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Chennai SWDP: Pre-treatment pilot test

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ABSTRACT

Chennai Seawater Desalination Plant (SWDP), with a production capacity of 100 MLD with a maximum extended capacity in future of up to 120 MLD, is located at Minjur (Chennai, India) and is being developed under a 25-year DBOOT contract. It will supply drinking water to the city of Chennai which currently experiences poor water quality, water shortages and restrictions. The Chennai SWDP is situated in close proximity to a river creek, an important port and an overpopulated urban area, resulting in a difficult to treat raw water source subject to very high suspended solids values, and a high level of pollutants. The different pilot plant treatment processes (gravity settling, flotation, gravity filtration and pressure filtration) can be connected in series or in parallel. Therefore, this paper describes the pilot plant studies performed to determine the feasibility, efficiency and best operation mode of the pre-treatment process designed for Chennai SWDP at the time of the publication as well as the main conclusions inferred from those studies. By applying the results of these studies to the full-scale design, the performance of the RO membranes will be kept optimal while reducing production and maintenance costs. It can be concluded that this pilot study has been important in developing the Chennai SWDP design, and provided valuable information for the plant start up and its operation later on.

Keywords: Pre-tretment; Seawater; Reverse osmosis; Desalination

1. Introduction

Water is indispensable for life and human development. In 2006, more than 700 million people in 43 countries live below water-stress threshold [1]. It is clear that competition for water will intensify in the decades ahead. Population growth, urbanization, industrial development and the needs of agriculture are driving up demand for water resource.

When natural water resources are no longer available or are scarce, alternative sources of water are the only solution. Desalination is being accepted by many countries, including India, to solve their water problems.

Desalination processes depend on several factors. One of them is the water quality. Depending on the location intake and the annual seasons, the water quality changes and the pre-treatment can be different for each case. Respect to reverse osmosis (RO), the water that reaches the RO membranes must have a minimum of quality and for that reason the pre-treatment plays a crucial role in these processes in order to assure the durability of the membranes and to produce the desired water.

The Chennai Seawater Desalination Plant (SWDP) is located at Minjur (Chennai, India) and has a production capacity of 100 MLD with a maximum extended capacity in future of up to 120 MLD. It is being developed under a 25-year DBOOT contract. The final goal of this study

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(which is still running) is to select the best pre-treatment as well as to determine the optimum value of the involved controlling variables for the Chennai SWDP. Later, these results will be checked under seasonal water quality variations. In this paper, Befesa Agua presents laboratory scale test and the results obtained up to date that this paper was written (last 3 months from the middle of June 2008).

2. Material and methods

2.1. Laboratory scale

The challenge was the optimization of the reagent doses and other parameters involved on the pre-treatment process. For that reason, it was necessary to carry out different experiments on a laboratory scale previous and during the operation on pilot plant scale. From May 2007, it was carried out different some test on lab scale, mainly Jar Test.

- Coagulant: $FeCl_3$ (99%) and $Ca(OH)_2$ (96%)
- Polyelectrolyte: The goal is to test different polyelectrolytes. Nowadays, only it has been tested the next: Magnofl oc 110L (Nalco) and LT25 LT27G (Ciba). Befesa Agua has planned to evaluate other polyelectrolytes
- Acid: H_2SO_4 (98%)
- Base: NaOH (98%)
- Disinfectant: The disinfectant selected was Cl_2. NaOCl was used.

In order to optimize the reagent doses different tests were made.

- Coagulation-flocculation: A typical equipment of Jar Test was used. It has 6 positions with speed governor for the agitation. Jar Test experiments were carried out in jars with a capacity of 2 L using seawater samples of 1.8 L. The coagulation time was 1 min with high speed whereas the flocculation time was 15 min with low speed. A final decantation stage was carried out during 40 min.

2.2. Pilot plant

In order to optimize the pre-treatment of Chennai SWDP, Befesa Agua has developed a pilot plant with a flow rate of 5 m^3/h and working 24 h/d. The pilot plant is located close to Chennai SWDP at Ennore Port and is composed by the following unit processes:

- Coagulation–flocculation: The coagulation is made before the flocculation tank by generating turbulences by means of a static mixer adding $FeCl_3$ (40%). The retention time is about 1 min. The flocculation is after coagulation step adding polyelectrolyte (nowadays Magnofloc 110 L). It has a vertical macerator and the retention time is 15 min. The concentrations of H_2SO_4 and $Ca(OH)_2$ were 90% and 92%, respectively.
- Flotation: This equipment corresponds to a dissolved air flotation (DAF) unit. It is located in parallel to the line of coagulation–flocculation. In this case, the coagulant and polyelectrolyte are added in the pipe previously to the DAF unit. It has a retention time of 30 min.
- Lamella clarifier: After coagulation–flocculation where chemicals are added. Its function is to remove suspended particles before filtration systems in order to increase the backwashing interval. It has a retention time of 40 min (6.5 m/h).
- Gravity filter: The plant configuration allows a direct filtration or filtration with previous coagulation–flocculation and settling (or flotation, alternatively). It is designed with a filtration velocity of 5 m/h and always works in the first stage. It has a washing system with water and air. This unit can take different filtration media configurations using sand, anthracite and expanded clay with different sizes. In Table 1, it can be observed the different filtration media configurations which are being tested on this time.
- Pressure filter: It is valid to make a direct filtration or filtration with previous coagulation–flocculation or flotation. It can be used like the first or second stage and has washing system. It has a filtration velocity about 15 m/h. In this case, the unit only take sand (Table 1)
- Disinfection: It was made on line using NaOCl (12%).

Initially, four operation modes were planned to be tested (Table 2). However, the experimental data and some meteorological problems (cyclones) made that

Table 1
Different media filters tested in the pilot plant

Gravity filter			Pressure filter		
Media filter	Size (mm)	Height (mm)	Media filter	Size (mm)	Height (mm)
Anthracite	0.8–1.6	450	Sand	0.4–0.8	650
Sand	0.4–0.6	400	Sand-Garnet	0.2–0.4	200
Gravel	2–6	100	Gravel	2–6	220
Gravel	5–10	100			
Gravel	10–20	100			

Befesa Agua changed the experimental strategy between 2007 and 2008. Actually, Befesa Agua was carried out different tests on pilot scale using the operation modes lternatively (depending on the needs) which can be observed in Table 2. Of course, in this paper, Befesa Agua presents the results obtained with the present experimental strategy, under which the plant is still being run. It can be observed that the operation mode number 3 has 2 options: (A) when the operation modes 2 and 3 are running at the same time and (B) when the operation mode 2 is not running and the coagulation–flocculation in chambers is available to be used by the operation mode number 3.

2.3. Strategy

The general strategy consists on: (1) studying the different doses of reagents and parameters involved on a laboratory scale as well as to evaluate new chemical reagents, (2) testing the different operation modes on a pilot scale and (3) checking the best operation mode under seasonal water quality variations: summer season (March–June), raining season (July–October) and winter season (November–February).

2.4. Analytical methodology

In order to determine the best experimental configuration, different water quality parameters have been analyzed using analytical methods recommended by APHA-AWWA-WPCF [2], Indian Standards [3] and USEPA [4]. The analyses were carried out by Befesa Agua in the laboratory located in the pilot plant and by an external laboratory which is contracted by Befesa Agua.

3. Results and discussion

3.1. Raw water

Analysis of the raw water was carried out regularly by Befesa Agua and external laboratories contracted by Befesa Agua. The main characteristic is the seasonal variability and the maximums of total suspended solids (TSS) obtained (60 mg/L). Respect to salinity and pH, reach values around 38 g/L and 8.1 respectively with a variable turbidity.

To ensure the results (SDI < 4, TSS around 1 ppm and turbidity < 1 NTU), a physical and chemical correlation was made between the seawater from Ennore Port pilot plant site and the site where the Chennai SWDP is located (near). The results were positives in the course of this operation time showing an excellent correlation.

3.2. Laboratory scale

3.2.1. Coagulation–flocculation–lamella settler

To establish the dose of $FeCl_3$, $Ca(OH)_2$, polyelectrolyte and the value of pH, it was necessary to make coagulation–flocculation experiments by means of Jar Test equipment. Befesa Agua decided to prove a greater number of experimental conditions unlike the external laboratory. For these experiments, the particle size range will be made by an external laboratory with a particle analyzer. The main and best results obtained till today are summarized next depending on the raw water conditions:

- Optimal dose of $FeCl_3$ and pH: around 10–15 ppm and 7.5 respectively
- Optimal dose of $Ca(OH)_2$ and pH: around 5 ppm and 8.4 respectively
- Optimal dose of polyelectrolyte Magnofloc 110 L: between 0.25 and 0.5.

3.2.2. Disinfection

After making the different experiments, it was obtained an optimal concentration of NaOCl of 0.5 ppm with a minimum residual concentration of Cl_2.

3.3. Pilot plant scale

Some modifications were made in the pilot plant to operate the whole line including all systems except DAF unit as well as to operate using 2 lines in parallel. These operation modes can be observed in Table 2. Therefore, in June 2008 the new tests on pilot scale were started again using the whole operation mode and later the operation mode 3B (C − F + GSF + PSF) because the lamella settler suffered some problems that are being solved at the time that this paper is being written. It was decided to operated with two kinds of filters in order to evaluated if it is necessary to install one or two stages on industrial scale.

Table 2
Operation modes planned to test in the pilot plant

Operation mode	C-F chamber	C-F line	Lamella settler	Gravity filter	Pressure filter	Flotation
1	1°		2°	3°	4°	
2	1°		2°			
3A		1°		2°	3°	
3B	1°			2°	3°	
4	1°					2°

Previously to start each test, a deep cleaning of the pilot plant was made including several backwashes of the filtrations systems in order to get similar conditions to the initials. In addition, a disinfection with a NaOCl was made despite the daily dose of this reagent. All graphs are divided in two parts by a vertical line: the first (left) corresponds to the operation mode 1 and the second (right) corresponds to the operation mode 3B. As well, it can be observed the doses of reagents applied by means of horizontal lines.

In Fig. 1 it can be observed the values of turbidity as a function of the operation time. In the first part, it can be observed that the turbidity decrease with the operation time due to the changes on the water quality. However, the most significant is that the TSS concentration for the lamella settler outlet is higher than TSS concentration of raw water. When the operation time increases, this difference is less. This is due to the purge in the lamella settler was made reducing the interval between every purge ranged from 12 to 2 h/d (optimal 6 h) which indicates that something wrong was happening in this system (the product water was good and the backwashes for GSF and PSF were 1 per 1–2 days and 7–9 days respectively). For that reason, Befesa Agua decided to study this system in depth making specific test to find the problem and solve it. Once the problem was found, nowadays the lamella settler is being fixed. While this happening, Befesa Agua stated to work using only the filtration systems (second part).

In this new experiment, initially the raw water was directly to the filtration systems (GSF and PSF respectively) without using any chemical reagent. In can be observed that the turbidity for raw water started to increase due to the seawater conditions in this season. However, the values obtained for GSF and PSF were low but not all right to go to the RO membranes (around 1 NTU for both filters which indicate that the PSF was working less that it was expected).

For that reason, it was necessary to decrease these values in order to get the water quality for RO. From this point, Befesa Agua started to dose 5 ppm of $FeCl_3$ previous coagulation–flocculation step. Now the values of turbidity decreased for GSF and PSF around 0.2 NTU more and less which now is a better value. Again, the effect on the turbidity by PSF was small.

The next test consisted on decreasing the $FeCl_3$ dose up to 2.5 ppm. It was found values of turbidity very similar to the previous test, and therefore, saving money in the O&M for the main plant.

Fig. 2 presents the same scheme that Fig. 1 but related to TSS. The evolution of the TSS results were similar that the turbidity ones. To emphasize that the TSS were more and less constant in the first and second part respectively except when the raw water was filtered directly without any chemical reagents and how happened with the turbidity. In this case, the TSS values were around 1 ppm depending on the case (directly filtration without chemical reagents reached values of 2–3 ppm). These values, initially, it could be very good to enter to RO membranes. Again, the PSF seems do not work because it was obtained values very similar to GSF.

Fig. 3 is similar to the previous ones but now it can be

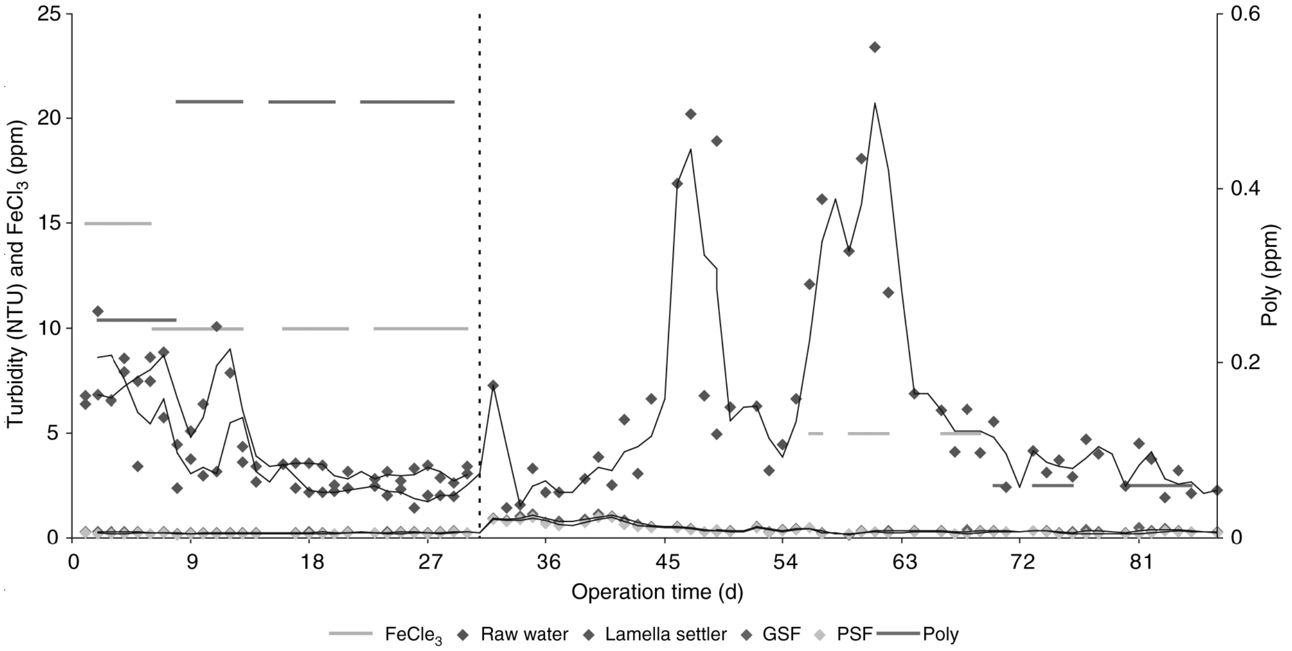

Fig. 1. Pilot plant: operation time vs. turbidity.

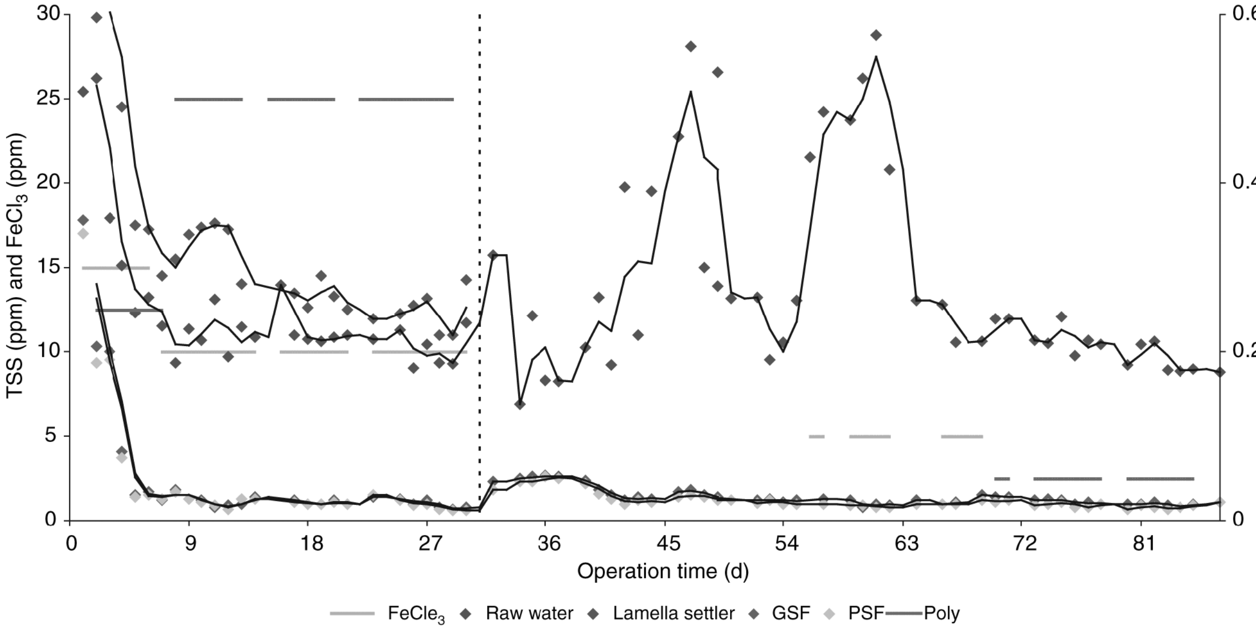

Fig. 2. Pilot plant: operation time vs. TSS.

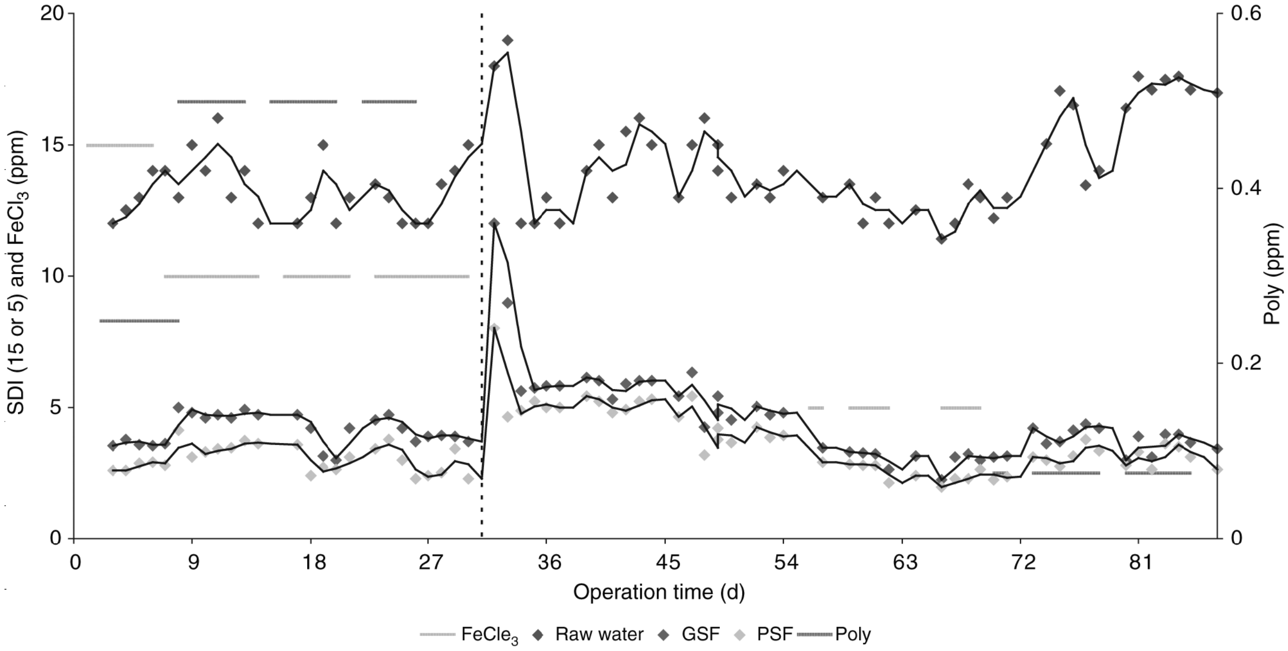

Fig. 3. Pilot plant: operation time vs. SDI.

observed the evolution of Silt Density Index (SDI) for raw water (5) and both GSF and PSF outlet respectively (15). In can be observed that the SDI (5) ranged from 12 to 16 (more and less and depending on the case). However, in both parts the SDI reached good values being the worst when the raw water was filtered directly without chemical reagent; this result is in consonance with the results found for turbidity and TSS. However, in the second part was reached the best results dosing 2.5 ppm (again in consonance with the results obtained for turbidity and TSS). In this case, the SDI values were around 2.5–3 in contrast to 3–4 for a dose of 5 ppm of $FeCl_3$.

Related to the backwashing interval, in the first part it was reached for GSF and PSF an interval of 30 h and

2–3 days for GSF and PSF respectively. On the second part (without lamella settler) was reached for GSF an interval of 10 days and for PSF in time did not reach the backwashing level. However, as it was explained before the water quality for this conditions was not all right and therefore it was dosed $FeCl_3$. For 2.5 ppm, a good water quality was found with an interval of 30 h for GSF and once per week for PSF. These values are agreed with the values established in the design of Chennai SWDP (every 1–2 days and every 7–9 days, respectively).

It must be highlighted that turbidity measurements, in both gravity and pressure filters, were within the range of 0.1 and 0.2 NTU. Therefore, it might appear that the use of the pressure filter could even be discarded under the conditions tested up to now. However, tested chemical doses are so high that would hardly make the operation and maintenance (O&M) economically feasible and all they show to this extent is that the process can be controlled. Chemical reagents must decrease in order to save operation costs and it should be expected that at that point the pressure filter would effectively work.

In regard to the disinfection system, the optimal dose of NaOCl obtained on a laboratory scale was used. After obtaining the colorimetric measures, it was necessary to increase the dose up to 0.75 in order to obtain a minimum residual concentration of Cl_2.

3.4. Clarification

The sludge from lamella clarifier was removed every 4–5 h. These values are in agreement with the values established in the design of Chennai SWDP (2.6 h).

4. Conclusions

The obtained results are not conclusive since the study has not been finished. In other words, it is necessary to fix the lamella settler to have an idea of its yield. In any case, it can be observed that the raw water can be treated directly by filtration systems. This indicates that with a previous lamella settler working the filters should work better, in other words, the backwashes would be less. Also, when the raw water quality is good, the lamella settler could be by-passed. On the other hand, it can be also observed that the chemical doses were different when the raw water is treated by the lamella settler or the filtration systems. A challenge is to make the PSF work better or discard it and reduce the global consumption of chemical reagents. These works are remaining and must be developed in the near future.

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