltage drop across the reference resistor (in Figure 2 this is the MCR-60); \( U_X \) is the voltage drop across the investigated section of the channel filled with electrolyte; \( R_N \) is the value of the reference impedance at the resistance box MCR-60.

The error in the measurements is estimated by the authors within ±5%. In this case, the reproducibility of the results does not exceed 0.2%, which indicates the possibility of improving the results when using a reference sample.

The dependence of the electric conductivity ratio on the frequency of the change in the current direction is related to the time of establishment of the equilibrium motion of the dissociated ions on one side and the time of blocking the current electrodes by ions of opposite polarity, on the other hand [4].

In this connection, the maximum electrical conductivity is observed as a function of frequency. Thus, as a result of the measurements, the dependence of the specific conductivity in the sample of the solution KOH on the temperature, the electric field intensity, and the frequency of the current direction change was determined. The obtained dependence was described by the authors as:

\[ \sigma = \sum_{i=0}^{m} \sum_{j=0}^{n} \sum_{k=0}^{k} b_{i,j,k} t^i E^j f^k \]  

(3)

Similar dependencies can also be found in the well-known literature [5,6,7]. For convenience of use, below are provided two equations that were built for the calculations, describing the dependence of the electrical conductivity on three variables.

The first equation (3) contains 142 coefficients with an average deviation of 0.28%,

\[ \sigma = \sum_{i=0}^{5} \sum_{j=0}^{4} \sum_{k=0}^{4} b_{i,j,k} t^i E^j f^k \]  

The values of the coefficients are given in Table 1.
In addition, taking into account the change in electrical conductivity in the investigated range from the coefficients describing the experimental result with a mean square deviation of 2.5%.

\[
\sigma = \sum_{i=0}^{2} \sum_{j=0}^{2} \sum_{k=0}^{2} b_{i,j,k} \frac{t^i}{E^j} f^k
\]  

(4)

The values of the coefficients are given in Table 2.

**Table 2. Equation coefficients (4)**

| b_{i,j,k} | b_{i,j,k} | b_{i,j,k} | b_{i,j,k} |
|-----------|-----------|-----------|-----------|
| b_{0,0,0} = 30.5969 | b_{1,0,0} = -1.44417 | b_{2,0,0} = -0.000482185 |
| b_{0,1,1} = -5.61612 | b_{1,1,1} = -0.000728914 | b_{2,1,1} = 8.4648*10^-6 |
| b_{0,1,2} = 0.00538671 | b_{1,1,2} = -0.00064297 | b_{2,1,2} = -0.000130328 |
| b_{0,2,0} = -7.20066*10^-6 | b_{1,2,0} = 1.33694*10^-6 | b_{2,2,0} = -1.6683*10^-8 |
| b_{0,2,1} = -0.000974536 | b_{1,2,1} = 6.22259*10^-7 | b_{2,2,1} = -7.0458*10^-9 |
| b_{0,2,2} = 0.00035106 | b_{1,2,2} = 7.83523*10^-8 | b_{2,2,2} = -9.82647*10^-8 |

4. Obtain of equation

In addition, taking into account the change in electrical conductivity in the investigated range from the electric field strength and the meander current frequency in the range of 3.7%, the dependence of the electrical conductivity ratio (\(\sigma, \Omega^{-1} \cdot m^{-1}\)) of the test sample on the temperature at the average constant values of the remaining arguments was constructed in the form (5):

\[
\sigma(t) = 1.0523 \cdot t + 27.615
\]  

(5)
As an example, confirming the above, in Fig. 5 shows the graphical dependence of the electrical conductivity on the electric field and frequency at a temperature of 40°C, in Fig. 6 shows the graphic illustration of equation with plotted on surface dots of electrical conductivity on temperature and electric field at a frequency of 100 Hz.

Figure 5. Graphic illustration of the dependence of the electrical conductivity ratio on the intensity of electric field and frequency at a temperature of 40°C.

Figure 6. Graphic illustration of the dependence of the electrical conductivity ratio on temperature and tension at a frequency of 100 Hz.

5. Conclusion
Measurements of the electrical conductivity of the electrolyte solution KOH have been carried out to further simulate heat transfer processes in ionic conductors. For the measurements, an experimental setup was designed and installed, providing both the necessary applied research and the results for the physical explanation of the processes that took place. The results of the studies are presented in the form of equations of different accuracy for describing the measured dependences.

Acknowledgments
This study was supported by the Russian governmental Megagrant, the project №14.Z50.31.0042.

References
[1] Stromberg A G, Semchenko D P 201 Physical chemistry: - Moscow: Higher school, pp. 527
[2] Robinson R A, Robert H S 2002 Electrolyte solutions. Courier Corporation
[3] Kolesnikov I M, Vinokurov V A 2017 Electrochemistry of electrolyte solutions. Part I. electrical conductivity: Moscow: Publishing center of Gubkin Russian state University of oil and gas (NRU), pp. 66
[4] Izmailov N A, Mishustin A I 1976 Electrochemistry of solutions, 3rd ed., M., pp. 68-89
[5] Yerdei-Gruz T 1976 Transfer phenomena in aqueous solutions, M.: Mir, pp. 596
[6] Frank Allebrod et al. 2012 Electrical conductivity measurements of aqueous and immobilized potassium hydroxide, International Journal of Hydrogen Energy, Vol. 37, Issue 21, pp.16505-16514
[7] Gilliam J, Graydon J W, Kirk D W, Thorpe S J 2007 A review of specific conductivities of potassium hydroxide solutions for various concentrations and temperatures, International Journal of Hydrogen Energy, Vol. 32, Issue 3, pp. 359-364