Fresh water production from municipal waste water with RO membrane technology and its application for agriculture and industry in arid area

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Abstract. One of the biggest problems of the 21st century is the global water shortage. Therefore it is difficult to increase the quantity of conventional water resources such as surface water and groundwater for agriculture and industry in arid area. Technical advancement in water treatment membrane technology including RO membrane has been remarkable especially in recent years. As the pore size of RO membrane is less than one nanometer, it is possible to produce the fresh water, which satisfies the drinking water quality standards, with utilizing RO membrane. In this report a new fresh water resource from municipal waste water is studied to apply to the plant factory which is the water saving type agriculture and industry in arid area.

1. Introduction

According to the report [1] of the United Nations in 1997, 97.5% of the water on the earth is sea water, while the remaining 2.5% is fresh water. The source of drinking water in fresh water, such as river, lake, pond and groundwater, constitutes only 0.8% of the entire water resources of the earth. On the contrary the world population will reach 8 billion in 2025 according to WHO [2].

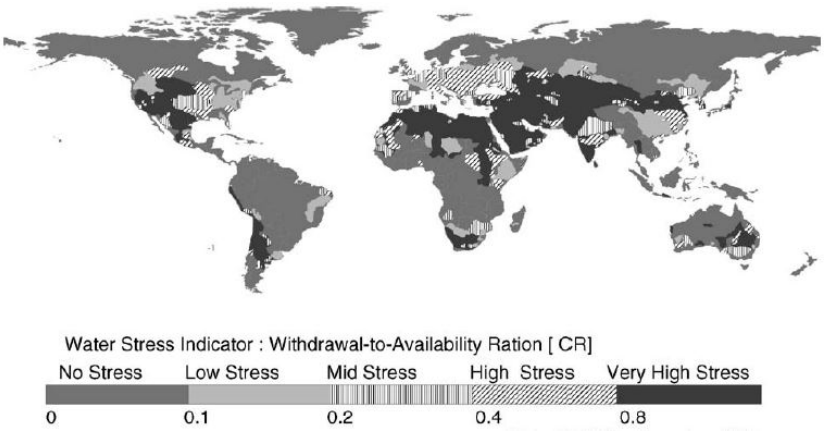


Figure 1. Prediction of global water shortage in 2025 (Water stress map) [3].

At that time half of the world population will live in the countries which suffer from water shortage because of increasing demand of drinking water by increasing population, increasing demand of

agricultural water by increasing food production and increasing demand of industrial water by progress of industry. It is difficult to increase the quantity of surface water and groundwater for agriculture and industry in arid area, because the quantity of them is limited in this area and the priority of drinking water is much higher than agricultural and industrial applications. Therefore it is very much attractive, if the fresh water for agriculture and industry in arid area can be produced with RO membrane from municipal waste water which is now discharged as drain.

2. Classification of water treatment membrane

There are four kinds of water treatment membranes. They are classified as RO (Reverse Osmosis) membrane with the smallest pore size, NF (Nanofiltration) membrane, UF (Ultrafiltration) membrane and MF (Microfiltration) membrane. The separation for MF and UF membranes is based on sieve filtration technology, whereas for RO and NF it is based on reverse osmosis technology**.**

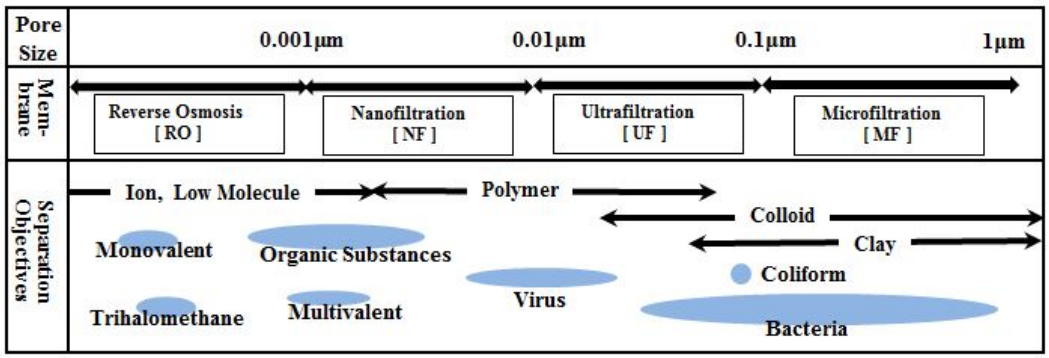


Figure 2. Classification of water treatment membrane.

3. Reverse osmosis membrane and its element structure

3.1. Structure of RO membrane and its element

There are two kinds of RO membrane form which are asymmetric and composite. Historically

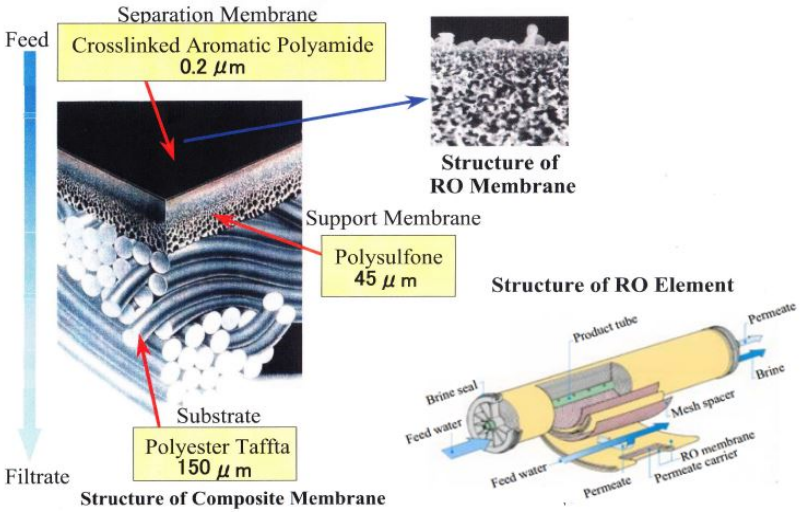


Figure 3. Structure of composite type RO membrane and spiral wound element.

asymmetric membrane of cellulose acetate was first developed and asymmetric membrane of liner polyamide followed. Later, a thin film composite membrane has been developed with different materials which make a separating functional layer and a supporting layer. The majority of RO membranes, which are currently used, is a thin film composite membrane. A spiral wound element is made spirally wound with envelopes of composite membranes, mesh spacers and permeate carriers. As configurations of RO elements, there are plate and frame, tubular and hollow fiber types in addition to spiral wound type.

3.2. History of RO membrane

In the 1950s, the research for sea water desalination has started under the support by Office of Saline Water in the United States. In 1960 Loeb and Sourirajan of University from California had developed the RO membrane of cellulose acetate which was the starting point of water treatment membrane progress.

Fortunately Shoji Kimura of University of Tokyo [4] and Haruhiko Ohya of Yokohama National University [5] had studied and researched jointly on RO membrane under Sourirajan and brought the knowledge back to Japan in the 1960s and the early 1970s. This is one of the reasons why the research on RO membranes in Japan has been kept the highest level in the world. It was very fortunate for Japanese membrane manufacturers to keep their research and technical levels of RO and other membranes globally high from the early stages. There are limited to only two countries of Japan and USA in the world for a long period who can produce spiral wound and hollow fibre types of RO modules, which are mainly applied to water treatment application.

3.3. Technical trend of RO membrane [6]

The trend in the development of RO membrane technology has three directions, shown as Figure 4.

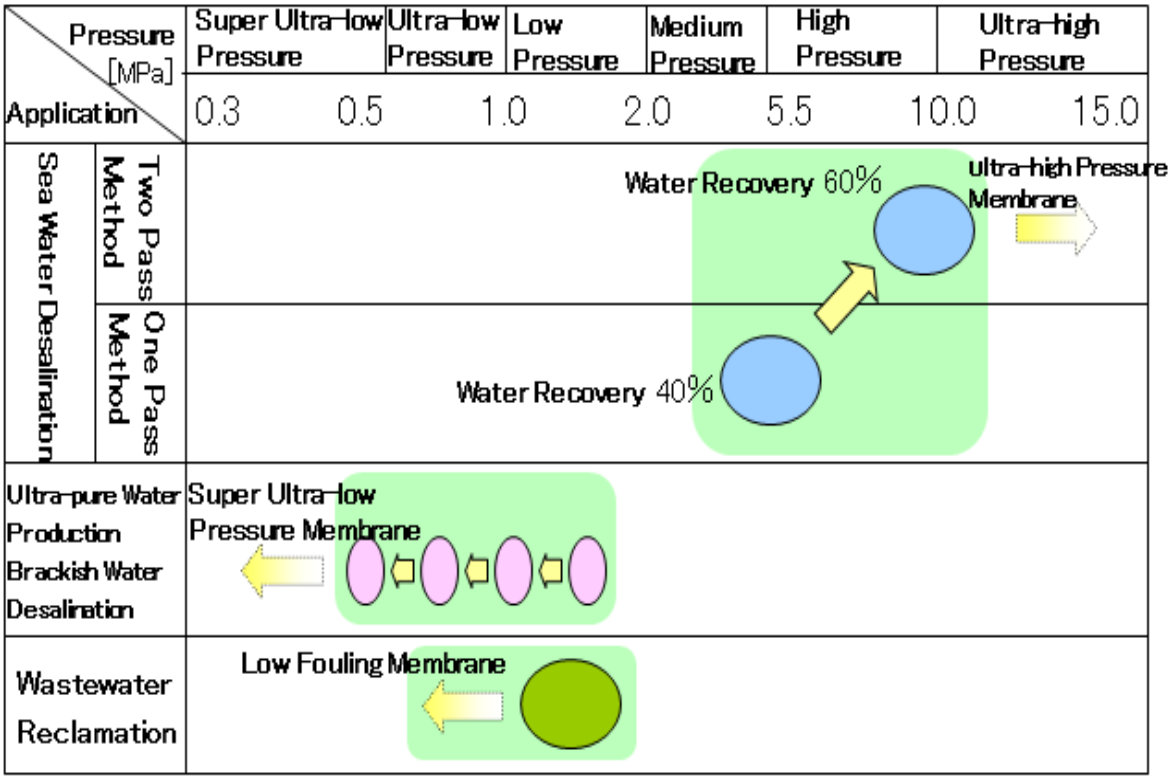


Figure 4. Technical trend of RO membrane.

One is the direction of development for sea water desalination under high salinity. In this area to reduce water production cost it is required to increase water recovery ratio from 40% of the conventional value to 60%. The development of RO membrane and element structure has been done for high pressure durability under more than 10MPa.

Second direction is the development of higher performance under a low salinity area for ultrapure water production and brackish water desalination. In this area to reduce operating cost it is required to increase water productivity under low pressure of less than 1MPa with keeping high salt rejection.

Third direction is the development of durability against membrane fouling for stable RO operation and to expand the application of waste water treatment.

3.4. Application of RO membrane

Reverse osmosis membrane is widely used as an important water treatment technology for production of ultrapure water, boiler feed water and drinking water with desalination of brackish water and sea water. As was mentioned in the beginning one of the answers to improve water shortage in the 21st century is production of drinking water from sea water with RO membrane technology. And it is expected that application of RO membrane will be expanded significantly in the near future.

4. Fresh water production from municipal waste water with membrane technology

4.1. Water resources for agriculture in arid area

Thinking about potential water resources of agricultural and industrial water in arid area, there are three kinds of water such as surface water of river, lake and pond, groundwater and sea water. Surface water and groundwater have been already used for agriculture and industry. Table 1 shows the potential water resources in arid area.

Table 1. Potential water resources in arid area.

Water Resource	Traditional Main Application	Quantity in Aread Area	Treatment Cost	New Water Resource Potentiality
Surface Water ・River Water ・Lake Water ・Pond Water	・Drinking Water ・Agriculture	Shortage	Reasonable	Difficult
Groundwater	・Drinking Water	Shortage	Reasonable	Difficult
Sea Water	・Drinking Water	Enough	Expensive	Low
Municipal Waste Water	・Drainrage Discharge	Enough	Reasonable	High

It is difficult to increase the quantity of surface water and groundwater for agriculture and industry in arid area, because the quantity of surface water and groundwater is limited in this area, and the priority of drinking water is much higher than that of agricultural and industrial water in arid area.

Though there is not the quantity problem for agricultural and industrial water from sea water, the cost of sea water desalination is much higher than those of surface water treatment and groundwater desalination, because salinity of sea water is extremely high ranging from 3.5% to 4.5%, comparing to those of surface water and groundwater which are normally less than 1%. Therefore it is very much attractive, if the fresh water for agriculture and industry in arid area can be produced from municipal waste water with water treatment membrane which is discharged as drain. The quantity of municipal waste water is in proportion to population and stable. The cost of municipal waste water treatment is much lower than that of sea water desalination.

4.2. Progress of municipal waste water reclamation process [7]

4.2.1 Advanced municipal waste water reclamation process (1st Step)
In the first step of advanced waste water reclamation process, the complicated pretreatment process with chemical and physical methods was adopted in order to get a high quality RO feed water as shown in Figure 5. The world famous Water Factory 21 at Orange County Water District is the real pioneer of advanced municipal waste water reclamation process in the world. Water Factory 21 has started its operation in 1979. The treated water from activated sludge tank was fed to RO process after lime clarification, re-carbonation and sand filtration. RO permeate was injected into the ground after chlorine disinfection. The water quality after treatment in Water Factory 21 met and exceeded the drinking water quality standards in USA.

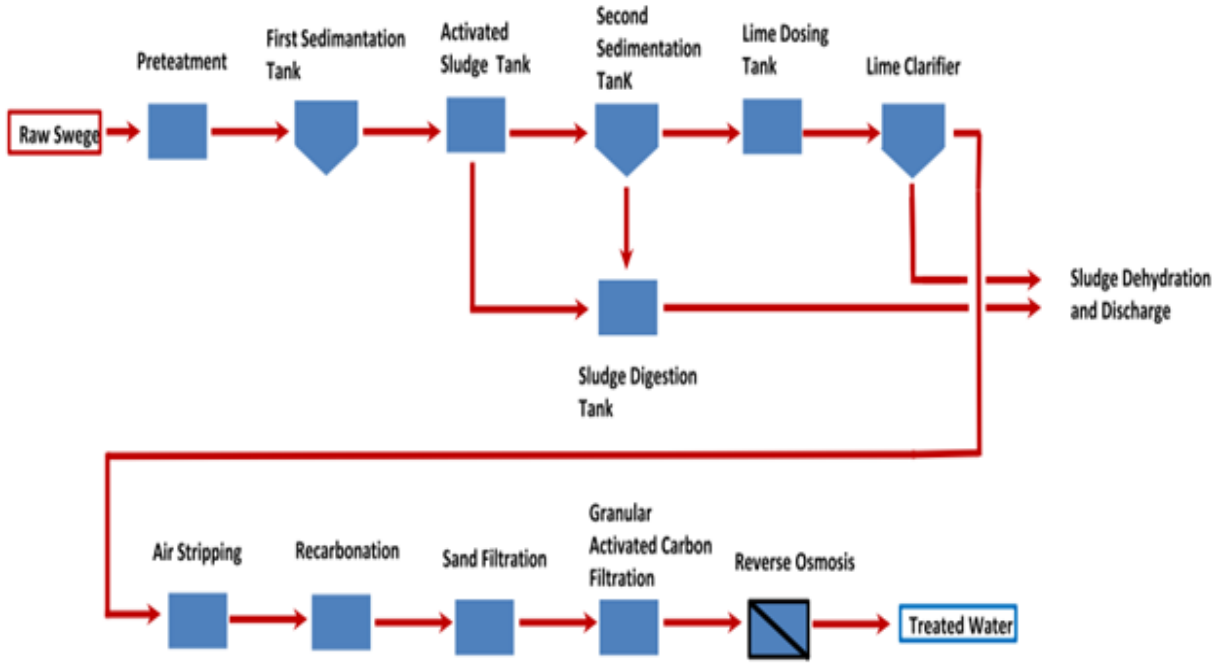


Figure 5. Advanced municipal waste water reclamation process (1st step).

4.2.2. Advanced municipal waste water reclamation process (2nd step) - Introduction of MF/UF membrane
Thanks to introduction of MF (UF) membrane, the pretreatment system for removal of suspended materials had become simple. Water after treatment in sedimentation tank from activated sludge tank was fed to RO system after treating with MF (UF) membrane system and removing suspended materials. RO permeate can be reused. The NEWater plant by PUB (Public Utility Board) in Singapore is one of the most recognizable examples of the 2nd step of advanced municipal waste water reclamation process. The NEWater plant was developed by modelling after Orange County

Water District Water Factory 21. The feature of this process was the adoption of MF membrane process instead of the complicated pretreatment process with chemical and physical methods, thus the total process became extremely simple and economical. PUB named their treated water "NEWater" for distinguishing it from other treated water from waste water.

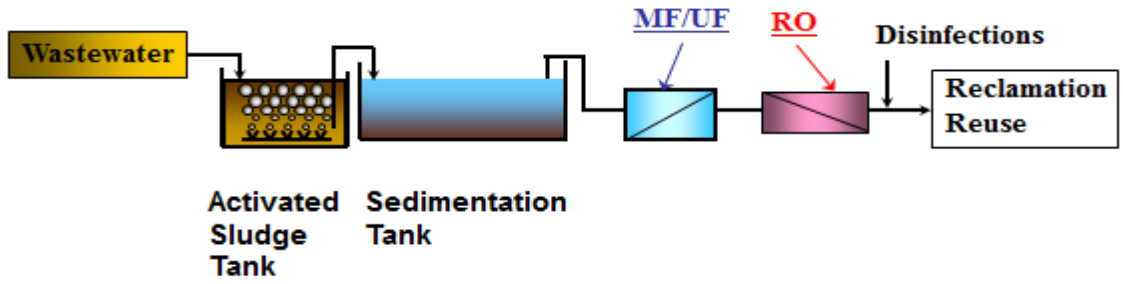


Figure 6. Advanced municipal waste water reclamation process with MF/UF before RO (2nd Step).

The water quality of NEWater can easily clear the WHO drinking water quality standards. Singapore government distributed more than 1,000,000 bottles of NEWater at school sports festivals and on National Holidays in Singapore in order to capture people's attention.

Figure 7. Singapore Seletar NEWater RO plant.

4.2.3. Advanced municipal waste water reclamation process with MBR before RO (3rd step)

With adoption of the Membrane Bio-Reactor (MBR) that combines activated sludge tank and MF process, the total process became simpler and more economical. In 2009 the Changi NEWater plant of the advanced municipal waste water reclamation process with MBR began its operation.

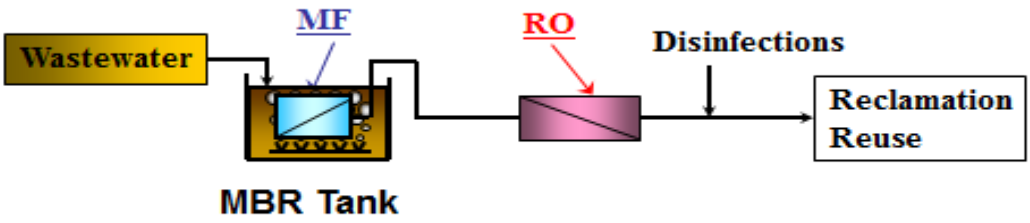
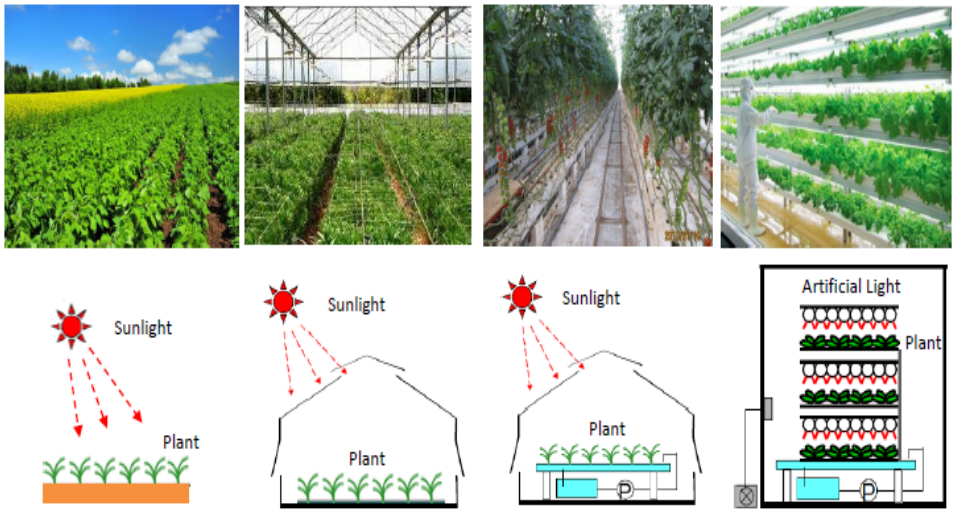


Figure 8. Advanced municipal waste water reclamation process with MBR before RO (3rd Step).

5. Agricultural application of fresh water from municipal waste water

5.1 Plant factory – water saving type agriculture

It is mentioned that in arid area fresh water from municipal waste water with membrane technology is expected as a new water resource for agriculture. The figure 9 shows the water consumption of agriculture by cultivation method [8],[9].



Cultivation System	Dry-field	Green House (Soil Culture)	Sun Light Type Plant Factory (Hydroponics, Open)	Artificial Light Type Plant factory (Hydroponics, Closed)
Water Vaporization from Soil	○	○	×	×
Water Penetration into Soil	○	○	×	×
Water Vaporization from Leaves	○	○	○	× (Recovery of Vaporized Water)
Water Consumption Ratio	1	1	1/2	1/20

Figure 9. Water consumption by cultivation method.

If the water consumption ratio of dry-field farming is 1, then the water consumption ratio of green house with soil cultivation is 1 – 1/2. The water consumption ratio of sunlight type plant factory with hydroponics is 1/2 – 1/10, because there is no water vaporization from soil and no water penetration into soil. The water consumption ratio of artificial light type plant factory decreases 1/10 – 1/100, because vaporized water from leaves is recovered by dehumidification with air conditioner.

5.2 Integration of new water resource, agriculture and photovoltaic generator [10],[11],[12]
In arid area it is difficult to increase quantity of surface water and groundwater for agriculture, because their quantity is limited. It is also difficult to apply the fresh water from sea water to agriculture because its desalination cost is high. Therefore it is very much attractive as a new water resource of agriculture in an arid area, if the fresh water of drinking water quality level can be economically produced from municipal waste water, which is discharged as drain, with advanced RO membrane technology. The new agricultural method in arid area is proposed as follows:

- Photovoltaic (PV) generator is applied for energy resource.
- Fresh water from municipal waste water with RO membrane technology is applied for agricultural water.
- Plant factory of water saving agriculture is applied for cultivation method.

Figure 10 shows a conceptual figure of “Fresh water production from municipal waste water with RO membrane technology and its application for plant factories with Photovoltaic (PV) generator”.

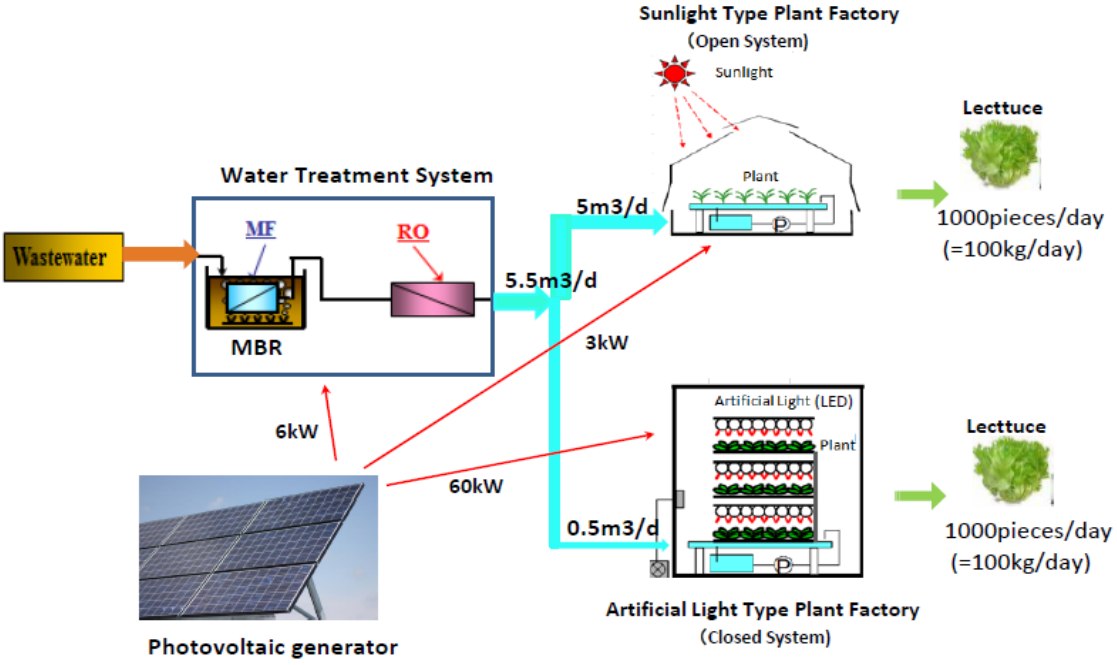


Figure 10. Fresh water production from municipal waste water with RO membrane technology and its application for plant factories with PV generator.

6. Industrial application of fresh water from municipal waste water

In arid area it is difficult to increase quantity of industrial water and in order to promote industries it is necessary to snatch existing water resources for drinking and agriculture against people and farmers. If the fresh water, whose quality is equal to or better than WHO drinking water quality standards, can be produced from municipal waste water with RO membrane technology, it is not necessary to snatch existing water resources. The fresh water from municipal waste water can be used for industrial water, promote industries and create many new jobs.

7. Conclusion

Municipal waste water is abundant and stable in proportion to population. Thanks to advanced RO (Reverse Osmosis) membrane technology it is possible to produce the fresh water, which satisfies WHO drinking water quality standards, from municipal waste water. Therefore municipal waste water becomes a potential water resource for agriculture and industry in arid area. The plant factory of hydroponic cultivation system with photovoltaic generation is a water saving type agriculture and suitable in arid area.

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