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Renewable Energy Powered Membrane Process for Removal of Excess Fluoride Ions and Safe Drinking Water Supply in Rural Areas in Senegal

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Abstract: The analysis results made on drinking water from the rural areas of Kaolack, Diourbel and Fatick central region of Senegal showed the excess of fluoride and chloride ions. Depending on the area, the fluoride concentration in the water can reach 3.5 mg/L. The values obtained are completely above of WHO (World Health Organization) limits. The objective of this study is to assess the performances of membrane filtration units powered by renewable energies for fluoride and salinity excess removal in remote village in Senegal. Many membrane filtration units have been installed in rural areas of regions such as Kaolack, Fatick and Diourbel. These membrane filtration units are equipped by the LPRO (Low Pressure Reverse Osmosis) membranes with 9 m^2 of surface. A rejection rate of fluoride and chloride ions obtained is 99.33% and 95.25% respectively. The conversion rates are ranged from 45% to 65%. These results clearly show that membrane processes can be used in Africa, especially in isolated rural areas, with the combination of renewable energies. Currently, more than twenty membrane filtration units are installed in Senegal and provide drinking water of very good quality for populations living in rural areas. The prospect is to expand it on a larger scale, which is already underway, with the construction of a desalination plant in Dakar.

Key words: Fluoride, renewable energy, LPRO membrane, drinking water, rural areas.

1. Introduction

Population growth across the world is increasing the demand of drinking water. Many countries, such as developing countries have real issues to access a safe drinking water. Fluoride is the most reactive, electronegative, and, freely soluble in water [1]. This nonmetallic-inorganic substance can be harmful and affects human health when its concentration in drinking water is above to standard levels from WHO (World health Organization) or US-EPA (United States Environmental Protection Agency). Due to negative effects on human health the WHO estimated the permissible limit of fluoride content in drinking water as 1.5 mg/L. Therefore, several studies are done in order to remove the high concentration of many contaminants from drinking water such as fluoride, lead, arsenic, copper and nitrate [2-4]. It is important to note that the moderate concentration of fluoride in drinking water, concentration less than or equal to 1.5 mg/L is beneficial to human dental health. However, the excess concentration of fluoride, above 1.5 mg/L can lead to serious health problems such as dental and skeletal fluorosis [5, 6].

In Senegal, people living in rural areas in groundnut basin (center and western of Senegal) consume brackish water with high fluoride ions concentration. Several research activities have reported the quality of water and many images showed the negatives effects of high amount of fluoride ions in the water [4, 7]. The high amount of fluoride in this groundwater is due to the geological nature of the aquifers. The main

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aquifers are Oligo-Miocene, the Paleocene, the Eocene and the Maastrichtian [8]. Furthermore, the fluoride amount in natural water can be due to anthropogenic sources. Industrial wastewaters from metallurgical and aluminum manufacturers, phosphates fertilizer, semiconductors, electronics, ceramics are the most source of natural water contamination by fluoride [1].

The negative effects of fluoride excess in drinking water being well known, thus several processes for fluoride removal have been developed. Some are based on adsorption technologies into clay or activated carbon [9-13] while others are focused on membrane technologies [14, 15]. Membrane technologies are well known for their effectiveness in fluoride removal, even though, sometimes, the operating cost of this technology can be expensive for the developing countries.

The purpose of this study is to evaluate the capacities of renewable energy powered LPRO (Low Pressure Reverse Osmosis) membrane. The membrane filtration units are installed in rural area at the center and western parts of Senegal, as said above for reducing the salinity and fluoride excess in drinking water. A focus will be made on the operating parameters of the membrane filtration units and the cost of water after treatment process.

2. Material and Methods

2.1 Membrane Filtration Units Description

The first-generation unit plants, shown on the schema (Fig. 1) used for these research activities are all a circular flat sheet membrane.

The second-generation units are compact, using less space compared to the first one (Fig. 2).

These two generation units are functioning with the similar operating parameters. The reverse osmosis membranes operating on low pressure are interrelated between 210 discs which ensure dynamic resistance of the systems. The total membranes area in the two units is 9 m^2. With one module, a water feed flow of 500 L/h can be reached by using these units. The feed pressure, depending on the water salinity and the fouling state, is ranging between 8 and 14 bars. Both generation units can be coupled to powered photovoltaic or electrical sector.

The configuration of filtration system through the reverse osmosis membrane is shown in Fig. 3.

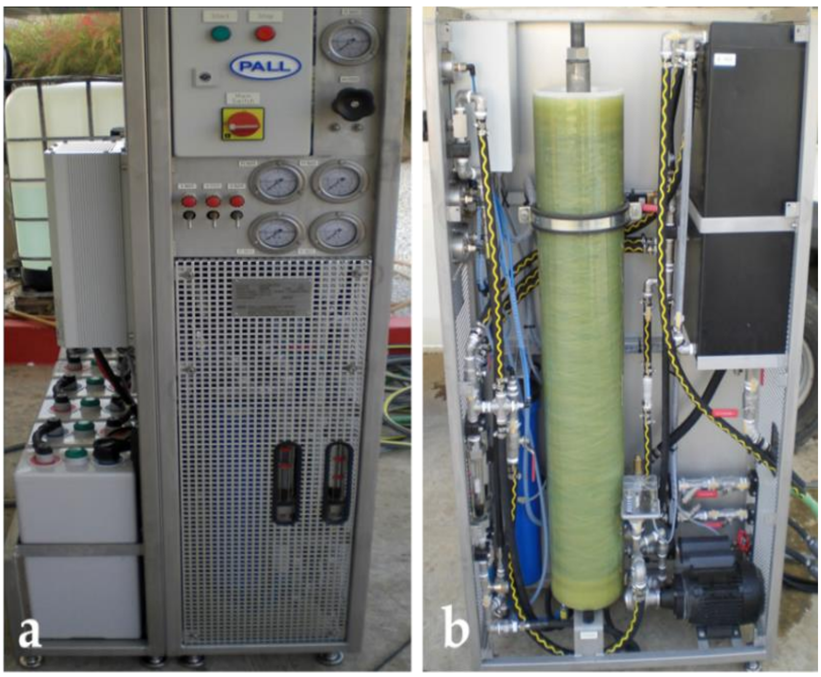

Fig. 1 First generation unit installed in rural areas. (a) external view; (b) internal view with the module, pump and cleaning tank.

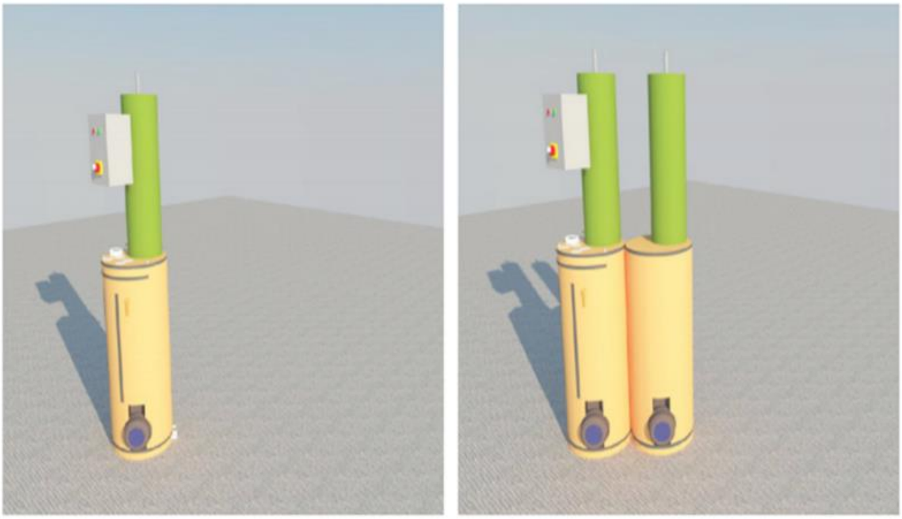

Fig. 2 Second generation unit with one or more than two modules.

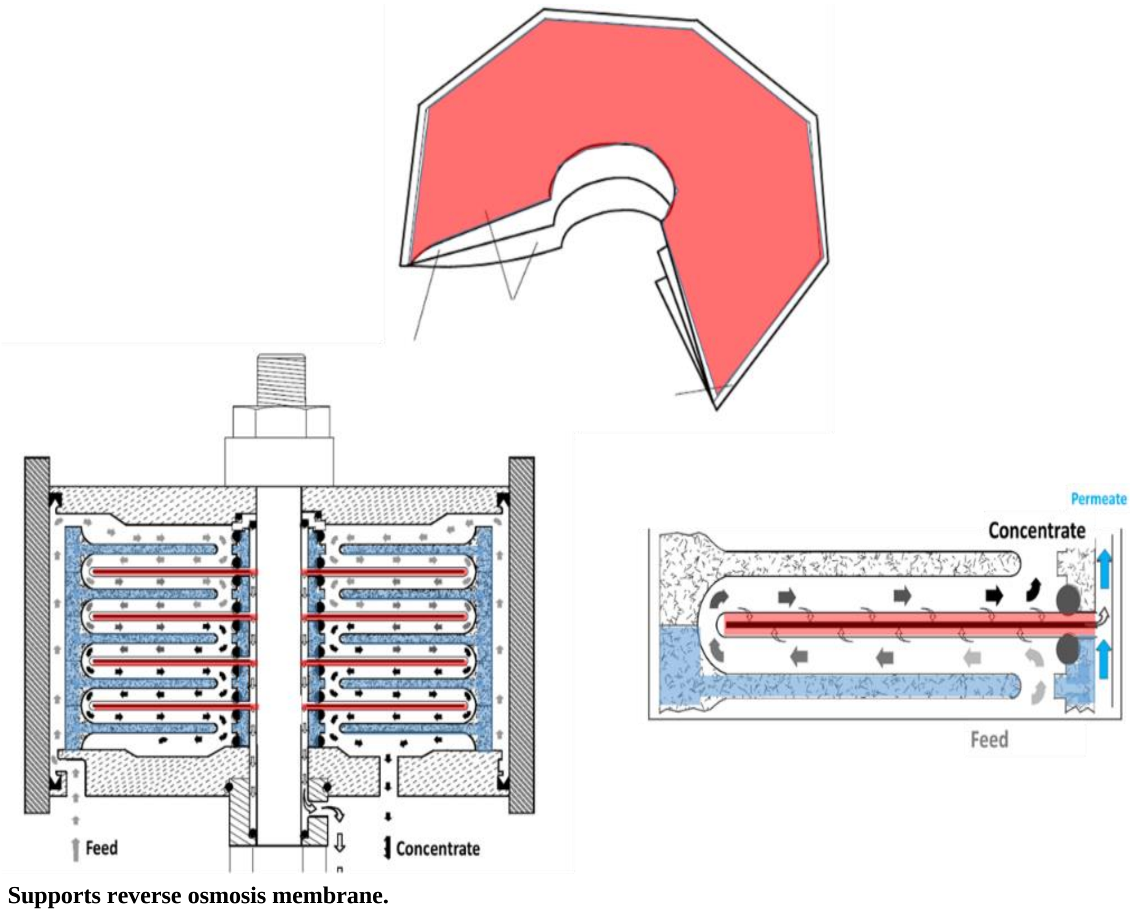

Fig. 3 Supports reverse osmosis membrane.

By this illustration, it becomes easy to understand how the filtration works between the reverse osmosis membrane, the disk and the support. The feed reaches the filtration system from below as shown in Fig. 3. Then the permeate is collected when water and some elements pass through both sides of LPRO membrane under adequate pressure applied.

The elements contained in feed that will be retained by the membrane are collected with part of water in the concentrate. There is a joint on the disk that allows the separation between permeate and concentrate. Each disk has a joint allowing this dispatching.

2.2 Operating Parameters and Measurements Methods

The operation parameters are important characteristics values for an efficient capacity assessment of these membrane filtration units.

The values related to rejection rate (R) are obtained by using the equation below (Eq. (1)).

$$R(\%) = \left(1 - \frac{C_p}{C_0}\right) \times 100 \qquad (1)$$

where:

C_p: concentration in the permeate and C_0: initial concentration in the feed.

Concerning the recovery rate, the values are obtained by using the equation below (Eq. (2)).

$$Y(\%) = \frac{Q_p}{Q_0} \times 100 \qquad (2)$$

where:

Q_0 and Q_p are the feed and permeate flow, respectively.

All the measurements of fluoride concentration were performed by using a french titration standard method (NFT 90-014). The salinity, conductivity and the water pH were also analyzed. The water was analyzed before and after filtration through the LPRO membranes. The initial fluoride concentration on raw water can easily reach more than 3.5 mg/L, value that is above the WHO limit for drinking water [4, 7].

3. Results and Discussions

3.1 Raw Water Analysis

Many sampling campaigns were conducted in the rural areas of Kaolack, Fatick and Diourbel, known by the quality of the water that people from these localities drink. One of these analysis results are listed in the table below (Table 1).

The analysis results of the water show that it is necessary to remove the excess of fluoride and other elements before supplying the water for drink. Other analysis researches are made and approximatively, the same results of fluoride concentration can be observed [4]. Beyond fluoride concentration excess, it is easy to deduce the brackish aspect felt by drinking this water. Indeed, when a water analysis reveals that chloride ions and sodium ions are present, mainly when the amounts are important, the water is often brackish. Even the water EC (electrical Conductivity) has been measured and the results can reach 2.80 mS/cm depending on the locality and the season. From this analysis result, the treatment is necessary before supplying this water.

Table 1 Analysis results of raw water.

Parameters	Content (mg.L^{-1})
F^-	3.96
Cl^-	543.15
SO_4^{2-}	14.71
Na^+	351.90
Total Dissolved Solids	20.00
Salinity	895.05

3.2 Efficiency of LPRO Membrane

Analyses of fluoride, sulphate sodium and chloride ions were realized. The water salinity was also measured on permeate to assess the rejection rate of the membrane with working pressure. The results are listed in Table 2.

As shown in Table 2, the reverse osmosis membrane working under low pressure (8 bars) retains both excess fluoride ions and chloride ions. The rejection rates for the fluoride ions and chloride ions are 88.87% and 88.04% respectively. In comparison with the removal efficiencies obtained in literature, our values are completive [1, 14]. The sulphate ions are also well removed from the drinking water, the rejection rate obtained reaches 99%. The LPRO membrane units

Table 2 Fluoride and chloride removal efficiency.

Parameters	Permeate content (mg/L)	R (%)
F^-	0.52	88.87
Cl^-	63.90	88.04
SO_4^{2-}	0.0	99.32
Na^+	41.40	88.23
Salinity	150.30	88.23

coupled with solar panels produces a permeate with the concentration of fluoride ions within the range of WHO recommendations.

The salinity concentration is also reduced from 895.05 (salinity in the feed water) to 88.23 mg/L in the permeate. The rejection rate obtained with the salinity corroborates with this reduction.

Concerning the EC, the measurements are carried out on several sites in rural areas of Kaolack and Diourbel. The values obtained are ranged from 2.087 mS/cm to 2.687 mS/cm in the feed water. As with fluoride and chloride ions, the LPRO membrane showed a high removal efficiency as well. In fact, the EC values in the permeate are below the limits recommended by WHO; they are summarized in table below (Table 3).

Each membrane filtration unit of twenty units installed produce water with EC less than 0.5 mS/cm. In term of rejection rate of EC, the values are ranged from 83.617% to 94.633%. With these values obtained in permeate, the objectives are reached by using renewable energy for supplying water in rural areas which is in the category of safe drinking water.

3.3 Recovery and EC Rejection Rate Variation

Measurements were carried out in order to observe the recovery and EC rejection rate over the time.

One of the important parameters of membrane especially, the recovery rates, is studied. Fig. 4 shows the variation of recovery rates, obtained with two filtration units installed at Koutal and Diourbel sites. The EC rejection rates are also plotted in the figure to show the membrane capacity to reduce this parameter.

Focusing on the recovery of these two filtration units installed in Koutal and Diourbel, it is easy to observe that the highest values are obtained when the membrane cleaning is realized or when the membranes are new. Just after membrane cleaning, the units become efficient and produce a high permeate flow with the same working pressure.

Table 3 EC variation in the feed and permeate.

Sites	EC (mS/cm)		*R* (%)
	Feed	Permeate	
Koutal	2.087	0.112	94.633
Kabatoki	2.181	0.319	85.374
Ndorong	2.148	0.352	83.617
Diourbel	2.687	0.147	94.529

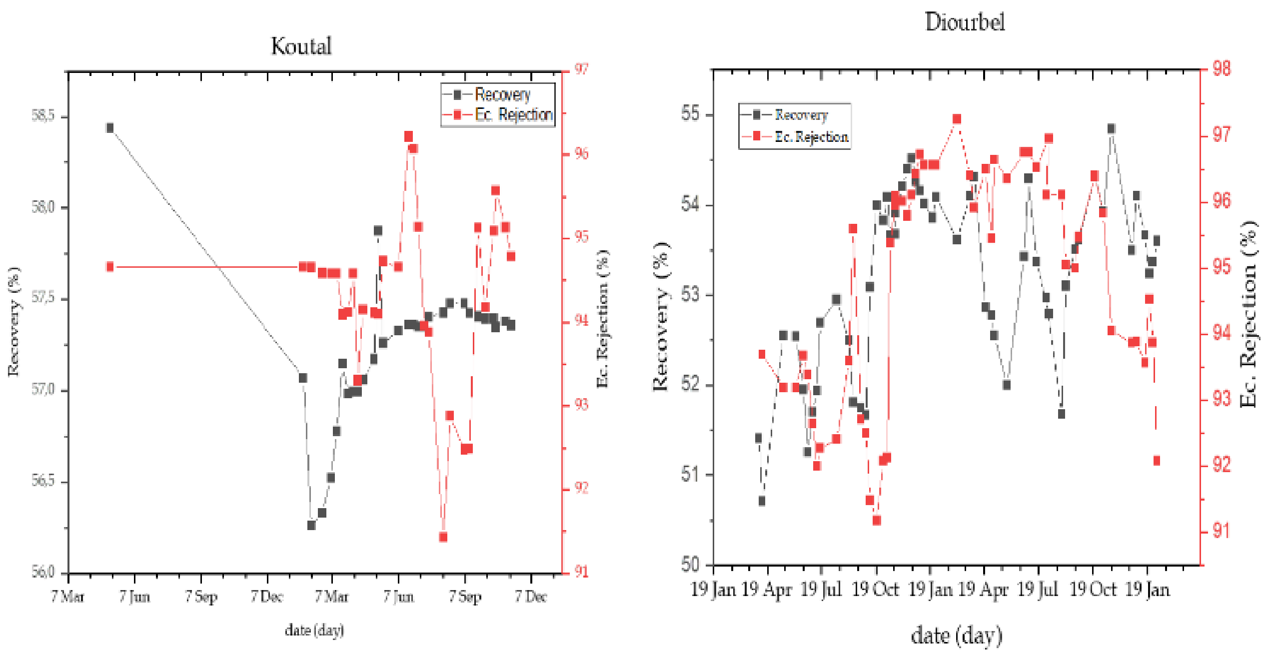

Fig. 4 Variation of the recoveries and EC rejection rates at Koutal (from May 2021 to November 2021) and Diourbel (from April 2019 to February 2020).

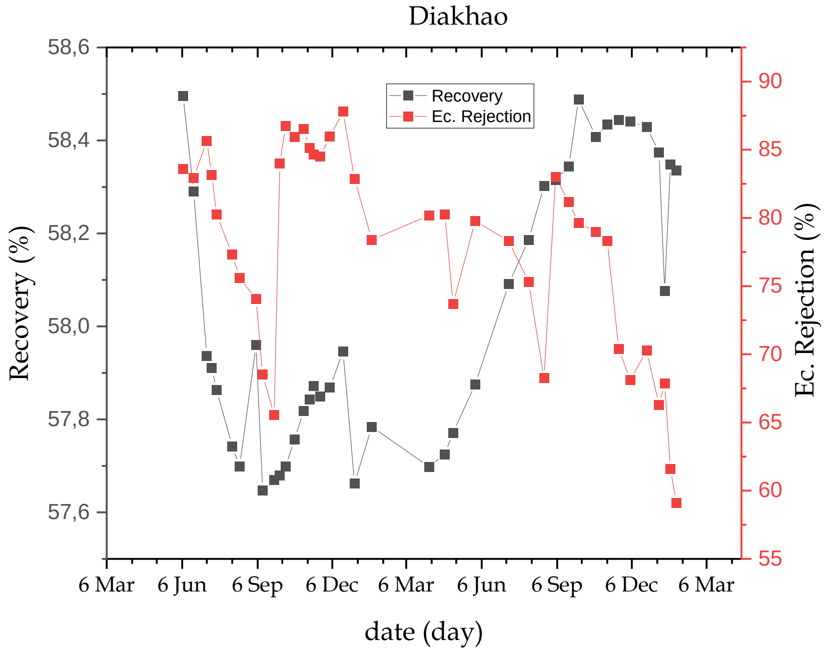

Fig. 5 Variation of recovery and EC rejection rate at Diakhao from June 2018 to January 2020.

Furthermore, when the units run a long time without cleaning, recovery rates decrease despite the increasing of the working pressure. Therefore, the energy consumption will easily increase and affects negatively the production profitability. Further, the recovery rate decreasing can be used to anticipate the membranes fouling.

The EC rejection rate obtained in these two filtration units are ranged from 90% to more than 95%. In fact, these waters are brackish water, with these values, the permeate is within WHO standards, and the people from these localities can drink safely this water and appreciate the pleasant taste.

The same study is performed with the filtration unit installed at Diakhao site (Fig. 5).

The high values of recovery obtained with this unit are due to the high permeate flow. A recovery rate of 58.8% is reached due to the new membrane installed to this unit. In addition, the variation of EC rejection is similar to that obtained with the two first units installed in Koutal and Diourbel.

Ultimately, the filtration units coupled with solar panels show high performance on the partial removal of fluoride ions and salinity reducing. Thus, the populations living in these rural areas of Senegal can be supplied with safe drinking water obtained from these filtration units.

4. Conclusion

In the present study, a focus was made on rejection rates of fluoride and chloride ions excess and the conversion rate for LPRO filtration units installed at different sites. From the results obtained, the renewable energy coupling with membrane processes can be a suitable solution for safe drinking water supply in rural area. As many countries in Africa, the sunshine in Senegal is perfect for using photovoltaic panels as an energy supply. After membrane filtration unit installation, the treated water can be sold with an affordable price (less than 0.008 €/L) for the people from rural areas.

In term of membrane efficiencies, rejection rates of fluoride and chloride ions are 88.87% and 88.04% respectively. With a variation of recovery rate ranged between from 45% to 65%, these units produce more than 500 L/h by using renewable energy for certain of them. The main objective of this study has been achieved, since the selling price of treated water is very affordable for the population from rural area of Kaolack, Fatick and Diourbel, three regions of Senegal.

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