A phenomenological approach to optimize work of water desalting devices and technology of their creation. III

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We continue here discussion of the simple phenomenological approach / 1 / that allows to us to optimize work of water desalting devices and technology of their creation. In the framework of this approach, using the simplest equivalent electrical circuit, presented in Fig 1,
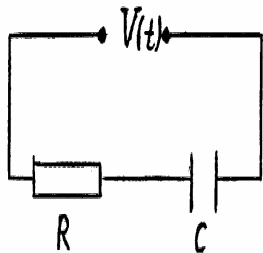

Fig. 1

we have considered optimization of such characteristics of device operation like the maximal productivity, the spent electrical power, and the maximal productivity per unit of the spent power for different shapes of applied voltage of device operation / 2 / and for specific one in the case of nonlinear inner medium of the device / 1 /. We have also considered complete optimization of device operation including in consideration a phenomenological material balance equation for the average concentration of ions that must be removed from water in water desalting devices / 3 /. However, in / 3 /, we have considered the phenomenological equation for very specific case of presence of selective ion membranes in the device. Here, we present the main formulae for optimization of device operation for the device that doesn't use selective ion membranes.

In / 1 /, we discussed a phenomenological material balance equation for the average concentration of ions that must be removed from water in water desalting devices. In the case of cylindrical symmetry of the device, this equation can be presented in the following form

$$\partial C(r, t)/\partial t - U_0 R_0/r \, (\partial C(r, t)/\partial r) = -$$
$$(1/(F\delta))\text{sign}(q(r, t)) \, j(r, t), \qquad (1)$$

where the working cell of the device is supposed containing the pair of parallel circular flat porous electrodes of the radius R_0 with a hole of the radius R_i in the middle in one of them. The water to be purified is injected in the inner space of the working cell through the external lateral cylindrical surface of this space with velocity U_0 and leave this space through the mentioned above hole. The water flow rate is $Q = U_0 \, 2\pi R_0 \, \delta$ where δ is the size of the inner space of the cell between the electrodes in direction perpendicular to the electrodes. The concentration of the ions to be removed in the injected water is C_0.

If we can neglect spatial dependence of the current density in the device ($j(r, t) = j(t)$), the solution of (1) can be written in the form

$$C(r, t) = C_0 - 1/(F\delta) \int_{t - \frac{R_0^2 - r^2}{2U_0 R_0}}^{t} \text{sign}(q(t)) \, j(t) \, dt, \qquad (2)$$

The concentration of the ions to be removed in the output pure water (at $r = R_i$) is

$$C(R_i, t) = C_0 - 1/(F\delta) \int_{t - t_{res}}^{t} \text{sign}(q(t)) \, j(t) \, dt, \qquad (3)$$

and can be considered as the result of extraction and injection of the ions along the whole path of the water inside the device during the residential time

$$t_{res} = ((R_0)^2 - (R_i)^2) / (2U_0 R_0).$$

The solution (2), (3) have very clear physical sense and optimization of productivity of desalting with application of these solutions gives useful conclusions.

Use of a material balance equation like the equation in (1) supposes that the equivalent electrical circuit for the device is one with distributed parameters. Nevertheless, if $j(r, t) = j(t)$, then for $j(t)$ in (2) we can use the approximate expression $I(t) / \pi R_0^2$ where $I(t)$ is the current for the electrical circuit presented in Fig. 1.

It is convenient to get the expression for the current in this circuit from the general solution for this circuit presented in the following form

$$q(t) = q(0) \exp(-t/RC) +$$
$$+ (\int_0^t dt' V(t')/R \exp(t'/RC)) \exp(-t/RC), \qquad (4)$$

In the case, when we can't neglect spatial heterogeneity of the current density in the device, the solution of (1) can be presented in the form

$$C(r, t) = C_0 - 1/(F\delta R_0 U_0) \int_r^{R_0} dx \, x \, \text{sign}(q(x, t +$$
$$+ (r^2 - x^2) / (2R_0 U_0))) \, j(x, t + (r^2 - x^2) /$$
$$(2R_0 U_0)), \qquad (5)$$

If spatial heterogeneity of $j(r, t)$ are not strong, we can look for $j(r, t)$ and $C(r, t)$ in the framework of perturbation theory, using for it (5) and, for example, experimental or theoretical dependence $j(r, t)$ on $C(r, t)$. As zero approximation, we can use in this case functions $j(t)$ and $C(r, t)$ that we got from formula (2) and (4).

However, because integration in (5) averages $j(r, t)$, we can suppose that even in the case of a strong spatial heterogeneity of $j(r, t)$, iteration procedure will converge rather quickly, and (2) gives a good approximation for $C(r, t)$ even in this case.

Acknowledgements

References
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