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A Review of Recent Development of Membrane based Drinking Water Treatment Systems

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Abstract—**Membrane technology has undergone a rapid development in the last three decades in most application fields, and has been widely chosen as an outstanding application in the field of drinking water treatment (DWT). Improvements in membrane technology have made it an increasingly popular choice for removing micro-organisms, particulates and natural organic materials that foul the taste of water and taint its clarity, making membrane processes the key technology for drinking water production. In this work, a review of recent development of membrane based DWT systems is done to help giving a complete vision for all relevant experts. With a detailed analysis in the review of existing membrane based DWT treatment systems, this paper contributes most updated knowledge on the application of Ultrafiltration and Microfiltration. This brings a crucial huge scientific data base for further researches studying on proposing suitable drinking water treatment solution in certain specific situations which will be sustainably maintained for a full lifetime capacity.**

Keywords—membrane technology, drinking water treatment (DWT), pressure-driven membrane

I. INTRODUCTION

Basically, the application of which type of membrane processes is decided based on the molecular weight and size of the materials which are expected to be separated by the membrane process. The different application of membrane processes can be virtually summarized as depicted in Fig. 1. The application of membrane processes can function as single purification steps in water treatment plants or can be combined to make an integrated membrane process [1, 2]. An integrated membrane system can consist of two or more membrane processes or it is a system combining a membrane process with other treatment technology [3]. In the scope of this paper, the development of membrane based DWT systems are focused to the application of MF and UF in Point-of-Entry (POE) or Point-of-Use (POU) and decentralized DWT systems.

II. A REVIEW OF UPDATED DEVELOPMENTS OF MEMBRANE BASED DWT SYSTEMS

Recently, many membrane based systems are commercially developed in the form of Point of Entry (POE) or Point of Use (POU) treatment devices, which may offer a feasible option for providing drinking water to small communities, household or individual. Besides, many systems also play important role in disaster relief. Table 1 shows an overview over all the systems which have been commercialized, and are here noticed with letters (A-H) concerning their main features and distinguish parameters. A: Serve for person (p) / household (h) / community (c), B: No external energy demand, C: No external chemical demand, D: With back flushing, E: Simple handling and maintenance, F: Built-in storage container, G: Easy transported in the area of operation, H: Filtration cartridge replicable, I: Robust, J: emergency and disaster relief.

Besides, there are some projects which have been developed for long-term used. As an example, the SkyHydrant or SkyJuice Foundation has been configured into multi-unit banks as a permanent plant [4, 5]. Ceramic MF membranes are applied in different configurations between industrial and developing countries, corresponding with different rate of efficiency of removing bacteria and viruses. Examples of well-known ceramic membrane filters are the ones introduced by Potters for Peace. These POU ceramic water filters are designed to gain the ease of use and simple maintenance. However, their performance on sites has not been evaluated [6].

III. DISCUSSION ON THE DEVELOPMENT OF MEMBRANE BASED DWT SYSTEMS

Membrane technology is interested worldwide because it provides absolute barriers for controlling hygiene hazards, and the available diversity of the module types allows their implementation on varied scales. Membrane filtration is foreseen by most experts to be applied with greater frequency in decentralized systems as an alternative to the conventional filtration due to its advantages on both technical and economic aspects. The membrane material itself could be more expensive than some other traditional filtration technology, but the development in designing of membrane based systems makes the application easily handled with simple operation. Due to its simple operation and maintenance, this high technology is more and more designed aiming towards poor and less developed communities. In these cases, the systems run without requiring skilled personnel, and in some cases without energy demand, thus significantly lower the annual operating cost. In addition, as advancements are made in membrane production and module design, there are more possibilities to decline capital and investment cost.

TABLE I. OVERALL REVIEW OF MF/ UF DWT APPLICATIONS – Part 1

Trade Mark	Product	Description	Pore size/ MWCO	Flow rate	TMP	Notification
LIFESAVER systems, Great Britain Source: www.lifesaversystems.com	 LIFESAVER bottle	POU, personal water filter. UF, hollow fiber. Including handle pump, activated carbon at cap. Lifetime filtration capacity: 4,000 and 6,000 L Cost: £ 120 to £ 160 per bottle; 30 to 26.66 £/m^3	15 nm MWCO of: 200 KDa	2 L·min^{-1}		A:p, B, C, E, G, H
	 LIFESAVER Cube	POU, UF, hollow fiber. Optional activated carbon disc. Lifetime filtration capacity: 5,000 L Dimensions: (H·W·L) (200·200·20) mm^3 Dry weight: 1.2 kg Cost: £ 120 per unit; £ 24/m^3	15 nm MWCO of: 200 KDa	0.75 L·min^{-1}	500 bar	A:f, B, C, E, G, H
	 LIFESAVER® C2™	POU, Ultra Nano filtration hollow fiber. Hand pump creates pressure. Membrane cartridges are replaced after 2-3 years (after 2 million L) Storage capacity: 750 L. Dry weight: 75 kg Lifetime filtration capacity: 2 million L.	15 nm	12 to 18 L·min^{-1}	at 600 mbar (flow is 6 L·min^{-1})	A:c, B, C, E, H, I
	 LIFESAVER hydrocarry	POU, UF, hydrophilic hollow fiber. Membrane material: eludium. Optional integrated hand pump. Activated carbon at the filter tap. Dimensions: (H·D·W): (16.5·12.6·2.2) in^3 . Dry weight: 725 g. Lifetime filtration capacity: 4,000 L	15 nm MWCO of: 200 KDa	2.5 L·min^{-1}	250 mbar	A:p (spectacularly designed for soldier), B, C, G,H, I
Sawyer USA Source: www.sawyer.com	 Sawyer MINI Water Filter	POU, MF, gravity filtration, hollow fiber, Lifetime filtration capacity: 378,541.18 L Weight: 56.7 g	0.10 µm			A: p, B, C, D, E, G
	 Sawyer PointONE™ Bucket	POU, MF, gravity filtration hollow fiber Bucket capacity: 20 L Lifetime filtration capacity: 3 million L Cost: US$ 75/unit; US$ 0.025/m^3	0.10 µm	1,800 L per day or 1 to 1.25 L·min^{-1}		A: h+c, B, C, D, E, G, J
	 Sawyer Point ZeroTWO™	POU, UF hollow fiber With adapter to tap syringe to backwash Lifetime filtration capacity: 378,541.18 L Cost: US$ 132/unit; US$ 0.3487/m^3	0.02 µm	170 L per day		A: h+c, B, C, D, E, G
	 Sawyer Personal Bottle	POU, MF. BPA free bottle, hollow fiber. Including backwash syringe weight: 155.9 g Lifetime filtration capacity: 3,785,411.78 L Cost: US$ 40/unit; US$ 0.01/m^3				A: p, B, C, D, E, G
Sotrad Water Source: www.sotradwater.be	 Sotrad Water Box Unit	UF, hollow fiber. Combination of UF and TwinOxide to create chlorine dioxide solution for disinfection. Consisting of 50 µm prefiltration, activated carbon to remove taste, odor. Backwash possibility. Weight: 58 kg Dimensions: (H·W·L) (0.5·0.5·0.9) m^3	0.01 µm	300 L·h^{-1}	0.5 to 1.5 bar	A: c, B, C, D, E, G, H, I, J
	Pump & Drink Unit	UF hollow fiber. Combination of UF and TwinOxide. Consisting of pre-filtration 80 µm; activated carbon filter. Manual pump. Backwash possibility. Weight: 110 kg Dimensions: (H·W·L): (900·600·900) mm^3	0.01 µm	800 L·h^{-1}	0.5 bar	A: c, B, C, D, E, G, H, I
	 Sotrad Water Mobile Units	Using energy. UF hollow fiber. Combination of UF and TwinOxide, activated carbon Dimensions: (H·W·L): (1·0.6·0.9) m^3 Weight: 100 kg	0.01 µm	1,000 L·h^{-1}		A: c, C, D, E, G, H, I

Note: the description in Table 1 refers to the membrane materials, operation (dead end/ cross flow, flat sheet/ hollow fiber/ lifetime or total capacity/ price per m^3 produced.

TABLE I. OVERALL REVIEW OF MF/ UF DWT APPLICATIONS – Part 2

Trade Mark	Product	Description	Pore size/ MWCO	Flow rate	TMP	Notification
Zenon Canada Source: www.homespring.com	 Homespring Purifier	POE, UF hollow fiber. Activated carbon prefilter. Automatic daily backwash, activated by electricity Dimensions: (H·W·L): (1880·450·450) mm^3	0.02 µm	14 to 17 $L \cdot min^{-1}$		A: h, C, D, G
Katadyn, Switzerland Source: www.katadyn.ch	 Endurance series	Products: Katadyn Pocket, Katadyn Combi, Katadyn Expedition, Katadyn Siphon, Katadyn Drip Ceradyn, Katadyn Drip Gravidyn. POU, MF, ceramic membrane. Personal or group consumption. Manual pump. Activated carbon prefilter. Lifetime filtration capacity: 20,000 to 100,000 L Cost: 79.95 to 1,500 (US$/unit)	0.2 µm	1 to 4 $L \cdot min^{-1}$		A, B, C, E, G, H, I
	 Backcountry series	POU, MF, 0.2 µm glass fiber filter, ceramic prefilter, and active charcoal filter. Lifetime capacity: 750 L to 1,150 L Cost: 74.95 to 99.95 (US$/unit)	0.2 µm	1 to 2 $L \cdot min^{-1}$		A: personal or group, B, C, E, G, H
	 Ultralight series	POU, MF, pleated glass fiber MF and granular activated carbon. Lifetime capacity 7,000 L Cartridge capacity: 100 L Cost: 44.95 to 109.95 (US$/unit)	0.2 µm	0.5 $L \cdot min^{-1}$		A: p, B, C, E, G, H
CleanWater Systems, Germany Source: http://www.cleanwater-systems.com/	 Outdoor Water Filter	POU, MF ceramic filter or nanofibrous web with activated carbon, CWS nano-cluster. Dimensions: (22 cm x 7.3 cm). Weight: 230 g Ceramics life expectancy: 4000 L, carbon cartridge life expectancy: 1000 L.	0.1 to 0.2 µm	0.5 $L \cdot min^{-1}$		A:p, B, C, G, H, I, J
	 Inline Water Filter	POU household/hotel/office. reinforced ceramic membranes, consisting micron ceramic filter or nano-fibrous web with activated carbon, CWS nano-cluster, nanosilver, nanocopper Dimension: (31 cm x 11.6 cm) Weight: 1,130 g Ceramics life expectancy: 30,000 L	0.1 µm	3 $L \cdot min^{-1}$	1 to 4 bar	A:h, B, C, G, H, I
MEMFIL Water Specialist, Malaysia Source: www.memfilwater.com	 Ultra Water Filter	POE. Domestic system. Indoor/ Outdoor UF, hollow fiber. Including pre-filters and activated carbon	0.01 µm	1,500 to 3,000 $L \cdot h^{-1}$	1.5 to 3.5 bar	A:h, C, D, E
GRIFAID Aquafilters, UK Source: http://www.grifaid.org/	 AquaFilter Family	POU. UF, Hollow fibers. Cross-flow operation. 120 µm mesh pre-filter Hand pumping. Back washing. Cleaning tablet included. Lifetime capacity 100,000 L Dimensions: (H·W·D): (480·100·140) mm3 Dry weight: 1.2 kg. Cost: £40 per unit	0.01 µm, 150 KDa	90 $L \cdot h^{-1}$		A:h, B, C, D, G
	 AquaFilter Community	POU. UF, Hollow fibers. Cross-flow operation. 120 µm mesh pre-filter. Hand pumping. Back washing. Cleaning tablet included Dimensions: (H·W·D): (480·250·250) mm^3 Lifetime capacity 1,000,000 L Dry weight: 12 kg. Cost: £250 per unit	0.01 µm	300 $L \cdot h^{-1}$		A:c, B, C, D, G
DESEE University of Kassel Germany	PAUL 	POU. Gravity driven UF, flat sheet membrane, polymetric material. Dead-end operation Membrane Lifetime : 10 years	40 nm	1,200 $L \cdot d^{-1}$ Flux: 5 $L \cdot m^{-2} \cdot h^{-1}$	Typical 0.04 bar Maximum: 0.08 bar	A:c, B, C, E, G, I, J

Note: the description in Table 1 refers to the membrane materials, operation (dead end/ cross flow, flat sheet/ hollow fiber/ lifetime or total capacity/ price per m^3 produced.

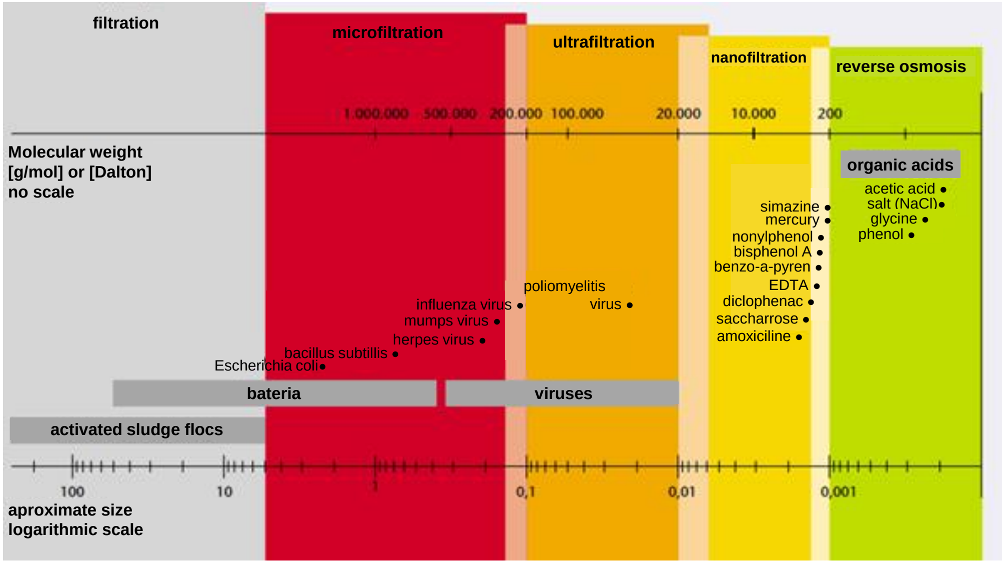

Figure 1. Different fields of application of membrane processes [4]

Another promoting factor for the development of membrane technology in potable water production is the increased stringency of drinking water regulations. With the outstanding capability of separation, membrane process is a promising solution which can be employed as a primary disinfection technique to meet many of the existing and anticipated drinking water standards [7]. As examples, the Surface Water Treatment Rule and the Groundwater Disinfection Rule promote the application of UF and MF for turbidity and microbial removal as the Surface Water Treatment Rules aims at preventing water borne diseases caused by viruses, *Legionella*, and *Giardia lamblia* [8]. Similarly, the Ground Water Rule aims at improving drinking water quality and providing additional protection from disease-causing microorganisms. These rules require that water treatment and disinfection systems are in charge of reducing the occurrence of these microbes. Whereas the Disinfectants/Disinfection by product Rules encourage the investment of NF and UF systems for DBP removal [9, 10].

IV. Conclusion

This paper has given out a full review over the recent development of MF/UF DWT systems which are in the form of POU, POE or decentralized plants. This summary contributes a huge updated information not only on technical specification but also the cost of the commercialized systems. This provides valuable information for all relevant scientists, being a necessary fundamental for the further researches on suitable and sustainable drinking water supply solutions, as well as the experimental works in the laboratory or the field tests.

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