Studies on pre-treatment of seawater using tubular ceramic MF membrane of 19-channel configuration

Tanmoy Dey, Ganesh C. Sahoo*, Somendra N. Roy, Sibdas Bandyopadhyay

CSIR-Central Glass & Ceramic Research Institute
196 Raja S. C. Mullick Road, Kolkata 700 032, India

Abstract: The pre-requisite for operation of a RO plant requires feed pre-treatment for removal of suspended solids, bacteria, colloidal particles, etc, which would otherwise lead to fouling of RO membrane. In recent years, the performance of polymeric membranes for seawater pre-treatment has improved significantly. This enables a more advanced SWRO system design by providing good quality feed for RO system, which results in increased reliability and lower water cost. However, use of disposable polymeric cartridge leads to higher running cost and increased plant downtime because of the need of frequent replacement.
The present study describes the pilot scale performance obtained on Arabian coastal sea water using tubular ceramic membrane (average pore diameter 0.1 µm) of 19-channel configuration as a pre-treatment system for RO. The MF pilot unit operated at fixed TMP of 1.2 bar with 40 hrs continuous run, using filtrate water of pressure sand filter (PSF) as feed. Flux obtained was around 350-370 LMH. Turbidity came down to 1.0 NTU and SDI value to less than 3. The filtrate obtained was virtually free from any suspended solids, colloids and bacteria, etc.

Index Terms: Membrane, Ceramic microfiltration, Reverse osmosis, Turbidity, Pre-treatment, Sea water.

I. INTRODUCTION

Reverse osmosis (RO) is currently one of the most prevalent methods used for seawater desalination. Research is still underway to reduce the operation costs and maintenance problems and thus improve the performance of RO systems. The most important maintenance problem associated with RO operation is membrane fouling; especially biofouling [1-3]. Hence, pre-treatment process is a significant factor for determining the success of the seawater reverse osmosis (SWRO) system. Many SWRO systems have failed because of inappropriate pre-treatment. A combination of techniques such as air flotation, flocculation-coagulation, lamella clarification, sand filtration, activated carbon treatment and filtration, followed by use of disposable polymeric cartridges to separate particles above 0.5 micron prior to reverse osmosis (RO) membrane have been widely utilized in seawater treatment plants as pre-treatment mechanism [2, 4]. Frequent replacement of the polymer cartridges after every 3 – 4 months not only involves higher recurring cost but also leads to more downtime, affecting production. However, ceramic microfiltration (MF) membrane operation based on cross-flow membrane filtration (CMF) technique is now considered an alternative pre-treatment process for sea water desalination using RO membrane. This is due to the advantageous features of ceramic MF membranes in fouling control and flux improvement [5, 6]. These special features extend the lifetime of RO membranes and enhance the economic feasibility of the desalination process [7, 8]. A study shows that MF membrane pre-treatment provides stable and predictable quality of feed water supply for RO system resulting in 40% increase in flux over traditional pre-treatment methods [9] using polypropylene membrane of 0.2 µm pore diameter in continuous mode under a pressure gradient of 100 Kpa. Energy saving in the order of 13-15% has been documented by Cardona *et al.* [10] with insertion of MF membrane pre-treatment system. Teng et. al. [11] observed that the higher permeate flux of the MF membrane pilot system was achieved at the expense of increased transmembrane pressure (TMP) in CMF mode of operation and periodic membrane washing. Silt Density Index (SDI) of the membrane filtrate was reported in the permissible limit of RO feed. Since, ceramic membranes have longer life span due to their chemical and mechanical stability, a feed pre-treatment system based on ceramic membranes may be a viable alternative to the existing pre-treatment processes. Ahmad and Mariadas [7] used tubular single channel ceramic membranes with nominal pore size of 0.2 µm and found that the insertion of helical baffle increased the permeate flux (520.8 LMH) up to 104.9% as compared to a system without baffle using feed of 1.0 g/l TiO_2 at 20 psi TMP. Clay-alumina-based low cost tubular ceramic elements of single and 19-channel configurations have been indigenously developed and characterized [12]. This has been used to demonstrate community supply of safe drinking water from iron and arsenic contaminated ground water under field condition [13] and the process has been documented [14, 15].
In this paper, a study has been presented on performance evaluation in pilot scale using indigenously developed low cost clay-alumina based tubular 19-channel ceramic MF membranes under cross-flow membrane filtration (CMF) mode fitted after PSF as a seawater pre-treatment system for RO.

II. WATER QUALITY FOR STABLE RO SYSTEM OPERATION

Feed water for RO systems should be bacteria free and maximum suspended solid load should not exceed 1.0 ppm for steady operation and longer life. This level of solid load cannot be minimized by the conventional feed pre-treatment processes such as flocculation – coagulation, lamella clarifier, pressure sand filter, polymer cartridge filter, etc. Most of the disposable polymeric cartridges required frequent replacement which results in high recurring cost.

A. Silt Density Index (SDI)

The RO industry relies on the SDI value of feed water prior to feeding it to the RO system [9]. It is observed that feed water processed by the installed indigenously developed ceramic MF membrane in pilot trial showed SDI value at always less than 3. This value is acceptable as feed for RO operation.

B. Turbidity (NTU)

Reference [9] reports that turbidity data is not a good measurement for RO, since it is not related to SDI. However, turbidity measurement has been reported (along with the SDI) by many researchers [8, 11] as supplementary evidence. There is some limitation on SDI used as indicator, as the SDI test does not give any information on the number of particles present [11].

III. PILOT AND MF MEMBRANE DESCRIPTION

Fig. 1 shows the schematic diagram of the pilot MF unit fitted after pressure sand filtration, so that total solids load, colloidal particles, turbidity, etc. could be minimized to some extent. It operates at a constant set of filtrate flow and performs time-based backwash sequences. The backwash flow is adjusted depending on the filtrate flow.

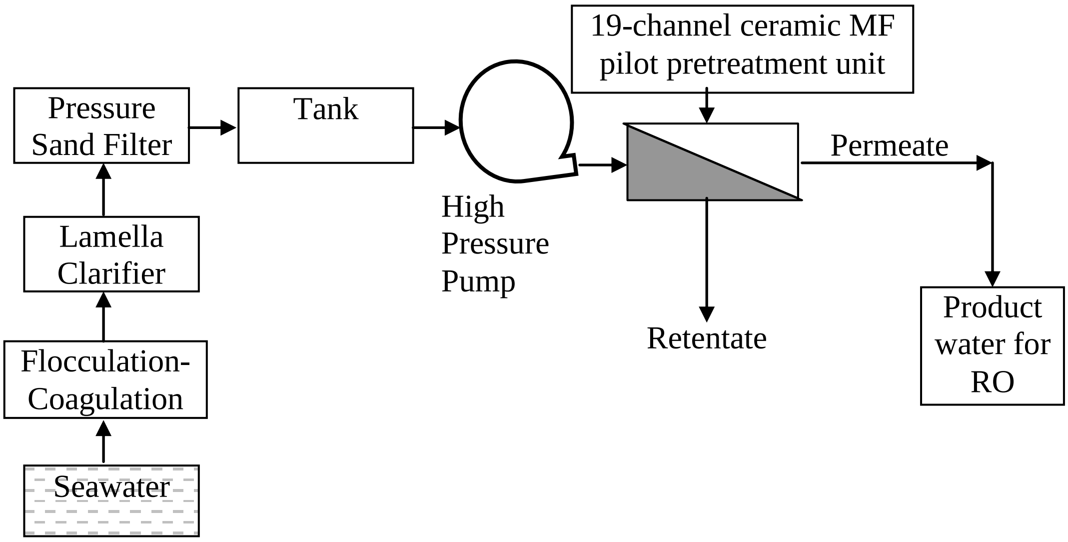

Figure 1: Schematic diagram of MF pilot pretreatment unit fitted after pressure sand filter of seawater for RO feed.

The ceramic MF pilot unit was equipped with 7-element 19-channel membrane having filtration area of 1.75 m^2. The physical properties of the indigenously developed low cost, clay-alumina based ceramic 19-channel MF membrane element are summarized in Table 1. Fig. 2 shows the configuration of the tubular 19-channel MF membrane element of 1.0 meter long. Pore size distribution of ceramic membrane has been characterized using Mercury Intrusion Porosimeter (PM60, Quantachrome, USA) and shows a unimodal 0.1 µm pore size distribution (Fig. 3). MF membrane surface feature analysis using FESEM (Leo S430i, UK) shows isotropic microporous structure as shown in the micrograph (Fig. 4).

Table 1: Physical properties of MF membrane

Properties	19 Channel Ceramic Membrane Element
Ceramic membrane O.D (m)	0.034
Channel I.D (m)	0.0042
Effective length (m)	1.0
Flow area (sq.m)	0.000263
Filtration area (sq.m)	0.25
Bulk density (kg/cu.m)	2.46
Water absorption (%)	9.6
Apparent porosity (%)	23.5

The inside – to – outside cross-flow membrane filtration (CMF) allows operation of permeate of pressure sand filter (Table 2) and facilitates backwash cleaning by clean compressed air to avoid cake layer formation leading to constant resistance to flow. As a result, TMP may remain constant with time during MF pilot run.

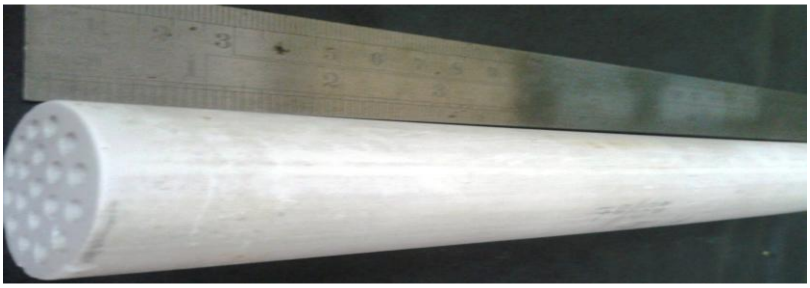

Figure 2: Configuration of low cost alumina based tubular 19-channel MF membrane element of 1 meter length.

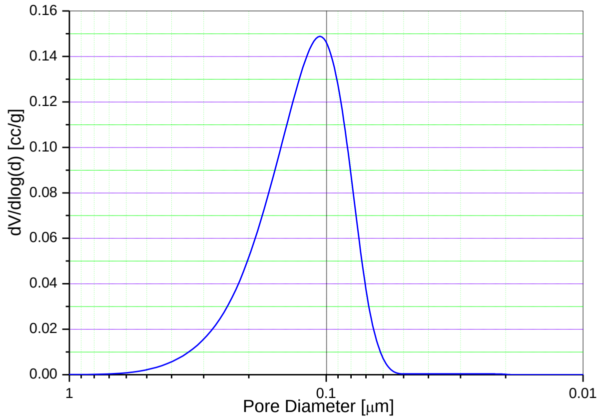

Figure 3: Pore size distribution of MF membrane.

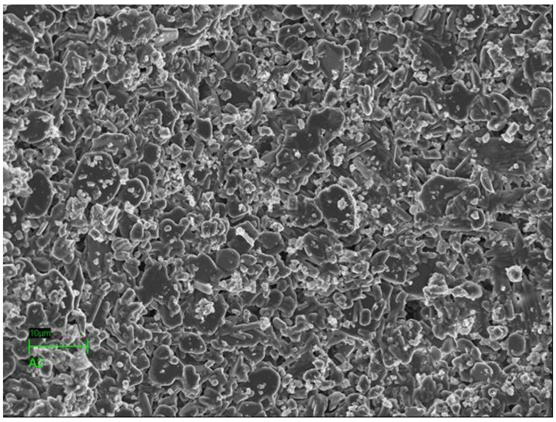

Figure 4: FESEM surface feature of MF membrane.

Table 2: Water quality at various stages of RO operation

Description	Particle size (µm)	Turbidity (NTU)	SDI	Total Coliform (cfu/100ml)
Coastal sea water	10 – 15	Up to 100	---	---
Permeate of lamella clarifier	10 – 12	40	---	---
Permeate of pressure sand filter	5 – 8	28	---	---
Permeate of 0.1 µm ceramic MF membrane filter	0.1 – 0.3	0.1 – 0.3	< 3.0	< 1

IV. RESULTS

A. SDI and Turbidity (NTU) of Filtrate

During pilot testing, MF membrane filtered water samples were tested for SDI and turbidity (NTU) every 5 hrs for a total of 40 hrs of run time. The results are shown in Fig. 5. It was observed that both the parameters fluctuated within permissible limits. SDI values remained below 3 during 40 hrs of continuous operation of the MF pilot unit with the adjusted backwash pulse at 30 minutes interval.

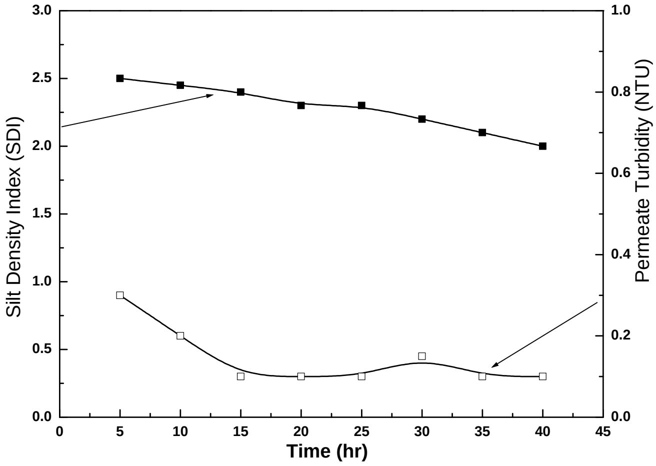

Figure 5: SDI and turbidity of MF permeate with time (hr).

B. Permeate Flux of MF Pilot Unit

Flux performance data is shown in Fig. 6 where TMP of 1.2 bar was maintained. There was minor reduction in permeate flux during continuous operation. This may be due to fluctuation of TMP and membrane fouling. But, it was regenerated by pulse backwash intermittently. Little fluctuation at TMP may result in cake layer formation. Intermittent pulse backwash led to maintain the fixed TMP at 1.2 bar and obtained steady flux of 350-370 LMH.

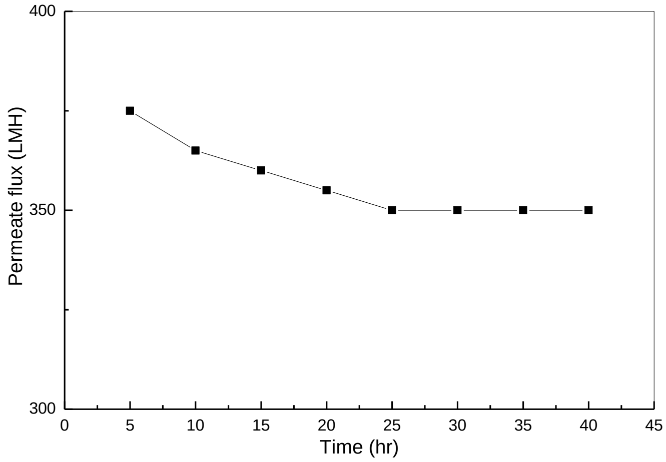

Figure 6: Permeate flux trend of the pilot unit.

V. CONCLUSION

Many RO plant trials have failed in the past because of poor pre-treatment of seawater, even with the use of disposable polymeric pre-filter cartridge and frequent replacement of the same. This study indicates that indigenously developed low cost, alumina based ceramic MF membrane of 19-channel configuration having 0.1 µm av. pore size is a suitable choice for the pre-treatment of RO plants, irrespective of foulants and suspended components such as solid loading, colloidal particles, bacteria, etc. MF membrane permeate flux obtained around 350-370 LMH having turbidity down to 1.0 NTU and SDI less than 3. The advantage of ceramic MF pre-treatment system over polymeric MF membranes are (i) membrane life is extended, (ii) can withstand extreme pH conditions, (iii) plant downtime is reduced, (iv) stable RO operation, (v) increase in flux rate and finally (vi) stable and predictable treated-water quality. Based on this study, MF pre-treatment unit of higher capacity are being installed in both Bally and Taki Municipality areas in West Bengal, India.

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AUTHORS

First Author – Tanmoy Dey, M. Tech.

Second Author – Dr. Ganesh C. Sahoo, Ph. D., CSIR-Central Glass & Ceramic Research Institute, 196 Raja S. C. Mullick Road, Kolkata – 700 032, India, gcsahoo07@gmail.com, gcsahoo@cgcri.res.in

Third Author – Dr. Somendra N. Roy, Ph. D., CSIR-Central Glass & Ceramic Research Institute, 196 Raja S. C. Mullick Road, Kolkata – 700 032, India, snroy@cgcri.res.in

Fourth Author – Dr. Sibdas Bandyopadhyay, Ph. D., CSIR-Central Glass & Ceramic Research Institute, 196 Raja S. C. Mullick Road, Kolkata – 700 032, India, sibdas4@rediffmail.com

Correspondence Author - Dr. Ganesh C. Sahoo, CSIR-Central Glass & Ceramic Research Institute, 196 Raja S. C. Mullick Road, Kolkata – 700 032, India, snroy@cgcri.res.in
Fax: 91 33 24730957, Tel: +91 33 24733469/96, +91 9433244935 (M)