Technology for salt brines utilization on distant pastures in the arid zone of the Republic of Kazakhstan

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Abstract. The aim of the research is to develop technology for integrated treatment of surface, underground and mineralized waters, collected by drainage network contaminated by pollutants, to produce both water of the required quality and saturated brines. During experiments the main task was to select and reveal the optimum mode of desalination of initially mineralized ground water belonging to a certain type. The operation mode of reverse osmosis system was selected by gradual change of pressure and change of permeate and concentrate volume ratio (%), parameters of desalination regime change (flow rate, pressure, salt output) were recorded in time. The research was conducted in Zhambyl region, located in the southern part of the Republic of Kazakhstan in 2021. Each operation stage of changing desalination regime lasted for 50 hours, while non-stop work being performed. The tests of reverse osmosis system with natural ground waters of sulphate-chloride-sodium and sulphate-carbonate-sodium types revealed quite reliable and stable desalination regime under changing flow discharge and permeate and concentrate volumes ratios and multiple initial water concentrations. Application of the proposed technological scheme will allow providing the good quality drinking water for shepherd brigades on summer distant pastures and further utilization of salt brines (concentrated waste waters, remained after desalination) in a safe for the environment manner.

1 Introduction

The problem to obtain drinking water is global for mankind in the new millennium. Fresh water scarcity is acutely felt in over 40 countries in arid regions of the globe, which areas account for about 60% of the total land surface. World water consumption at the beginning of the 21st century reached 120 – $150 \cdot 10^9$ m^3 per year. The growing world deficit of fresh water can be offset by desalination of saline (salt content over 10 $g.l^{-1}$) and brackish (2-10 $g.l^{-1}$) ocean, sea and underground waters, which reserves amount to 98% of all water in the world. [1].

Some regions in Central Asia with the largest mineral resources do not have any fresh water sources. Meanwhile, a number of Kazakhstan regions have large reserves of groundwater with a total salinity of 1.0 to 35 $g.l^{-1}$, which are not used for water supply due to the high content of salts dissolved in the water. These waters can become a source for water supply provided that they are further desalinated [1-4].

During mineralized water desalination with the aim to provide population and animals with potable water, brines of maximum concentration are obtained, which are discharged into natural water reservoirs, ravines, causing harm for the environment. In rare cases the brines are discharged to evaporation sites, and the resulting salt of a multicomponent composition is utilized in burial grounds. Along with that, in Kazakhstan the commercial salt which complies with the requirements of standards is scarce. Low-quality lake salt is used in many areas and districts instead. Such salt has a high content of insoluble impurities (granite, marble, etc.), and its composition contains the salts of calcium, magnesium, iron, copper, lead in quantities exceeding the maximum permissible concentrations.

In this regard, it is necessary to revise the technological foundations for multi-purposed water desalination, i.e. obtaining water of drinking quality, utilizing the resulting brine and producing commercial salt and some types of fertilizers from it. Combining two issues such as desalination and obtaining commercial salt from discharged brines and regional salt deposits into one technological scheme is a fundamentally new task to solve water supply problem and to provide the population with iodized commercial salt.

2 Materials and methods

The electrodialysis desalination technology uses an electrodialysis desalination method on charge-selective sodium and chlorine membranes, which makes it possible to obtain a concentrate (brine) containing predominantly singly charged ions (NaCl) and desalinated water enriched with doubly charged ions ($CaS0_4$, $MgS0_4$). The obtained desalinated water, after being assessed for irrigation suitability, can be recycled for crop irrigation, while the brine after evaporation gives commercial salt [5-8].

The existing cationite method to reduce hardness before the desalination system requires a significant number of reagents to regenerate the filter load, along with that, a large amount of contaminated runoffs is formed after washing the load. The proposed method of preliminary hardness reduction on the dialysis system makes it possible to reduce the load on the cationite filters, use the brine concentrated on the electrodialysis system for the dialysis process, and direct a part of the brine and the runoffs from the cationite filters after treatment with bleach and in filter press to the regeneration of the cationite filters load [9].

The degree of water desalination and the effectiveness of the reverse osmosis membrane for water desalination depend on various factors, primarily on the total salinity of the initial water, as well as the salt composition of the desalinated water, the pressure, and the temperature. [10].

Nowadays electrodialysis (ED) is mainly used at industrial scale for the selective ion removal from aqueous solutions and for brackish water desalination [8]. Along with the technology of electrodialysis, such technologies as reverse and bipolar electrodialysis were widely studied in the last decade, moreover, new technologies using hybrid reverse electrodialysis were proposed [11].

During water desalination by reverse osmosis method the mineralized water is passed through semi-permeable membranes under the pressure which significantly exceeds the difference between fresh and sea water osmotic pressures [13-14].

Before the research the economic efficiency calculations for desalination water systems were made to determine the specific capital costs for water supply, according to the generally accepted method for electrodialysis, reverse osmosis and solar desalination systems (SDS) of the tray type.

The annual economic effect from the use of the systems is calculated according to the Guidelines "Economic efficiency calculation for research or research and development projects in melioration and water management field (Taraz, 2001, RGKP "KazNIIVH")" [15].

Capital cost indicators for various desalination types are shown in Table 1.

Table 1. The indicators of specific capital costs for various desalination types*

No.	Name	Unit	Unit cost, rub	Solar desalination system (SDS) (film)		Reverse osmosis system		Electrodialysis system	
				number	cost, rub.	number	cost, rub.	number	cost, rub.
1	Effectiveness	$m^3.day^{-1}$		2.0		2.0		2.0	
2	20-micron-thick polyethylene film	m^2	25	4,000	100,000	-	-	-	-
3	Steel frame construction	T	21,100	6.1	128,710	-	-	-	-
4	Aluminium construction	T	150,176	1.0	150,176	-	-	-	-
5	Asbestos-cement flat sheets	m^2	140	793.5	111,090	-	-	-	-
6	80-mm-thick Styrofoam sheets	m^2	117	520.6	60,840	-	-	-	-
7	Various sealants	Kg	193	20.0	3,860	-	-	-	-
	Total				554,676		877,193		789,474

Note*: The cost of the system elements as a whole can vary and depends on the changes in the market prices

Specific capital costs are determined by the formula:

$$k_c = \frac{\sum K}{Q_{year}}, \ rub.m^{-3} \qquad (1)$$

where: $\sum K$ – capital investments, rub; Q_{year} – annual drinking water volume, m^3/year, (2x365=730).

Specific capital costs are:
- for the SDS - $k_c = 762$ rub.m^{-3};
- for the reverse osmosis system - $k_c = 1202$ rub.m^{-3};
- for the electrodialysis system - $k_c = 1082$ rub.m^{-3}.

The laboratory studies revealed that the most economically efficient option is a solar desalination system (SDS). However, under the conditions of distant pastures, which are used only in summer, and with all the equipment enabling the watering point being transported to the base for winter storage, the use of SDS technology would be irrational.

Therefore, the most acceptable option, despite the higher specific indicators, is the use of a mobile reverse osmosis system. In this case, the amount of drinking water for the shepherd's brigades is desalinated by alternately bypassing the watering points and desalination on a mobile desalination system.

3 Research results and discussion

The technology is intended for the integrated treatment of surface, underground and mineralized waters, collected by drainage network, containing pesticides, herbicides, insecticides, fungicides, to obtain the water of required quality and saturated salt brines.

During the tests, the main task was to select and establish the optimal desalination regime for the initial underground mineralized water of a certain type. According to the test experience, the operation mode was selected by gradual change of pressure and change of permeate and concentrate volume ratio (%), parameters of desalination regime change (flow rate, pressure, salt output) were recorded in time. At the same time, the failures of specific system blocks and the technological scheme as a whole were registered, if they occurred. Each operation stage of changing desalination regime lasted for 50 hours, while non-stop work being performed.

The studies were carried out on waters with a salinity of 2.6 g.l^{-1}and 4.1 g.l^{-1}, which are similar in physical and chemical composition to the water intake facilities on the pilot plots of the farms "Senim" and "Urker" of the Zhambyl region in the Kazakhstan Republic.

The physical and chemical composition of the initial water (water intake No. 1 of the farm "Senim" is shown in Table 2.

Table 2. Initial water physical and chemical composition.

T°C	**pH**	**General hardness, mg-eq.l^{-1}**	**Ca^{++} mg.l^{-1}**	**Mg^{++} mg.l^{-1}**	**Na^{+} mg.l^{-1}**	**Cl^{-} mg.l^{-1}**	**SO^{--}_4 mg.l^{-1}**	**NO^{-}_3 mg.l^{-1}**	**CO^{-}_3 mg.l^{-1}**	**$\sum_{min}$ в-в mg.l^{-1}**
16	7.4	22.4	368	86	369	180	1,315	-	317	2,635

Table 3. The indicators for the test mode of the reverse osmosis module.

Initial water mineralization, C in, g.l^{-1}	**Operation time, hours.**	**Working pressure, P mPa**			**Flow rate Q, l.hour^{-1}**		**Mineralization C, g.l^{-1}**	
		at the entrance	**at the permeate outlet**	**at the brine outlet**	**permeate**	**brine**	**permeate**	**brine**
1	2	3	4	5	6	7	8	9
2.635	10	0.2	0.18	0.19	60	60	0.15	5.12
	20		0.18	0.19	60	60	0.15	5.12
	30		0.175	0.18	60	60	0.15	5.12
	40		0.18	0.19	60	60	0.15	5.12
	50		0.18	0.182	60	60	0.15	5.12
2.635	10	0.4	0.36	0.38	72	48	0.20	5.07
	20		0.36	0.38	72	48	0.20	5.07
	30		0.36	0.38	72	48	0.20	5.07
	40		0.36	0.38	72	48	0.20	5.07
	50		0.36	0.38	72	48	0.20	5.07
2.635	10	0.6	0.45	0.54	84	36	0.30	4.97
	20		0.45	0.54	84	36	0.30	4.97
	30		0.45	0.54	84	36	0.30	4.97
	40		0.45	0.54	84	36	0.30	4.97
	50		0.45	0.54	84	36	0.30	4.97
2.635	10	0.8	0.50	0.72	96	24	0.45	4.82
	20		0.50	0.72	96	24	0.45	4.82
	30		0.50	0.72	96	24	0.45	4.82
	40		0.50	0.72	96	24	0.45	4.82
	50		0.50	0.72	96	24	0.45	4.82
2.635	10	1.0	0.60	0.85	108	12	0.6	4.67
	20		0.60	0.85	108	12	0.6	4.67
	30		0.60	0.85	108	12	0.6	4.67
	40		0.60	0.85	108	12	0.6	4.67
	50		0.60	0.85	108	12	0.6	4.67

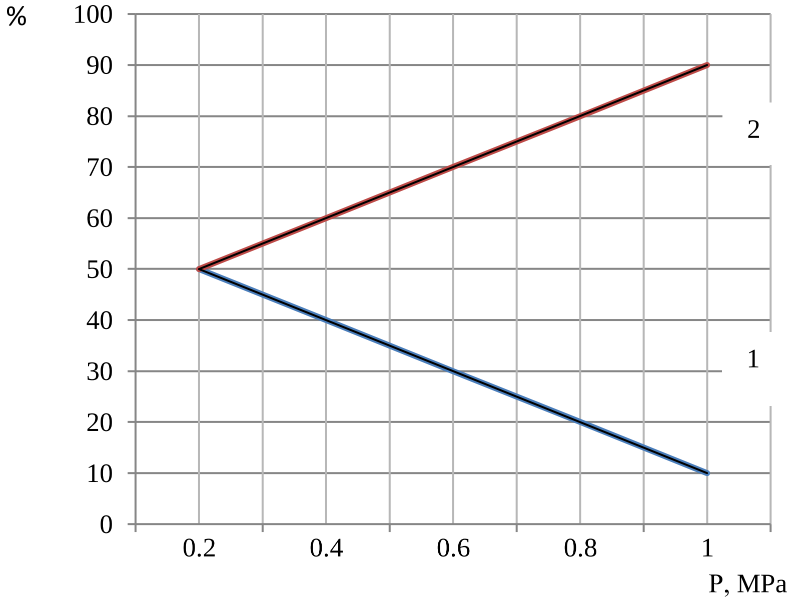
The indicators for the test mode of the reverse osmosis module are shown in Table 3. The physical and chemical composition of the desalinated water obtained at various pressures (P) on the reverse osmosis system, at the established permeate and brine flow rates, are shown in Table 4.

Based on the test data, one plotted the dependences on the volume ratio (%) of the obtained permeate and the discharged brine to the total volume of initial water, the changes in the permeate mineralization depending on pressure, the change in the system effectiveness (Q) under the generated pressure (P), which are shown in Figures 1, 2, 3.

Table 4. Physical and chemical composition of desalinated water.

P, mPa	**pH**	**General hardness, mg-eq.l^{-1}**	**Ca^{++} mg.l^{-1}**	**Mg^{++} mg.l^{-1}**	**Na^{+} mg.l^{-1}**	**Cl^{-} mg.l^{-1}**	**SO$^{--}_{4}$ mg.l^{-1}**	**NO$^{-}_{3}$ mg.l^{-1}**	**HCO$^{-}_{3}$ mg.l^{-1}**
1	2	3	4	5	6		8	9	10
0.2	7.3	7.2	21.08	0.07	0.080	-	128.85	-	
0.4	7.3	7.3	25.21	0.09	0.08	-	174.62	-	
0.6	7.3	7.5	34.30	0.2	0.12	-	265.4	-	
0.8	7.3	7.7	51.25	0.35	0.35	6.0	284.1	-	
1.0	7.0	8.0	81.50	0.51	0.92	7.10	510.09	-	

The tests of reverse osmosis system with natural ground waters of sulphate-chloride-sodium and sulphate-carbonate-sodium types revealed quite reliable and stable desalination regime under changing flow discharge and permeate and concentrate volume ratios and multiple initial water concentrations.



1 – brine, 2 - permeate

Fig. 1. Dependence of permeate and brine volume ratio (%).

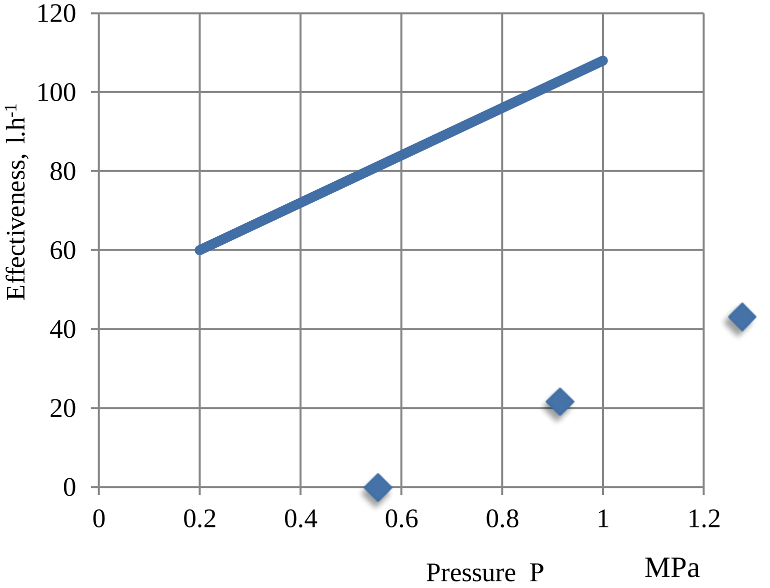


Fig. 2. Change in the reverse osmosis system effectiveness calculated for permeate depending on the system pressure.

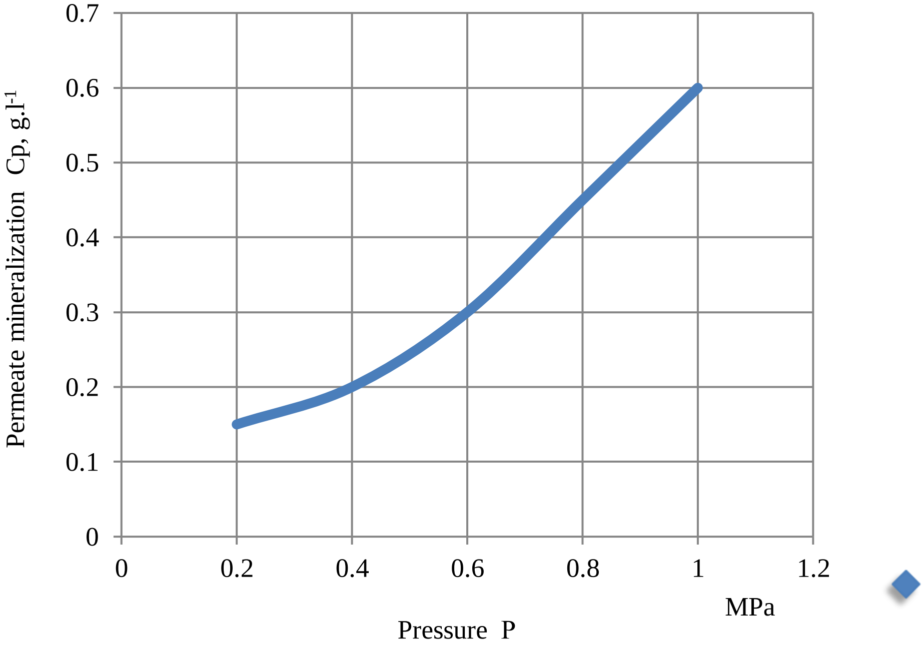
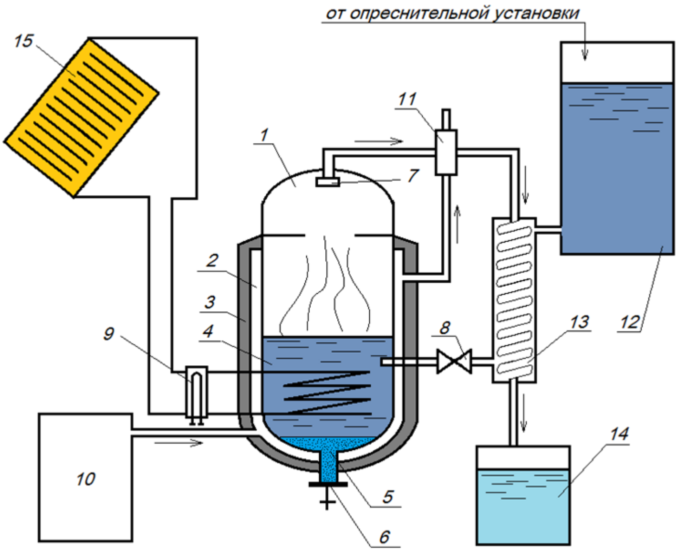


Fig. 3. Change in permeate mineralization.

With this equipment layout drinking-quality water enters a clean water tank while brine enters another one. The drinking water is drained into a tank (container) of clean water. The brine goes into a greenhouse-type solar evaporator, where it evaporates forming a distillate and precipitated salts.

The vacuum brine evaporator operates after water desalination (Figure 4) as follows: the initial brine is supplied from the desalination system to the storage tank (12) with a volume of 200 litters. From the accumulator tank through the condenser (13) (where it is partially heated) it goes through the dispenser (8) into the evaporation chamber of the vacuum evaporator (1). In the evaporation chamber it is heated by the solar water heater (15), the electric heater (9) and the exhaust gases (2), the brine is heated to 400-700 degrees Celsius from the electric generator (10).



1. Vacuum evaporator
2. Exhaust gases jacket
3. Insulation
4. Initial brine
5. Salt sediment
6. Hatch to unload sediment
7. Liquid trap
8. Initial brine dispenser
9. Electric heater
10. Electric generator
11. Ejector (Venturi tube)
12. Initial brine storage tank
13. Condenser
14. Distillate
15. Solar water heater

Fig. 4. Vacuum brine evaporator after water desalination.

The resulting steam is sucked off by the ejector (11), powered by the exhaust gases of the electric generator, by creating a vacuum in the evaporation chamber. The steam enters the condenser (13), where it is cooled by the initial brine. After passing through the condenser (13), it is converted into distillate and drained into the storage tank (14). After evaporation, a precipitate of salts is formed in the dry residue (5) and is unloaded through the receiving hatch (6).

The proposed technological scheme will allow providing shepherd brigades with good quality drinking water on summer distant pastures and further utilization of salt brines remained after desalination in a safe for the environment manner.

The number of drinking points enabled by the system depends on the road condition, the distance between the drinking points (travel time), and the operating time to obtain drinking water (producing time), which depends on the initial water salinity and the volume required for each point. To maintain several drinking points with one desalination system, which includes technological elements for brine utilization based on mobile evaporation sites, an equipment layout has been developed on a tractor trailer with a load capacity of up to 3 tons.

The system being developed can also be used in mass animal transportation along cattle routes to seasonal summer distant pastures, and in other arid zones of Kazakhstan.

4 Conclusion

Technical and economic comparisons have shown that for the conditions of pasture settlement water supply (insignificant daily volumes of water consumption) and the initial water salinity of 3-10%, it is advisable to use reverse osmosis systems, because their efficiency is higher in all respects than that of electrodialysis.

The reverse osmosis module has been tested in the labarotaries, which made it possible to establish the relation between the regime parameters: pressure and salinity, permeate and concentrate ratio, the values of specific indicators for capital investments and desalinated water cost.

With an increase in the initial water salinity from 3.5 to 7 g.l^{-1} and a corresponding increase in pressure, the permeate mineralization is within permissible limits (up to 1 g.l^{-1}), and the volume of desalinated water decreases over time by 2-5% (limit value 15 %).

A technological scheme of a mobile desalination system is proposed to use in summer remote pastures, including a brine utilization block.

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