DESALTER EFFICIENCY IN REMOVING SALTS FROM BRACKISH WATER IN PERNAMBUCO'S SEMI-ARID REGION

EFICIÊNCIA DE DESSALINIZADORES NA REMOÇÃO DE SAIS DE ÁGUA SALOBRA NO SEMIÁRIDO PERNAMBUCANO

EFICACIA DE LAS DESALINIZADORAS EN LA ELIMINACIÓN DE SALES DEL AGUA SALOBRE EN EL PERNAMBUCO SEMIÁRIDO

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ABSTRACT
Water scarcity is a problem in remote locations. The desalination of brackish underground sources through reverse osmosis (RO) is a solution for producing drinking water to meet the needs of the diffuse population. Therefore, the aim was to investigate the quality of desalinated water offered to the population of the municipalities of Cumaru and Riacho das Almas, located in Pernambuco's semi-arid region, through the amount of total dissolved solids (TDS) and electrical conductivity (EC). To this end, visits were made, and permeate and concentrated well water were collected from communities with desalination systems installed and in full use. The results show that 85% of the operating systems in these municipalities have salt removal efficiencies greater than 80%. It was also found that there is no specific minimum salt removal efficiency to achieve the potability of brackish water since the TDS concentrations of brackish sources vary. Thus, desalination systems that use the RO technique for salt removal are efficient for treating brackish water from artesian wells, provided that the equipment has periodic maintenance and presents good operating conditions.

KEYWORDS
Desalination; electrical conductivity; reverse osmosis.

RESUMO
A escassez de água é um problema em locais remotos. A dessalinização de fontes salobras subterrâneas, por meio de osmose reversa (OR), apresenta-se como uma solução para a produção de água potável a fim de atender a população difusade localidades difusas. Diante disso, objetivou-se investigar a qualidade da água dessalinizada ofertada à população dos municípios de Cumaru e Riacho das Almas, localizados no semiárido pernambucano, por meio da quantidade de sólidos totais dissolvidos (STD) e da condutividade elétrica (CE). Para isso, foram realizadas visitas e coletas de água do poço, do permeado e do concentrado nas comunidades que possuem sistemas de dessalinização instalados e que encontram-se em pleno uso. Como resultados, a maioria dos sistemas em funcionamento nesses municípios (85%) apresentam eficiência na remoção de sais superior a 80%. Verificou-se também que não existe uma eficiência

de remoção de sais mínima especifica para atingir a potabilidade da água salobra, visto que as concentrações de STD das fontes salobras é variável. Dessa forma, os sistemas de dessalinização que utilizam a técnica da OR na remoção de sais são eficientes para o tratamento de água salobra de poços artesianos, desde que os equipamentos tenham manutenções periódicas e apresentem boas condições de funcionamento.

PALAVRAS-CHAVE
Condutividade elétrica; dessalinização; osmose reversa.

RESUMEN
La escasez de agua es un problema en lugares remotos. La desalinización de fuentes de agua subterránea salobre mediante ósmosis inversa (OI) es una solución para la producción de agua potable destinada a la población de localidades difusas. Teniendo esto en cuenta, el objetivo fue investigar la calidad del agua desalinizada ofrecida a la población de los municipios de Cumaru y Riacho das Almas, localizados en la región semiárida de Pernambuco, por medio de la cantidad de sólidos disueltos totales (SDT) y conductividad eléctrica (CE). Para ello, se visitó y recogió agua de pozo, permeado y concentrado de las comunidades que tienen instalados sistemas de desalinización y que están en pleno uso. Los resultados muestran que el 85% de los sistemas en funcionamiento en estos municipios tienen una eficacia de eliminación de sales superior al 80%. También se comprobó que no existe una eficiencia mínima específica de eliminación de sales para alcanzar la potabilidad del agua salobre, ya que las concentraciones de ETS de las fuentes salobres varían.

PALABRAS CLAVE
Conductividad eléctrica; desalinización; osmosis inversa

1. INTRODUCTION

Despite a large number of freshwater sources in Brazil, its poor distribution aggravates a scenario of water scarcity that affects a large part of the population (MOREIRA et al., 2021) as happens in the Northeastern semi-arid region (CUNHA; PONTES, 2022). This has led the state to constantly seek measures to cope with this problem and guarantee access to water for the entire population. As defined by Law 9433, the National Water Resources Policy's (PNRH) objective is to ensure the availability of quality water for the present and future generations (BRASIL, 2017).

Several studies have pointed out that water scarcity has been one of the main causes of the occurrence of conflicts in remote locations and has forced the emigration of thousands of people from the areas affected by the problem (CASTRO, 2012; FILHO et al., 2022; REGAN; KIM, 2020). Improved water management and conservation are essential measures to combat its scarcity. However, additional interventions will be necessary, starting with using non-conventional water sources to increase freshwater supplies, which are getting smaller and smaller (PATEL et al., 2021).

In order to make water potable in locations where there is scarcity, as well as in the Brazilian semiarid region, the desalination process of underground brackish water sources has been a relevant tool (CUNHA; PONTES, 2022; ASHRAF et al., 2022). The desalination of saline and brackish waters has been a good alternative for producing drinking water in arid lands, such as the Brazilian semiarid, which encompasses 12% of the national territory and has water with a high content of dissolved salts due to its proximity to crystalline rock (CUNHA; PONTES, 2022). This technique, already widespread worldwide, accumulates desalination plants, producing from small daily flows to several million cubic meters per day, generating quality water for domestic and industrial purposes.

Reverse osmosis (RO), for example, is the technique that offers the most versatility for applications in which the salinity of the feed water varies considerably and it facilitates when different degrees of salt removal need to be achieved (PATEL et al., 2021). Therefore, it is an essential direction for efficient brackish water desalination.

Therefore, RO is one of the most widespread desalination techniques globally, accounting for over 80% of freshwater production from brackish water (JONES et al., 2019). Kabir et al. (2018) analyzed a brackish water reverse osmosis system in rural Bangladesh, where the groundwater had an average TDS of 7,500 ppm, with its salt content reduced to 100 ppm after the desalination process at the cost of $0.0022/liter. The authors state that reverse osmosis is the best water purification system in terms of cost and ease of maintenance.

Taha and Al'sead (2018) affirm that the efficiency of RO has improved over the years with the development of new low-cost membranes, the use of energy recovery devices, and the use of improved membranes, among other methods that have allowed the technique to evolve. Almeida et al. (2020) developed a pilot project of brackish water desalination in Paraná (Brazil) from the mixture of raw water from the Pombas River with seawater until it reached a concentration of total dissolved solids (TDS) of 1500 ± 100 mg L-1. The researchers performed desalination by RO, with ultrafiltration and softening as pretreatment. The results proved that pretreatment could not remove TDS or electrical conductivity, but reverse osmosis reduced TDS and conductivity with 99% efficiency.

The government authorities, whose function is to guarantee society access to its rights provided by law (BRASIL, 2017), have applied methods to either supply the need for access to water by this population or to alleviate the suffering caused by the environmental water shortage in semi-arid areas. One of the methods adopted is the desalination of brackish waters, found in underground sources with mineral properties that make them unsuitable for human use (LI et al., 2023).

Brazilian water potability parameters are governed by national legislation, Ordinance No. 5 of September 28, 2017, which deals with the consolidation of standards on health actions and services of the Unified Health System (BRASIL, 2017), and Resolution No. 357 deals with the framing of water bodies based on this legislation (CONAMA, 2005). In this resolution, "saltwater" is defined as containing salinity greater than 30‰. For brackish water, salinity values are between 30 and 0.5‰, and for freshwater, these values must be less than 0.5‰. Thus, Brazilian legislation is as restrictive as the Environmental Protection Agency of the United States of America (USA), which stipulates a threshold of total dissolved solids (TDS) of 500 mg L-1. However, contrary to North American legislation, the Brazilian Ministry of Health stipulated that the maximum allowed value of total dissolved solids in water should be 1000 mg L-1, showing that the management of water resources in the country is still incipient (BRASIL, 2017).

Authors such as Stanton and Dennehy (2017) state that it is common for various supplies to exceed this limit, but that water with a TDS greater than 1,000 mg L-1 is not desirable for human consumption as it can have a bitter, salty, or metallic taste, as well as an unpleasant smell, and can even be toxic.

Given the above, it is possible to observe that great application has been given to desalination systems using the reverse osmosis technique throughout the world and in the local context of the Brazilian semiarid region. Thus, the objective was to analyze the operation of desalination systems in the municipalities of Cumaru and Riacho das Almas to determine the efficiency of removing salts from underground brackish water.

2. METHODOLOGY

2.1. Location

The visits to desalination systems operating in Pernambuco were conducted in the municipalities of Cumaru and Riacho das Almas. These municipalities were chosen due to the amount of equipment installed, as well as the receptiveness of the municipal managers, who facilitated access to the systems. The visits began after a partnership was established with the Secretary of Infrastructure of the State of Pernambuco (SEINFRA) and the State Secretary of Water Resources (SERH), through registered requests sent to the municipal governments of Cumaru (No. 350/2020-SERH/PERNA) and Riacho das Almas (No. 349/2020-SERH/PERNA), Figure 1.

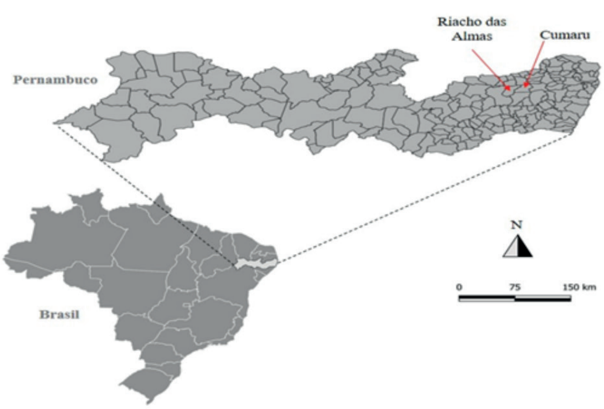

Figure 01: Location Cumaru and Riacho das Almas in PE.
Source: Authors.

The first municipality, Cumaru, has a land area of 292.2 km², an estimated population of 10,192 inhabitants, and is approximately 90 km from Recife, the capital of the state of Pernambuco (IBGE, 2021). The second municipality, Riacho das Almas, neighboring Cumaru on the west side, has 314.0 km² of land area and an estimated population of 20,646 people, according to IBGE estimates (IBGE, 2021). Both municipalities are in the semi-arid mesoregion of Pernambuco and have the Caatinga as a distinct biome and a climate of type As, according to the Köppen classification.

2.2. Collection and analysis

Between January 27 and 29, 2021, the places with desalination systems present in communities located in the municipality of Cumaru were visited, and between January 25 and February 4, 2021, the visits to communities belonging to the municipality of Riacho das Almas took place. In both, the visits were accompanied by an official of the local municipality.

In the communities with desalination systems in operation, four in Cumaru and 11 in Riacho das Almas, water was collected before and after undergoing the desalination process (named well and permeate, respectively), as well as the wastewater discharged after desalination, which contains high levels of salts (concentrate). This collection was performed in small 300 ml PET bottles, properly identified with the contents' locality code, name, and designation.

The water samples were transported to the Soil Physics Laboratory of the Department of Nuclear Energy (DEN) of the Federal University of Pernambuco (UFPE), where the analyses of electrical conductivity (EC) and total dissolved solids content (TDS) were performed. Six water samples were collected from each desalination system; three before the desalination process and three after. The analyses followed the standards stipulated by the Manual of Procedures and Laboratory Techniques for Analysis of Sanitary and Industrial Water and Sewage of the Polytechnic School of the University of São Paulo (USP, 2004).

From the conductivity and TDS data, the calculation of salt removal efficiency was performed, as proposed by Lopes (LOPES, 2018). Besides the salt removal percentage for EC, equation (1), the ratio between the TDS of the water resulting from desalination and the water contained in the artesian well was calculated, as clarified in equation (2). This measure was found to verify how close the efficiency values are to the two parameters and check the existence of a discrepancy in using one or the other type of data.

$$E_{EC} = \left(1 - \frac{EC_{permeate}}{EC_{well}}\right) \times 100 \quad (1)$$

$$E_{TDS} = (1 - \frac{TDS_{permeate}}{TDS_{well}}) \times 100 \quad (2)$$

Where: EEC and ETDS are the percentages of salt removal efficiency by EC and TDS, respectively; ECpermeate and TDSpermeate are the electrical conductivity of water samples from the desalter (dS m-1) and the amount of total dissolved solids of the permeate water sample from the desalter (mg L-1), respectively; ECWell and TDSWell are the electrical conductivity of the water sample taken from the locality well (dS m-1) and the amount of total dissolved solids of the water sample taken from the locality well (mg L-1).

In cases where desalination was not enough to reach the level of potability for human consumption, a calculation was made to simulate the second desalination using the system's current efficiency, equation (3). This calculation was made to verify whether, under the current conditions of the local desalination system, the second desalination of the water would be sufficient to make it potable and safe to be consumed by the population.

$$TDS_{double\ permeate} = STD_{permeate} - \left(\frac{E \times TDS_{permeate}}{100}\right) \quad (3)$$

Where: TDSdouble permeate represents the amount of total dissolved solids in the water from the second desalination process (mg L-1); STDpermeate is the amount of total dissolved solids in the water sample from the first desalination process (mg L-1); and E represents the salt removal efficiency, in percent.

Finally, the minimum efficiency to reach 1,000 mg L-1 (proposed by the Brazilian Ministry of Health) was found in the same places where the desalination system produced water with TDS amounts above this limit after a single desalination process. The equation (4) illustrates how this minimum efficiency necessary to achieve potability was simulated with the original data from field samples.

$$E_{nec} = \frac{TDS_{well} - 1000}{TDS_{well}} \times 100 \quad (4)$$

Where: Enec is the minimum efficiency required to reach 1,000 mg L-1, in percent; TDSWell represents the amount of total dissolved solids in the water sample from the local well, in mg L-1.

2.3. Results and discussion

From the collection and analysis of water samples, it is possible to see how the quality of desalinated water produced by desalination systems installed in communities in the municipality of Riacho das Almas and Cumaru, located in the state of Pernambuco, is. The EC of a sample can quantify the potential capacity of the solution to transfer electrical charges so that the more salts there are in a solution, the higher its potential. Table 1 shows the EC data for the samples.

Municipality	Locality	EC (dS m^{-1})		
		Well	Permeate	Concentrated
Riacho das Almas	Sítio Chambá	11.610	1.137	16.280
	Sítio Trapiá	5.670	0.758	6.990
	Pau Ferro	8.900	0.269	9.920
	Pau Ferro 2	9.570	0.588	10.040
	Centro-Nova Esperança	3.000	0.567	4.030
	Pinhões	10.860	0.367	11.550
	Camorim 2	12.090	2.080	12.590
	Sítio Ramada	5.170	1.195	8.430
	Vila Nova	16.350	6.240	18.600
	Sítio Caldeirão	12.470	9.850	16.780
	Sítio Salinas	3.520	0.181	5.340
Cumaru	Assentamento Gavião	6.690	0.111	8.950
	Água doce de cima	5.000	0.148	6.810
	Campos Novos	16.240	1.135	21.100
	Poço de pedra	9.110	1.022	11.690

Table 01: EC of water samples from the localities.
Source: Authors.

By means of Table 01, it is possible to observe the difference between the EC values for the different water samples of the locations. Moreover, it is also noted a reduction in the EC of the raw water available in underground sources (well) for the permeate and an increase when related to water with a higher concentration of salts (concentrate), which is rarely reused for consumption.

However, the observation of these isolated data does not provide information about the quality of the water produced by the desalter, besides not informing which dissolved salts are in higher or lower concentration, increasing or decreasing the capacity of electrical conduction. Moreover, despite the drastic reduction in conductivity values observed after the desalination process, seven of the fifteen samples analyzed showed that the EC values exceeded 1 dS m-1, the average Nunes et al. (2022) observed when analyzing the EC of groundwater in Brazilian semiarid regions. This indicates that these seven water samples have moderate salinity concentrations, even after desalination.

The amount of TDS followed the pattern of the EC data, with a higher concentration for the concentrate samples, followed by the well water, and a lower concentration for the permeate samples, confirming the efficiency of the treatment. The TDS results obtained for the samples collected in each of the localities with desalination equipment visited are shown in Table 02.

The data analysis in Table 02 confirms that the water quality in all the wells analyzed where a desalter was installed is brackish (STD above 1000 mg L-1), according to the classification used by Brazilian Ministry of Health. This classification states that when the STD values are below 1000 mg L-1, the water is fresh; between 1000 and 30000 mg L-1, it is brackish; and above 30000 mg L-1, it is considered salty. Prior analysis of the locality for installing a desalter relies on

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the quality of the well water, which for the referred cases, confirmed the need for a desalination system to improve the quality of the water available in the underground sources of these localities.

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Regarding the water treated by the desalter for consumption by the population, only eight out of the 15 localities had access to water in potable conditions for human use, based on the maximum TDS value of 1,000 mg L-1, which is the Maximum Allowable Value (MPV) for human consumption according to the Ministry of Health (BRASIL, 2017).

However, considering Resolution No. 357 (CONAMA, 2005) to analyze the freshwater parameters, only five locations presented desalinated water with a concentration below 500 mg L-1. The same is true for compliance with North American standards. The TDS values for the systems outside the potability standard are well below the TDS values for well water from these locations. However, salt removal is notable for these systems but was still insufficient to generate quality water for the population.

The concentrate, which is also a product of desalination but with a high salt concentration, is more concentrated than the raw water (from the well) that is introduced into the system, which can negatively impact the environment (NUNES et al., 2022). Nonetheless, despite having a higher salt content, the analyzed concentrate is still considered brackish, according to Silveira et al. (2015). Moreover, this waste generated by the desalination process has been used in many communities in the Brazilian semiarid region

Municipality	Locality	TDS (mg L^{-1})			Classification Silveira et al. (2015)		
		Well	Permeate	Concentrated	Well	Permeate	Concentrated
Riacho das Almas	Sítio Chambá	11870	1098	17190	Mod. brack.	Slight. brack.	Heav. brack.
	Sítio Trapiá	4877	728	5464	Slight. brack.	freshwater	Mod. brack.
	Pau Ferro	4587	475	5879	Slight. brack.	freshwater	Mod. brack.
	Pau Ferro 2	7221	910	7877	Mod. brack.	freshwater	Mod. brack.
	Centro-Nova Esperança	2302	442	3279	Slight. brack.	freshwater	Slight. brack.
	Pinhões	6890	1181	10780	Mod. brack.	Slight. Brack.	Mod. brack.
	Camorim 2	9629	1638	10820	Mod. brack.	Slight. Brack.	Mod. brack.
	Sítio Ramada	3463	635	3638	Slight. Brack.	freshwater	Slight. brack.
	Vila Nova	4689	3998	10745	Slight. Brack.	Slight. brack.	Mod. brack.
	Sítio Caldeirão	10757	6273	12685	Mod. brack.	Mod. brack.	Mod. brack.
	Sítio Salinas	2543	1030	3303	Slight. brack.	Slight. brack.	Slight. brack.
Cumaru	Assentamento Gavião	2220	385	6432	Slight. brack.	freshwater	Mod. brack.
	Água doce de cima	3005	357	4360	Slight. brack.	freshwater	Slight. brack.
	Campos Novos	10824	1221	14579	Mod. brack.	Slight. brack.	Mod. brack.
	Poço de pedra	5214	251	7380	Mod. brack.	freshwater	Mod. brack.

Table 02: Total Dissolved Solids (TDS) of the water samples collected at the locations.
Source: Authors.

to produce tilapia (DARRE; TOOR, 2018).

It should be considered that the water collection from these systems occurred when the systems' maintenance was impaired due to the paralysis of services performed by public agencies because of the COVID-19 Pandemic. Nevertheless, even during this period, and especially therein (due to the redoubled hygiene care), the population in these and other communities had an even greater need for good quality water, corroborating what was said by Rodrigues et al. (2022).

However, in the seven communities where the permeate contained a concentration of TDS above 1,000 mg L-1, the population has inadvertently employed this product in noble activities, such as human and animal consumption and food preparation, because, although the desalinators in these communities considerably reduced the amount of salt in the well water, the permeate produced in these locations does not present the minimum quality for human consumption, as recommended by the standards and health authorities in Brazil.

This deficiency in salt removal may be related mainly to the quality and time of use of semipermeable membranes since they are mainly responsible for removing salts from water in reverse osmosis desalination (ABEDI et al., 2022; LEON et al., 2021). The absence or low frequency of maintenance and service poor quality may also be related to the low efficiency of the systems and, consequently, the low quality of the water produced by these systems. These salt removal efficiencies analyzed as a function of the ratio between permeate and well water (Tables 1 and 2) based on EC values and TDS concentrations are presented in Table 03.

Municipality	Locality	TDS Efficiency (%)	EC Efficiency (%)
Riacho das Almas	Sítio Chambá	90.75	90.21
	Sítio Trapiá	85.07	86.63
	Pau Ferro	89.64	96.98
	Pau Ferro 2	87.40	93.86
	Centro-Nove Esperança	80.80	81.10
	Pinhões	82.86	96.62
	Camorim 2	82.99	82.80
	Sítio Ramada	81.66	76.89
	Vila Nova	14.74	61.83
	Sítio Caldeirão	41.68	21.01
	Sítio Salinas	59.50	94.86
Cumaru	Assentamento Gavião	82.66	98.34
	Água doce de cima	88.12	97.03
	Campos Novos	88.72	93.01
	Poço de pedra	95.19	88.78

Table 03: Efficiency in salt removal.
Source: Authors.

When comparing the salt removal efficiency (Table 03) with the gross value of the STD concentrations of the permeate (Table 02), it is possible to realize that a large percentage in the removal of salts does not necessarily imply the ideal quality of permeate water for human consumption. In Sítio Chambá, for example, the TDS efficiency was higher than 90%. However, the permeate water still has a TDS of more than 1,000 mg L-1. At the Centro-Nova Esperança site, in turn, an 80% removal efficiency of total dissolved solids generated permeates water with TDS values below 500 mg L-1. Nevertheless, the comparison of efficiencies calculated from EC and TDS shows that the values obtained by EC are, in most communities, higher than those obtained with TDS.

Moreover, only one of the desalters in Vila Nova that had well water salinity below 8,000 mg L-1 did not show efficiency higher than 80% of one of the two calculated options, EC and TDS. This equipment, in turn, had a much lower efficiency than the others, indicating problems with the proper functioning of the system, which may range from the need to change filters to the integrity of the semi-permeable membranes responsible for removing salts from the solution (LEON et al., 2021).

However, salt removal efficiency can serve as a measure of water quality, provided that the well content has a salinity that, depending on the efficiency, produces a permeate with TDS amounts below the MPV of 1,000 mg L-1. For example, for well-water with TDS up to 10,000 mg L-1, a salt removal efficiency of 90% describes the water salt concentration within the MPV.

One solution that can be applied at sites where the TDS concentrations of the permeate are higher than recommended is to subject this permeate water to a new desalination process. Considering that the efficiency of salt removal from the desalter is not affected by the number of salts present in the system's feed water, new desalination in waters that remained with high concentrations of TDS after the first desalination with the same efficiency would be sufficient to bring the water within the proper parameters of potability stipulated by the Ministry of Health of Brazil.

However, a second desalination process implies double the energy required for desalinating these permeate with high TDS content, which represents extra costs to the process. However, despite being a region with low annual rainfall averages and high insolation rates, the Brazilian semiarid region has a great potential for solar energy generation with photovoltaic cells (ALMEIDA; ALMEIDA, 2021; HAGUENAUER, 2021). In this way, it can be observed that

Municipality	Locality	TDS of the first permeate (mg L-1)	TDS efficiency of the system (%)	TDS of the second permeate (mg L-1)
Riacho das Almas	Sítio Chambá	1098	90.75	102
	Pinhões	1181	82.86	202
	Camorim 2	1638	82.99	279
	Vila Nova	3998	14.74	3409
	Sítio Caldeirão	6273	41.68	3658
Cumaru	Campos Novos	1221	88.72	138

Table 04: TDS of permeate after second desalination.
Source: Authors.

the investment in the installation of photovoltaic systems is an asset that reduces the cost of electricity and contributes to the sustainability of the environment (ALMEIDA; ALMEIDA, 2021).

Table 04, containing the amount of TDS in the permeate waters after new desalination, was created to illustrate how much a second desalination cycle could improve the TDS concentrations of the permeate in communities where the values were above 1000 mg L-1. For this, the efficiency percentage obtained based on the TDS values from the first desalination was considered. In addition, the second desalination considered that the values of the concentrations of total dissolved solids are equal to those of the permeate generated in the first feed cycle of the desalination system, instead of the well water, as in the first phase of the process.

For systems with satisfactory salt removal efficiency above 80%, the second desalination is efficient in making the permeate potable, generating TDS concentrations of the final product well below the MPV and even within the freshwater standard framed by Resolution No. 357 of CONAMA and the Environmental Protection Agency of the EUA (500 mg L-1). However, the two sites with salt removal performance below 50% would not obtain the desired minimum salinity even after the second desalination of the permeate, keeping the TDS values well above the maximum stipulated for consumption.

Therefore, to reduce the TDS concentrations of the permeate to values below 1,000 mg L-1 after this second desalination cycle, a minimum salt removal efficiency of 75% would be necessary for Vila Nova and 84.06% for Sitio Caldeirão. Another way to reach the minimum necessary parameters stipulated by the regulatory agencies in Brazil would be to improve the desalination system to achieve higher efficiencies with a single desalination cycle. Thus, Table 05 presents the minimum efficiency for the systems listed in Table 4 to reach a threshold TDS concentration of 1,000 mg L-1.

Thus, if there were more efficiency in the equipment that does not currently play its role optimally so that the percentages and efficiency reached those stipulated in Table 05, it would be possible to generate drinking water for noble purposes, such as human and animal consumption and food preparation. For all 15 systems currently operating to reach the maximum TDS for classification as freshwater of 500 mg L-1, according to the CONAMA standards, the minimum efficiencies shown in Table 06 would be necessary.

Municipality	Locality	Minimum efficiency (%)
Riacho das Almas	Sítio Chambá	91.58
	Pinhões	85.49
	Camorim 2	74.99
	Vila Nova	78.67
	Sítio Caldeirão	90.70
Cumaru	Campos Novos	90.76

Table 05: Minimum efficiency to reach 1,000mg L^{-1} in STD.
Source: Authors.

Municipality	Locality	Minimum efficiency for 500 mg L^{-1} (%)
Riacho das Almas	Sítio Chambá	95.79
	Sítio Trapiá	89.75
	Pau Ferro	89.10
	Pau Ferro 2	93.08
	Centro-Nova Esperança	78.28
	Pinhões	92.74
	Camorim 2	94.81
	Sítio Ramada	85.56
	Vila Nova	89.34
	Sítio Caldeirão	95.35
	Sítio Salinas	80.34
Cumaru	Assentamento Gavião	77.48
	Agua doce de cima	83.36
	Campos Novos	95.38
	Poço de pedra	90.41

Table 05: Minimum efficiency to reach TDS of 500 mg L^{-1}.
Source: Authors.

Thus, it is necessary to repair and improve these desalters to make them more efficient in removing salts from the brackish water of wells in communities located in the semiarid region of Pernambuco. These improvements would benefit the population living in the dispersed localities of the states encompassed by the Brazilian semiarid region.

Among the various social needs, including water use and human and animal consumption are the priorities. The dispersed communities in the Brazilian semi-arid region have great difficulty accessing water, regardless of its quality. This difficulty is amplified when accessing water suitable for human consumption (AMARAL; NAVONI, 2023).

Desalination has benefited hundreds of communities in the Brazilian semi-arid region, enabling access to potable water for human consumption. Fifteen desalination plants were in full operation in Pernambuco at the beginning of 2021, treating brackish water from wells in the municipalities of Riacho das Almas and Cumaru. The results of the present study confirm the brackish condition of the water from wells in these municipalities, ranging from slightly to moderately brackish.

3. CONCLUSION

The electrical conductivity is a useful parameter in identifying the presence of salts in water and allows their quantification since there is a proportionality between the numbers of total dissolved solids present in an EC sample. However, it is not sufficient to determine the potability of a water sample unless the relationship between the EC of the salts present in the sample and the salinity it represents in mg L-1 is known. The estimation of salt removal is more reliable if performed from the TDS data of brackish source water and permeates.

In addition, the repeated desalination of already permeate water can further reduce the number of dissolved salts. However, this procedure tends to increase the desalination costs since it requires more electricity to produce quality water and maintenance for the equipment, with early replacement of the membranes. However, investment in frequent maintenance of the systems will likely enable them to produce a permeate of the same quality obtained through a second desalination cycle, thus guaranteeing removal efficiency for a longer period.

Improved equipment maintenance can potentially increase the quality of water offered by systems that currently do not reduce the TDS of the permeate water to at least 1,000 mg L-1.

Furthermore, preventive maintenance not only reduces the cost of desalination but also ensures the proper functioning of the equipment, increasing its life span.

REFERENCES

Abedi, M. S.; Hashemi, S. H.; Fazeli, M. 2022. Feasibility of Increasing Water Recovery of Inland Reverse Osmosis Systems and the Use of Reject Brine. **Arabian Journal for Science and Engineering**, v. 47, p. 6525-6534.

Almeida, J. P.; Kummer, A. C. B.; Carranza, G.; Campos, L. C.; Széliga, M. R.; Acevedo, M.; Gevarsoni, R.; Wiecheteck, G. K. 2020. Eficiência de um sistema piloto de dessalinização de água salobra. **Engenharia Sanitaria e Ambiental**, n.25, p. 107-114.

Almeida, H. A.; Almeida, E. C. V. 2022. Potential of photovoltaic solar energy in the northeastern semi-arid region. **Lium Concilium**, v. 22, p. 198-210.

Amaral, K. D. S.; Navoni, J. A. 2023. Desalination in rural communities of the Brazilian semi-arid region: Potential use of brackish concentrate in local productive activities. **Process Safety and Environmental Protection**, v. 169, p. 61-70.

Ashraf, H. M.; Al-Sobhi, S. A.; El-Naas, M. H. 2022. Mapping the desalination journal: A systematic bibliometric study over 54 years. **Desalination**, n. 526, p. 1-17.

Brasil, Ministério da Saúde. Portaria de Consolidação nº 5, de 28 de setembro de 2017: Consolidação das normas sobre as ações e os serviços de saúde do Sistema Único de Saúde, **Anexo XX**, p. 454.

Castro, C. N. 2012. **Gestão das águas: experiências internacional e brasileira**, Instituto de Pesquisa Econômica Aplicada (IPEA), Brasília.

Conselho Nacional De Meio Ambiente(CONAMA), **Resolução CONAMA n° 357, de 17 de março de 2005**, Dispõe sobre a classificação dos corpos de água e diretrizes ambientais para o seu enquadramento, bem como estabelece as condições e padrões de lançamento de efluentes, e dá outras providências, Brasília: Diário Oficial da União, 18 de março de 2005.

Cunha, D. P. S.; Pontes, K. V. 2022. Desalination plant integrated with solar thermal energy: A case study for the Brazilian semi-arid. **Journal of Cleaner Production**, v. 310, p. 1-11.

Darre, N. C.; Toor, G. S. 2018. Desalination of Water: a Review. **Current Pollution Reports**, n. 4, p. 104-1011.

Filho, W. L.; Totin, E.; Franke, J. A.; Andrew, S. M.; Abubakar, I. R.; Azadi, H.; Nunn, P. D.; Ouweneel, B.; Williams, P. A.; Simpson, N. P. 2022. Understanding responses to climate-related water scarcity in Africa. **Science of The Total Environment**, v. 806, p. 1-18.

Haguenauer, G. M. 2021. **Fontes renováveis de energia no processo de dessalinização para o abastecimento hídrico em zonas rurais vulneráveis do semiárido brasileiro**. 2021, 143p. Tese (Doutorado em Planejamento Energético) - Universidade federal do Rio de Janeiro, Rio de Janeiro.

Instituto Brasileiro de Geografia e Estatística, Cidades (**IBGE**). Available at: https://cidades.ibge.gov.br/ (Accessed on: 24th August 2021).

Jones, E.; Qadir, M.; Van Vliet, M. T. H.; Smakhtin, V.; Kang, S. 2019. The state of desalination and brine production: A global outlook. **Science of The Total Environment**, v. 657, p. 1343-1356.

Kabir, K. M.; Matin, M. A.; Misran, H.; Amin, N. 2018. Solar photovoltaic assisted cost-efficient brackish water purification system. In: 2018 4th International Conference on Electrical Engineering and Information & Communication Technology (iCEEiCT). **IEEE**, pp. 510-513.

Li, Y.; Thomas, E. T.; Molina, M. H..; Mann, S.; Walker, W. S.; Lind, M. L.; Perreault, F. 2023. Desalination by membrane pervaporation: A review. **Dessalination**, v. 547, p. 1-14.

Leon, F.; Vaswani, A. R.; Mendieta, J.; Brito, C. S. 2021. Climate Change Mitigation Strategy through Membranes Replacement and Determination Methodology of Carbon Footprint in Reverse Osmosis RO Desalination Plants for Islands and Isolated Territories. **Water**, v. 13, p. 1-17.

Lopes, T. M. N. 2018. **Caracterização experimental de um dessalinizador de água por membrana polimérica**, Trabalho de Conclusão de Curso (Graduação), 2018, Universidade Federal do Rio de Janeiro, Rio de Janeiro.

Moreira, F. S.; Lopes, M. P. C.; Freitas, M. A. V.; Antunes, A. M. D. 2021. Future scenarios for the development of the desalination industry in contexts of water scarcity: A Brazilian case study. **Technological Forecasting and Social Change**, v. 167, p. 1-9.

Nunes, K. G.; Raimundo N. T. Costa, R. N. T.; Cavalcante, I. N.; Gondim, R. S.; Lima, S. C. R. V.; Mateos, L. 2022. Groundwater resources for agricultural purposes in the Brazilian semi-arid region. **Revista Brasileira de Engenharia Agrícola e Ambiental**, v. 26, p. 915-923.

Patel, S. K.; Biesheuvel, P. M.; Elimelech, M. 2021. Energy Consumption of Brackish Water Desalination: Identifying the Sweet Spots for Electrodialysis and Reverse Osmosis. **ACS ES&T Engineering**, n. 1, p. 851-864.

Petersen, K. L.; Paytan, A.; Rahav, E.; Levy, O.; Silverman, J.; Barzel, O.; Potts, D.; Bar-Zeev, E. 2018. Impact of brine and antiscalants on reef-building corals in the Gulf of Aqaba – Potential effects from desalination plants. **Water Research**, n. 144, p. 183-191.

Regan, P. M.; Kim, H. 2020. Water scarcity, climate adaptation, and armed conflict: insights from Africa. **Regional Environmental Change**, n. 20, p. 1-14.

Rodrigues, E. A. M.; Coutinho, A. P.; Souza, J. D. S.; Costa, I. R. A.; Neto, S. M. S.; Antonino, A. C. D. 2022. **Rural Sanitation: Scenarios and Public Policies for the Brazilian Semi-Arid Region. Sustainability**, v. 14, p. 1-18.

Silveira, A. P. P.; Nuvolari, A.; Degasperi, F. T.; Firsoff, W. 2015. **Dessalinização de Águas**, São Paulo: Oficina de texto.

Stanton, J. S.; Dennehy, K. F. 2017. **Brackish groundwater and its potential to augment freshwater supplies**, US Department of the Interior, US Geological Survey.

Taha, M.; Al-Sa'Ed, R. 2018. Application potential of small--scale solar desalination for brackish water in the Jordan Valley, Palestine. **International Journal of Environmental Studies**, v. 75, p.214-225.

Universidade De São Paulo (USP), **Manual de procedimentos e técnicas laboratoriais voltado para análises de águas e esgotos sanitário e industrial**. São Paulo: Universidade de São Paulo, 2004. Available at: https://7e0ac9a3-5d91-4907-a147583b32e00e48.filesusr.com/

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