

The Theory of Thermal Desalination Systems Based on Sewed Polymer Networks

[Ibragim Suleimenov, Grigoriy Mun, Sergey Panchenko, Sherniyaz Kabdushev, Olzhas Erezheev, Dina Shaltykova]

Abstract — It is shown that it is possible to implement analog of a dialyzer based on sewed polymer networks, working on the basis of the temperature difference between two reservoirs containing low molecular weight salt. The result of such dialyzer using is enrichment of one those solutions by low molecular component and depletion of the other. It is shown that for providing the necessary temperature, it is possible to use energy of solar radiation.

Keywords — Dialysis, water deionization, polymeric hydrogels, green energy, contact potential difference.

I. Introduction

Relevance of activity in the field of "green energy" currently does not require full-scale justification. However, it is necessary to emphasize, that although main part of efforts in this area aimed at creating and improving sources of electricity using renewable energy, another works aimed at direct use of solar energy, bypassing the stage of generating electricity are also of importance.

Recently, it was proposed a number of advance methods of direct transforming of solar energy into mechanical one [1,2]. The methods are based on osmotic phenomena taking place in solutions of low- and high-molecular compounds. Regulation of local salt concentration due to contact of solution with strongly swelling polymer gel results in local variations of osmotic pressure [1] and amplification of circulation of the liquid in the counter; the effect may be used for cooling of solar panels, etc.

In present paper desalination and irrigating systems then are using osmotic phenomena and operating on the base of utilization of energy of solar radiation is proposed. The theory of operation of such systems is developed.

II. Description of the scheme

Proposed theory shows that there is an opportunity to realize analog of the dialyzer providing a deionization of water due to the difference of temperatures, created by solar radiation.

Fig. 1 shows a possible scheme of such dialyzer analogue. The device contains of the following:

- Volumes 1 and 2 are filled with cation-exchange and anion-exchange gel, respectively (for definiteness the grid on the basis of sodium polyacrylate-COONa and the grid on basis of chloride nitrogen base-NH₃Cl will be considered below).

- Reservoirs 3 and 4 are filled with warmed (T₁) and cooled (T₂) solutions of low-molecular electrolyte (for definiteness, sodium chloride will be considered below).

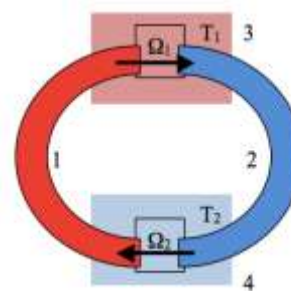


Figure 1. The scheme of thermal analog of the dialyzer on the basis of polymeric hydrogels, 1 – cation-exchange grid, 2 – anion-exchange grid, 3 и 4 – reservoirs with warmed and cooled solutions, respectively.

In the case of the non-equal temperature of volumes (1) and (2), the system, Fig.1 is converted into an analog of thermocouple. Let us show, that such thermocouple may operate as desalination system too.

In accordance with the mechanism analyzed in [3], on a surface of the acid hydrogel placed in solution the difference of electrostatic potentials is formed, and its magnitude can be estimated using equations:

$$[Na^+]_3 = \exp\left(-\frac{\Delta\phi_{31}}{kT_1}\right)[Na^+]_1, \quad (1)$$

$$[Cl^-]_3 = \exp\left(\frac{\Delta\phi_{31}}{kT_1}\right)[Cl^-]_1 \quad (2)$$

Where the chemical symbol in square brackets represents the concentration of the corresponding ions, $\Delta\phi_{31}$ - electrostatic potential difference between the solution in the region 3 and gel in region 2, T_1 – absolute temperature, k - Boltzmann constant. The signs of potentials correspond to the direction shown by an arrow in Fig. 1, which is taken as positive. Eq. (1) and Eq. (2) should be supplemented by relations expressing the neutrality of the medium inside and outside of hydrogel

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$$[Cl^-]_e = [Na^+]_e \quad (3)$$

$$[-COO^-] + [Cl^-]_i = [Na^+]_i \quad (4)$$

The system of the equations (1) – (4) is closed under the condition that the concentrations of ions in the surrounding solution are regarded as fixed values.

A similar system of equations can be written for finding the potential difference in the contact area of anion-exchange grid with solution.

For simplification we will use following indications:

$$\begin{aligned} [Cl^-]_j = n_j^-; [Na^+]_j = n_j^+; [-COOH^-] = N_1; \\ [-NH_3^+] = N_2 \end{aligned} \quad (5)$$

On condition that concentration of functional groups of a network significantly exceed concentration of ions in surrounding solution, on the basis of the equations (1) – (4) it is possible to receive the following formula for a potentials difference:

$$\Delta\phi_{31} \approx -kT_1 \ln \left(\frac{n_3^-}{N_1} \right) > 0 \quad (6)$$

The similar formula is true for a potential difference also D_j^{23}

$$\Delta\phi_{23} \approx kT_1 \ln \left(\frac{N_2}{n_3^+} \right) > 0 \quad (7)$$

or

$$\Delta\phi_{21} \approx -kT_1 \ln \left(\frac{c_3^2}{N_1 N_2} \right) > 0 \quad (8)$$

Where the condition of an neutrality of solution in area 3 is used $n_3^+ = n_3^- = c_3$.

For a total potential difference in area 4, it is possible to write down the similar equation with only difference that the sign changes to the opposite

$$\Delta\phi'_{12} \approx kT_2 \ln \left(\frac{c_4^2}{N_1 N_2} \right) < 0 \quad (9)$$

Therefore, in the considered contour thermo-electromotive force W arises, and it can be determined by the next equation

$$W \approx -kT_1 \ln \left(\frac{c_3^2}{N_1 N_2} \right) + kT_2 \ln \left(\frac{c_4^2}{N_1 N_2} \right) \quad (10)$$

However, compared with the case of the classical thermocouples, considered system has significant differences related to the fact that the balance of currents must be carried out for the charge carriers of both signs.

Namely, the balance equation of the currents is

$$I_1^+ = S_1 n_1^+ b e E_1 = I_2^+ = S_2 n_2^+ b e E_2 \quad (11)$$

$$I_1^- = -n_1^- b e E_1 = I_2^- = -n_2^- b e E_2 \quad (12)$$

Where $S_{1,2}$ – sections of 1 and 2 areas, $E_{1,2}$ – the electric fields, generated in these areas, cannot be valid together for any values of the electric fields. This can be verified directly by dividing Eq. (11) by Eq. (12).

Therefore, in considered system concentration gradients of low-molecular ions have to develop or additional currents should arise (however, these processes are interconnected).

Let's consider area Ω_1 , in which the field is directed from negatively charged (cation-exchange) grid to the positively charged grid (anion-exchange).

Carrying out integration of ions movement equations on this area, one can receive

$$S_{11} n_1^+ b e E_1 - S_{21} n_2^+ b e E_2 = \Delta I_1 \quad (13)$$

$$S_{21} n_2^- b e E_2 - S_{11} n_1^- b e E_1 = \Delta I_1 \quad (14)$$

Where S_1 and S_2 – effective areas of section of the current channel created by negatively and positively charged networks, ΔI_1 – measure of an imbalance for currents which can be connected, for example, with the fact that ions move from the Ω_1 area to the Ω_2 area (or inversely). In the case under consideration movement of ions from one area to another can take place just as it takes place in electrodialysis processes, i.e. cations move through a cation-exchange network, and anions – through anion-exchange one.

It is taken into account in the Eq. (13) and Eq. (14) that the measure of an imbalance for currents ΔI_1 has to be identical for both types of ions, which corresponds to the condition of neutrality implementation for areas Ω_1 and Ω_2 .

Signs in Eq. (13) and Eq. (14) correspond to the choice of the direction of a field in area Ω_1 : cations arrive in this area through the cation-exchange grid and are removed from it through anion-exchange one, and for anions it is vice versa.

For the Ω_2 area, in which the field is directed exactly the opposite, signs in the Eq. (13) and Eq. (14) should be changed to the opposite

$$-S_{11} n_1^+ b e E_1 + S_{21} n_2^+ b e E_2 = \Delta I_2 \quad (15)$$

$$-S_{21} n_2^- b e E_2 + S_{11} n_1^- b e E_1 = \Delta I_2 \quad (16)$$

This corresponds to the fact that in Ω_2 area positive ions derive from the region occupied by a positively charged grid and flow into the area occupied by the negative (for anions, respectively, it is vice versa).

Subtracting the equations (13) and (14) one from another, one can receive

$$S_1 (n_1^+ + n_1^-) b e E_1 - S_2 (n_2^+ + n_2^-) b e E_2 = 0 \quad (17)$$

References

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Result (17) can be interpreted as follows. Value $\frac{Snbe}{\Delta x}$ can

be considered as conductivity of the channel with section S , integrated concentration of low-molecular ions n and extension Δx . Consequently, (17) can be considered as expressing the formal Ohm's law in differential form (the constancy of the total current) for the electrical circuit that includes the area occupied by the networks of both signs. (In relation to total current it is necessary to speak about the formal law of Ohm because real values of the conductivity for ions of different characters are different).

Nevertheless, the ratio (17) can be used to find values of fields; it is enough to write it down in this form

$$\frac{S_i(n_i^+ + n_i^-)be}{\Delta l_i} E_i \Delta l_i = const; i = 1, 2, 3, 4 \quad (18)$$

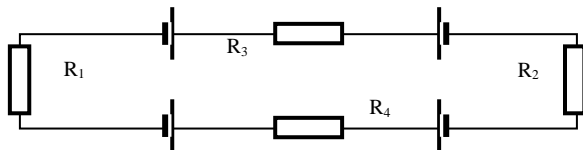


Figure 2. Equivalent circuit diagram of the heat dialyzer

Eq. (18) corresponds to the equivalent electric circuit presented in Fig. 2 and for an assessment it is possible to use a formula

$$R_i^{-1} = \frac{S_i(n_i^+ + n_i^-)be}{\Delta l_i} \quad (19)$$

Voltage sources on the equivalent scheme correspond to the double electric layers formed on surfaces of sewed grids. Using this scheme, it is possible to determine all interested parameters of system.

In particular, provided that density of functional groups in both grids significantly exceeds concentration of ions in surrounding solution, it is possible to receive the following result:

$$\Delta l_1 \approx \frac{W}{R_1 + R_2 + R_3 + R_4} \quad (20)$$

This result is essential: the formula (20) shows that practically all current proceeding through cation-exchange and anion-exchange grids is formed by ions "pumped" from 4 to 3.

III. Conclusion

Thus, the considered system is really functioning as a heat dialyzer, providing enrichment of solution for the low molecular weight component only by an external heat source, in which you can use solar radiation, utilizing, for example, the diagram of the solar collector for heating one of the solutions.