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Design of a Cost-Effective Portable Seawater Desalination Unit for Generating Drinkable Water

[1]Utkarsh Kumar, [2] Vishal yadav, [3] Chandan Kumar Mandal, [4] Rahul Kumar,

[1*] Amar Kumar Das

[1,2,3,4] B Tech Students, Department of Mechanical Engineering, Gandhi Institute For Technology (GIFT) Autonomous, Bhubaneswar.

[1*]Associate Professor, Department of Mechanical Engineering, Gandhi Institute For Technology (GIFT) Autonomous, Bhubaneswar.

Corresponding author: amar.das@gift.edu.in

Abstract

A portable seawater desalination system would be highly desirable to solve water challenges in rural areas and disaster situations. While many reverse osmosis-based portable desalination systems are already available commercially, they are not adequate for providing reliable drinking water in remote locations due to the requirement of high-pressure pumping and repeated maintenance. The current work focused on demonstrating a field-deployable desalination system with multistage membrane filtration processes, composed of two-stage ion concentration polarization, to convert seawater to drinkable water. A model is designed to be used with optimized the multistage configuration, and showed good agreement with the experimental results. The portable system desalinates seawater (2.5–45 g/L) into drinkable water (defined by WHO guideline), with the energy consumptions of 15.6–26.6 W h/L (seawater). In addition, the process can also reduce suspended solids by at least a factor of 10 from the source water, resulting in crystal clear water (<1 NTU) even from the source water with turbidity higher than 30 NTU (i.e., cloudy seawater by the tide). We built a fully integrated prototype (controller, pumps, and battery) packaged into a portable unit (42 × 33.5 × 19 cm3, 9.25 kg, and 0.33 L/h production rate) controlled by turbidity meter and IR unit. The demonstrated portable desalination system is unprecedented in size, efficiency, and operational flexibility. Therefore, it could address unique water challenges in remote, resource-limited regions of the world.

Keywords: Desalination; Freshwater production; waste energy; Reverse Osmosis.

1. Introduction

Water for living has been the second most pressing concern in the 21st century after population growth. On earth's surface, only one percent of the available freshwater is easily accessible, which is the water found in lakes, rivers, reservoirs, glaciers and underground sources. Also, the groundwater is getting deeply buried with the explosion in world population and excessive concentration level of dissolved salts does not allow it even to be used for industrial applications. Scientists and researchers have explored the possibility of utilizing the biggest water source, the sea, employing various methods of desalination. Malaysia has been blessed with many natural resources. Abundance of sweet water is one among them. If we look into the scenario of the neighboring country, Singapore, the situation is very much different. They have to strive to find freshwater as the island is surrounded by the sea. Same condition applies for the coastal areas in Malaysia. The water salinity is a major problem and this issue has drawn attention of the water authority recently.

Although the desalination industry in the Gulf area is dominated by the multistage flash desalination process [1], serious attempts are being made to adopt the more efficient reverse osmosis (RO) desalination process. In this regard, several small-scale RO plants are installed to desalinate either brackish water (BWRO) or high-salinity seawater (SWRO). Progress review of the RO process by Matsuura [2] shows simultaneous increase in salt rejection and normalized flux, where the salt rejection reached values close to 99.5% and a normalized flux of 2 m3 /m2 day MPa is achieved. Other developments include synthesis of membranes capable of withstanding high operating pressure for long periods of operation and higher resistance to chemical and biological fouling. Although there are a number of ways to convert seawater to fresh water, a common overall process applies to all schemes. Actual nature of each step would depend on the desalination method used.

2. Design and description of the Set up

The RO desalination process is energy intensive. This is due to the low recovery ratio (25 % to 40 %) and the high operating pressure (60 bar to 80 bar) [17]. A crucial condition for the layout of an RO system is the specific energy consumption, which should be kept as low as possible. This, therefore, means that the recovery ratio must be as high as possible and the associated feed water pressure be kept as low as possible without compromising the standards of the quality of water produced. For this reason, most, if not all, of the large and small scale seawater RO plants are fitted with energy-recovery turbines that help recover some of the pumping energy as shown in Figure 1.

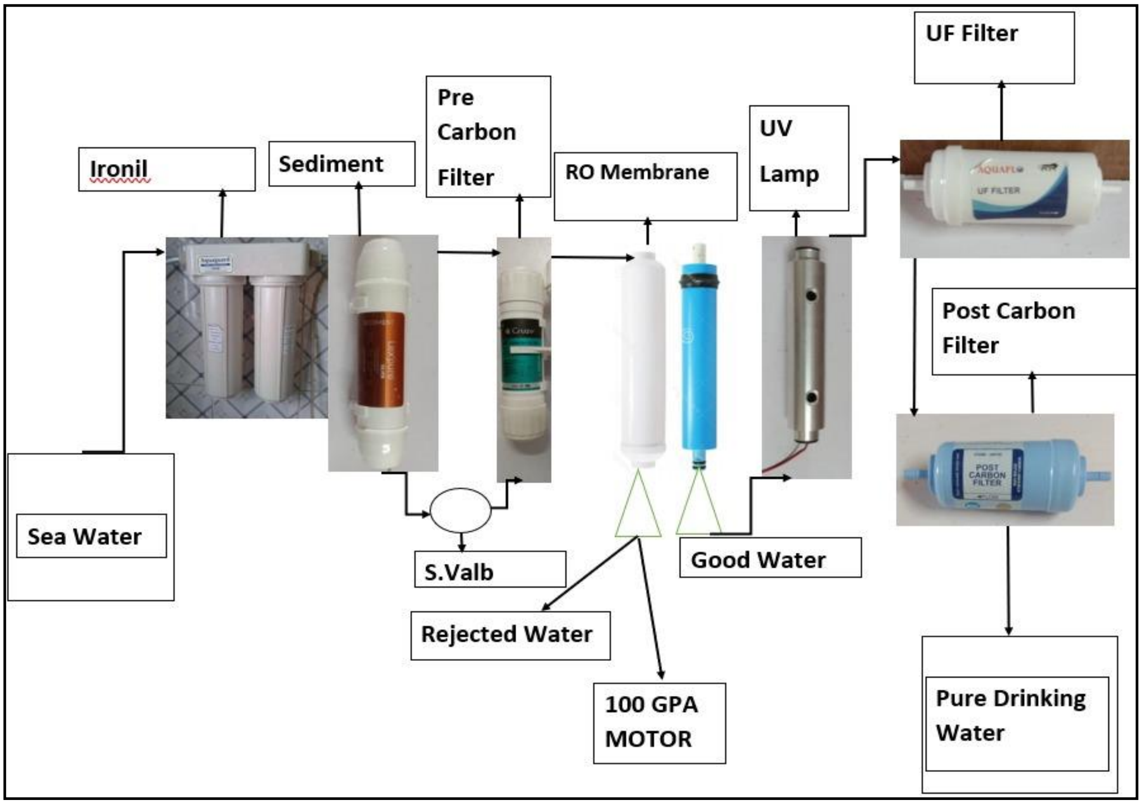

Figure 1 Schematic Layout of the desalination unit

Energy recovery devices (ERDs) are the components used to reduce energy consumption for RO desalination processes and this has been shown to recover the energy from the RO concentrate stream. The pressure from the concentrate stream is recovered by passing it through an ERD before the concentrate is sent for disposal. The efficiency of the system determines the fraction of power recovered.

3. Energy Recovery in RO Systems

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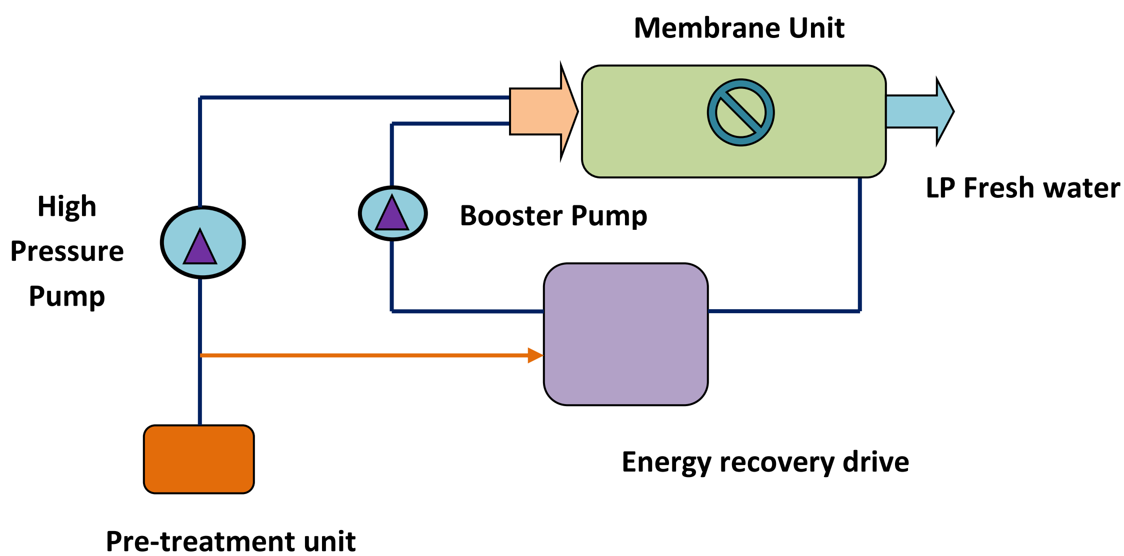

Figure 2 RO plant with an energy recovery device

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4. Pre-Treatment of Saline Water and its Effects

Naturally, water contains very small suspended particles (approximately 0.1 micron, defined as colloidal). The surface to mass ratio is huge compared to visible particles which cause them to deposit in unlimited patterns and therefore add up and thicken where they deposit. This accumulation and deposition of particles on membrane surfaces results in what are known as amorphous gels. Such membrane fouling agents are complex mixtures and are difficult, sometimes impossible, to clean [33]. Through pre-treatment, fouling is significantly reduced, if not prevented. There is also a possible reduction in the damage to reverse osmosis membranes. The pre-treatment method to be used depends on the extremes of the characteristics of the raw water [34].

Effective pre-treatment of saline water is required in order to increase efficiency and to increase membrane life time. Appropriate pre-treatment will maximize the process efficiency and increase membrane life by reducing formation of scales, fouling deposition and degradation of the membrane. The benefits of the pre-treatment will be product flow optimization, salt rejection optimization and product recovery, reduction of operating costs, and reduction or decrease in cleaning frequency and membrane replacement costs. There are several types of pre-treatment methods. These include coagulation, filtration, scale control and chlorination-dechlorination [17, 34]. Economic comparisons of the costs of pre-treatment methods, for example membrane filtration versus granular filtration, are intricate since they involve assumptions on the anticipated long-term performance. The experience of the evaluator heavily influences such assumptions [35].

5. Conclusion

Several studies have shown that the effects of energy consumption in RO desalination have been a thorn in researchers' flesh. Energy consumption has a negative impact on costs of running the plants and subsequently affects the costs of potable water production. Studies on reduction of energy consumption in desalination have been one of the major priorities in recent years and the results have been very significant. The incorporation of energy recovery devices has led to major benefits in the technology as some of the energy is recycled and turned into productive use. Research and development of energy and cost-effective desalination technologies has been, and still is, an ongoing process as sources of fresh water continue to diminish at an alarming rate whereas population growth is increasing dramatically.

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