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ZERO BRINE

D3.8 Report on the operation & optimization of the pilot system for the treatment of textile effluents

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Executive Summary

ZERO BRINE project objectives include demonstration of circular economy methodology in textile industry. In this manner, the developed Textile Pilot System (TPS) located at Zorlu Textile Industry (Luleburgaz/Tekirdag/Turkey) was operated for about a year from June 2020 to May 2021 within the context of Subtask 3.2. Zorlu Textile is operating in the field of manufacturing polyester yarn and cotton home textile products.

The TPS was designed for the treatment of reverse osmosis (RO) retentate of Zorlu Textile to recover recyclable salt as well as reusable water streams. The TPS comprised of a primary pre-treatment as well as a secondary concentration and softening stages. The pretreatment was designed to remove impurities in the RO retentate, whereas, in the following stage the pretreated RO retentate was concentrated and further softened to conform to the textile dye processes prerequisites.

The pretreatment stage incorporated ozone oxidation and a two stage nanofiltration (NF) membrane system. A RO unit was installed to concentrate the pretreated retentate. A cationic ion exchange (IEX) column was used to remove calcium and magnesium ions and obtain the softened product stream.

The TPS was designed and constructed to facilitate resilient operation practices. Along these lines two different configurations were tested: 1) IEX softening the NF permeate, which then was concentrated by RO, 2) RO concentrating the NF permeate, followed by IEX softening the RO retentate.

The rearrangement of treatment scheme was made based upon the experienced gained throughout the operation period and the results of monitoring activities. Both of the tested configurations showed satisfactory results. However, placing IEX after RO unit showed distinct advantages, especially from the point of view of operational ease. The applied pressure, recovery and fluxes of the NF and RO membrane processes were also adjusted. 50-60% salt recovery along with 70-95% reusable clean water recovery were attained throughout operation of TPS. The results obtained were also assessed for energy consumption, CO_2 mitigation prospects and financial issues including CAPEX and OPEX calculations and assessments within WP8. Textile fabric dye tests were applied by using the recovered salt stream from the TPS. The results of the dye tests were satisfactory. The performance of TPS throughout the operation is intended to be used for the assessment studies in WP7, subtask 7.1.4.

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1. Introduction

1.1. Textile Effluents & Environmental Problems

Rapid population growth along with industrialization brings the problem of pollution and depletion of water resources [1]. One of the important measures taken for the sustainability of water resources is the reuse of treated wastewater [2]. Industries that use large amounts of water, especially the textile industry, cause alarming pressures on natural water resources [3]. The specific water consumption in textile dyeing-finishing processes varies between 50 [4] and 400 L/kg of product [3], and is even higher for some specific products such as wool [5]. The specific water consumption in textile dyeing-finishing processes may vary depending on the fiber type, technical and technological process characteristics. The high water use of the textile industry is accompanied by high amount of wastewater generation. Textile wastewater contains color, organics, heavy metals, dispersing agents, softening agents and surfactants that affects the waste water and make its treatment difficult, as well as salts due to its high salt usage [6]. Textile wastewater is typically characterized by high chemical oxygen demand (COD), biochemical oxygen demand (BOD), color, and salt content. Discharging these wastewaters into receiving waters without adequate treatment may cause irreversible environmental effects [7].

Reverse osmosis (RO), one of the membrane separation technologies, is widely used in wastewater treatment. Besides its high removal efficiency, RO also produces concentrated wastewater called RO concentrate (retentate). Generally, RO retentate is characterized by high salinity and high organic content. If RO retentate is discharged directly into the natural environment, it will cause serious pollution [8].

Salinization is a worldwide problem affecting various types of land use: both agricultural and non-agricultural land, irrigated or non-irrigated, can be prone to salinization. According to FAO, soil salinization is considered to be the second largest cause of land degradation. Soil salinity is a major problem as it threatens agricultural sustainability and negatively affects crop production. In addition, salinization is a serious threat not only to arable land but also to water resources (freshwater lakes and wetlands, rivers and streams) [9].

In recent years, there appears to be an increase in studies of near zero liquid discharge (ZLD) or ZLD to eliminate RO retentate and thus reduce the risk of contamination. By treating the RO retentate, the RO retentate volume can be minimized as much as possible to achieve ZLD. Thus, while it is conceivable to recover salt, which possesses an important environmental problem, it is also possible to minimize the environmental risk by recovering a large part of the wastewater [8].

1.2. ZERO BRINE Project: WP3 Textile Demonstration

Work Package 3 emphasizes development of innovative solutions to achieve circular economy by closing the cycles in coal mining and textile process industries. The pilot system (TPS) at Zorlu Textile in Turkey aimed at recovering the brine from the RO concentrate (retentate) originating from the current advanced wastewater treatment and reuse system. Zorlu Textile industry is operating in the field of integrated polyester yarn and cotton home textile manufacturing. The textile wastewater generated from Zorlu Textile is treated with physicochemical, biological methods and membrane processes at advanced wastewater treatment plant in order to obtain a reusable stream. Currently, RO retentate of the advanced wastewater treatment system is circulated back to the input of the physicochemical and biological treatment plant.

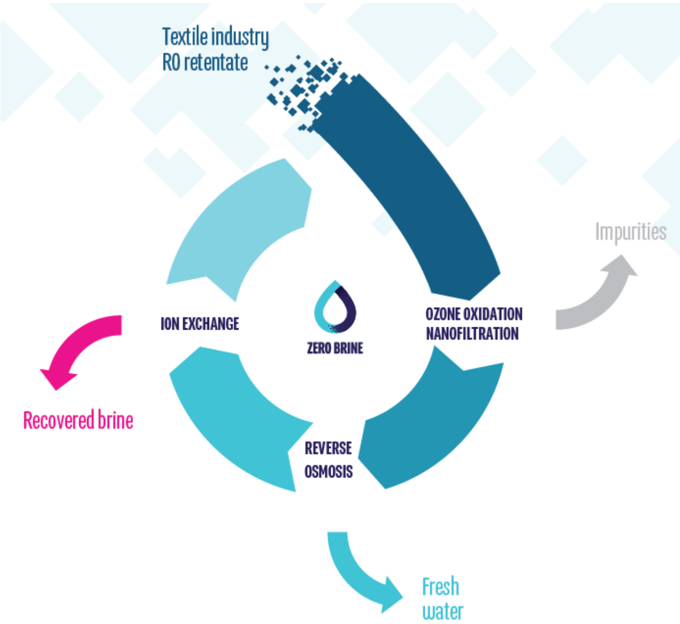

Figure 1 General scheme of the proposed approach to textile RO retentate water treatment

1.3. Scope of Deliverable

This deliverable presents the results from the operation and optimization of the TPS developed by TUBITAK. The system was installed on 22/02/2020 and operated during the period of 01/06/2020 to 30/05/2021.

The technology proposed in the ZERO BRINE project was aimed to recover high quality processes water and salt solution which can be used in dyeing processes. To assess and optimize the plant performance, two different configurations were tested. Dyeing test were also performed by using the recovered salt solution from TPS.

The treated and recovered concentrated salt solution from the TPS could be reused in the dyeing baths of textile plant and/or utilized for other processes, by other companies which may require salt. The TPS was mounted in a 40’ container (12.03 x 2.34 x 2.39 m). The installed power was 25 kW, the operation power at full capacity was 15 kW. TPS components were grouped into retentate feeding, pre-treatment, concentration and softening stages. The process design was accomplished to provide flexibility for operation in terms of flow rates and sequence of the treatment units to secure process optimization.

2. Technical Design and Operation Phases of the TPS

The input flow rate of the advanced treatment system in Zorlu Textile for reuse is 110 m^3/h, whereas the flow rate of RO retentate is about 20 m^3/h. During the TPS plant run, the portion of RO retentate was fed to the pilot plant, where it was treated by the oxidation-NF-RO-IEX system described further on. The general characterization of RO retentate is given in Table 1. Accordingly, RO retentate has high total hardness, salinity and color as well as organic matter and sulfate contents.

Table 1 Characterization of retentate

Parameter	Unit	RO Retentate
		Average ± Standard Deviation
pH	-	8.2±0.1
Conductivity	µs/cm	10630±253
TDS	g/L	5,2±0.5
COD	mg/L	220±150
Color	Pt-Co	40±18
Ca^{2+},	mg/L	80±4.5
Mg^{2+}	mg/L	28±2.3
Cl^-	mg/L	601±156
Na	mg/L	1359±180
SO_4^{2-}	mg/L	1350±105
Total Hardness	$CaCO_3$/L	340±27

The general flow scheme of TPS is given in Figure 2, whereas, Annex 1 (Figure 31, Figure 32, Figure 33) presents the treatment and auxiliary units implemented. The layout of the units in the container is illustrated in Figure 34 (see Annex 1).

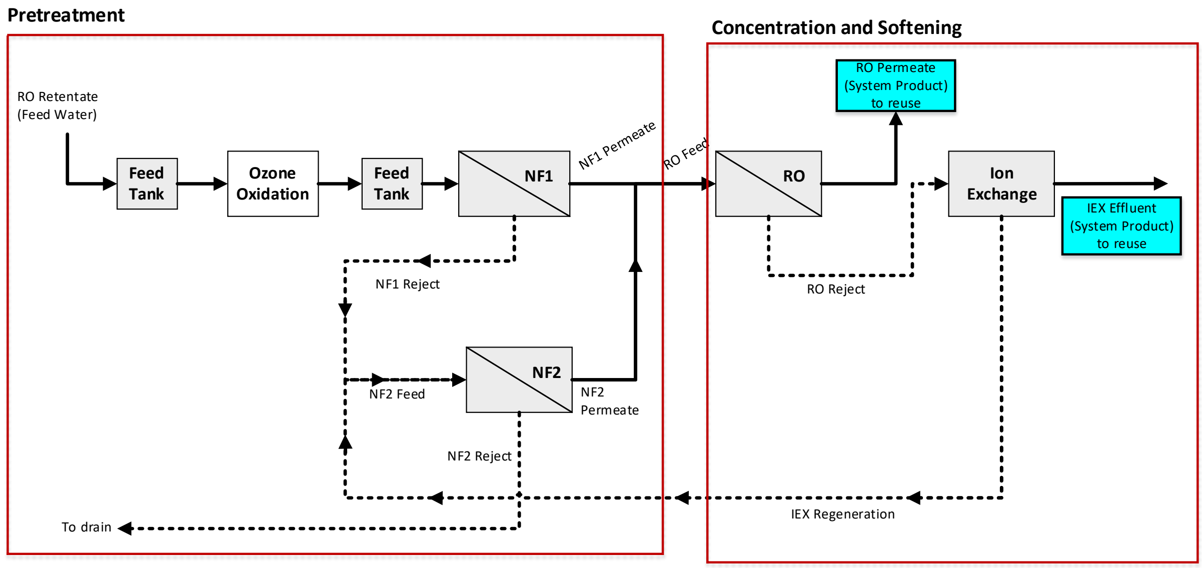

Figure 2 The general layout of the pilot plant

The TPS was operated with two distinct operation configurations namely Phase-1 and Phase-2. The IEX unit was installed following to the RO unit for the Phase-1 (Figure 2) whereas, for the Phase-2 IEX was placed prior to the RO. Both operation schemes showed characteristic advantages and disadvantages. Phase-2 provided operational ease due to the reduced membrane fouling, whereas Phase-1 resulted in lower hardness in the concentrated salt stream product. Moreover, some alterations were also tested for the recovery and the pressures applied for the NF and RO processes.

2.1. TPS Start-up

Following to the delivery and installation of TPS the treatment units, relevant connections, sensors and measurement devices were tested for leaks and operation accuracy. During the start-up period TPS was run 3 days a week and 8 hours a day starting from June 2020 until the end of May 2021, at a flow rate of 750 L/h. Approximately a total of 60 samples were taken and analyzed during this period. Cycle mode operation was practiced for treatment units.

The operational drawbacks encountered included pump failures, need for pipeline revisions, need for new membranes and associated membrane replacements, requirement for additional storage tanks for RO retentate due to occasional limited or interrupted supply. The operating conditions of the treatment units in TPS are given in Table 2 for start-up phase. The performances of the treatment units were evaluated by taking samples from inlet and outlet of each unit and analyzing them. The sampling points are illustrated in Figure 3, whereas, the composition of the samples are given in Table 11 (see Annex 2).

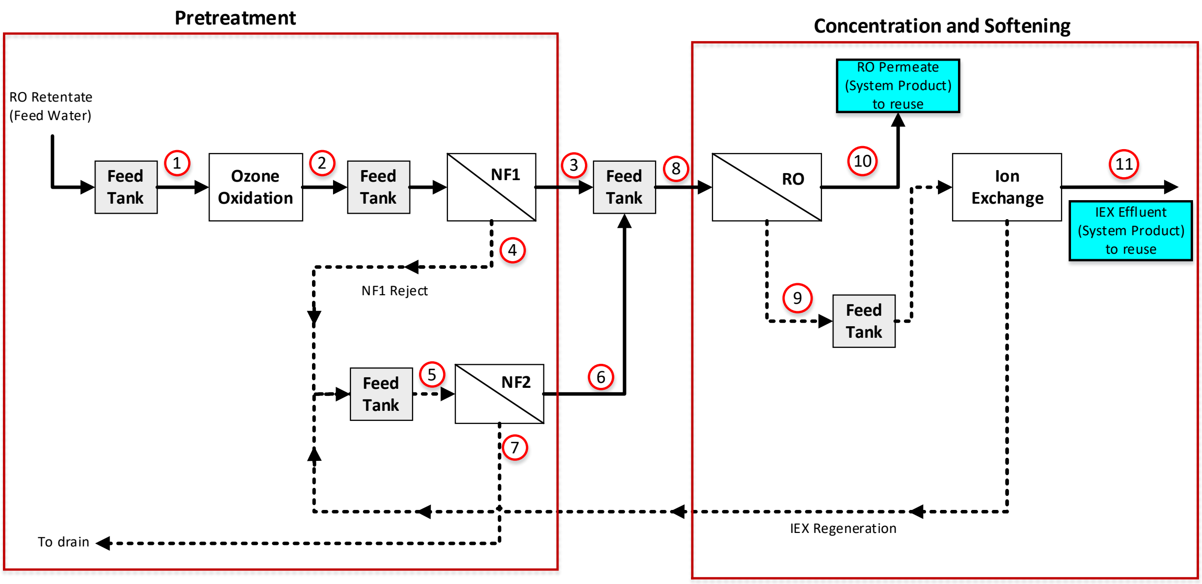

Figure 3 Sampling points for the plant process streams (1) raw RO retentate, 2) ozonation effluent (ozonation+activated carbon+UV), 3) nanofiltration-1 permeate, 4) nanofiltration-1 retentate, 5) nanofiltration-2 feed, 6) nanofiltration-2 permeate, 7) nanofiltration-2 retentate, 8) reverse osmosis feed, 9) reverse osmosis retentate, 10) reverse osmosis permeate, 11) ion exchange effluent (product)

Table 2 Operating conditions applied at the start-up phase of the systems in the pilot plan

Ozone		NF1		NF2		RO		IEX	
Contact Time, h	2	Number of stages	2	Number of stages	1	Number of stages	2	Operation flow rate, BV/h	2
Ozone dosage, g O_3/h	100	Total elements per stage	2	Total elements per stage	2	Total elements per stage	2	Resin volume, L	150
		Pressure, bar	10	Pressure, bar	20	Pressure, bar	30	Resin name	Dowex-HCR-S/S
		Recovery,%	60	Recovery,%	60	Recovery,%	70	Resin type	Strong acid cation
		Mode	Concent. Recyle	Mode	Concent. Recyle	Mode	Concent. Recyle	Regeneration cycle, Bed Volume	100

TPS was monitored by taking 4 samples from each sampling port during the start-up period. The performances of each treatment unit are given in Table 3. The contact time of the ozone oxidation system was applied as 2 h initially, and color and COD removal efficiencies were obtained as 86% and 56%, respectively.

Since the efficiencies were slightly lower than the efficiencies attained during laboratory tests, the contact time of 3 h was applied for the following runs. In addition, at the end of the start-up phase, RO retentate was concentrated approximately twofold and a brine solution with a TDS concentration of approximately 10 g/L was obtained. In general, NF and resin systems have shown satisfactory performances (Table 3).

Table 3 Performance of the pilot plant in the start-up phase

Removal or reject, %	Ozone	NF1	NF2	RO	IEX
TDS	-	19	36	85	-
COD	56*	21	53	87	-
Color	86*	75	89	>95	-
Ca	-	67	61	95	>99
Mg	-	62	64	96	>99
SO_4	-	37	70	>99	-
T. Hardness	-	72	67	96	>99

* This values achieved by ozone+activated carbon+UV system

2.1.1. Membrane Conditioning

Membrane conditioning process was accomplished based on the instructions provided by the membrane producers. In this manner, the membrane systems was operated by gradually increasing the inlet pressure. Flow, feed, permeate and concentrate streams pressure, temperature, operation period, pH were monitored and recorded. The fluxes determined are shown in Figure 4. Considering the flux values recommended in the membrane producer guide, no adverse effect were observed. Flow, flux, pressure and EC rejection data determined are given in Table 4.

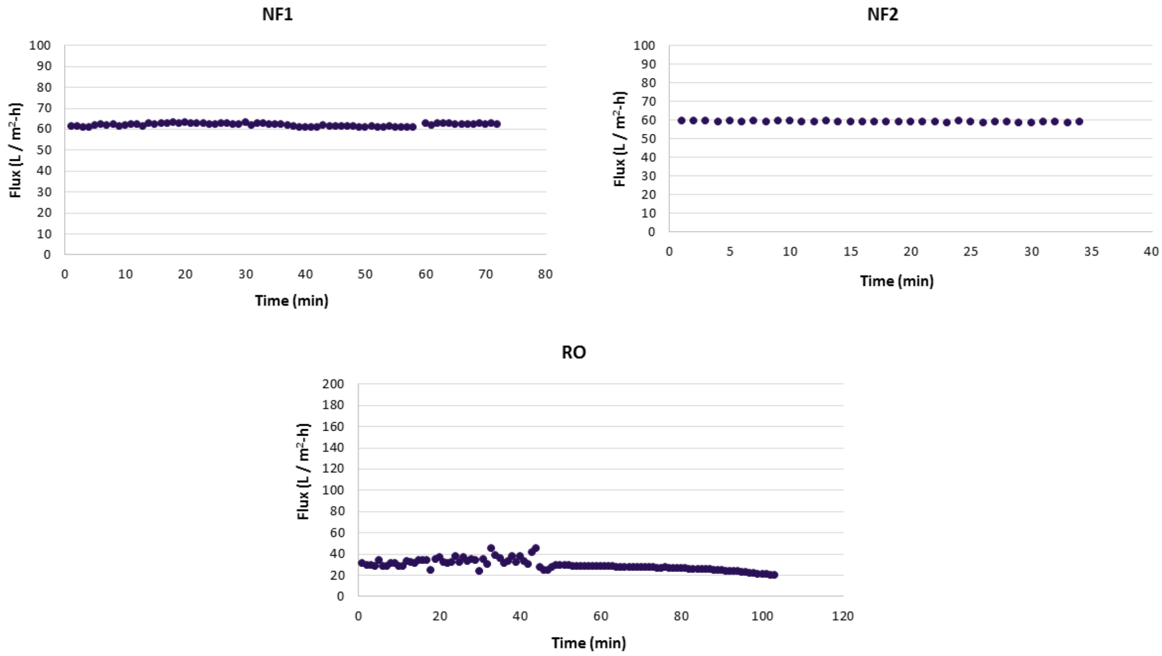

Figure 4 NF1, NF2, and RO membrane tap water fluxes

Table 4 Membrane conditioning tests results

	NF1	NF2	RO
Feed Water	Tap water	Tap water	Tap water
Membrane	NFG	NFG	BW30
Operating Flux, LMH	95-100	95-100	50
Total membrane area, m²	32.8	16.4	31.6
High pressure pump capacity, %	52	35	75
Average Feed EC	276	255	285
Average Permeate EC	251	231	<10
EC removal, %	9.1	9.8	>95
Flux, lmh	62	59	30
Flow, L/h	~2000	~960	~950
Recovery,%	68	25	35
Feed Pressure, bar	8	9	15
Retentate Pressure, bar	4	5	14

2.2. Phase-1 Results

2.2.1. Ozone Oxidation Unit

The ozone oxidation unit was operated with a contact time of 3 h and an ozone dosage of 100 g O3/h. Subsequently, retentate was passed through the activated carbon column and through the UV system before fed into the NF-1 feed tank. At the outlet of ozone oxidation unit, 75% COD and almost 100% of color removal were attained (Table 12 in Annex 3), whereas COD and color concentrations were on the average 54 mg/L and 1-2 Pt-Co, respectively.

2.2.2. Nanofiltration 1 (NF-1)

The aim was to pass high amount of salt into permeate, while rejecting color, COD and hardness. At the commencement, the operation was carried out by targeting the permeate flow of 350 L/h. The feed pressure was observed as 5 bar. The initial recovery was chosen as 60% to prevent sudden membrane fouling. In order to reach the targeted recovery, the system was operated in concentrate recycle mode. Therefore, the concentrated stream was circulated to the NF-1 feed tank during the operation. Meanwhile, although the concentration of pollutants in the feed tank increased, no major fluctuations in pollutant rejection efficiencies were observed. After 12 days of operation, the pressure was set at 10 bar. Average permeate flow rate at 10 bar was determined as 1660 L/h which corresponded to the flux of approximately 50 LMH. Although, the recommended flux for NFG was 95-100 LMH, lower fluxes were operated in order to avoid sudden blockage problems. The flux trend detected during Phase-1 is shown in Figure 5. While the tap water flux of NFG was determined as 62 LMH, the average flux determined for the RO retentate feed stream was 29 LMH. This flux reduction can be explained by the concentration of pollutants in the feed retentate fouling on membrane pores. The flux rate observed at the end of the phase-1 decreased by 24% as compared to the initial flux. Fluxes did not increase with the membrane flush procedure performed every 3-4 cycles. During this period, chemical cleaning was not performed. The effect of chemical cleaning on the recovery in the NF processes was investigated during the Phase-2 tests.

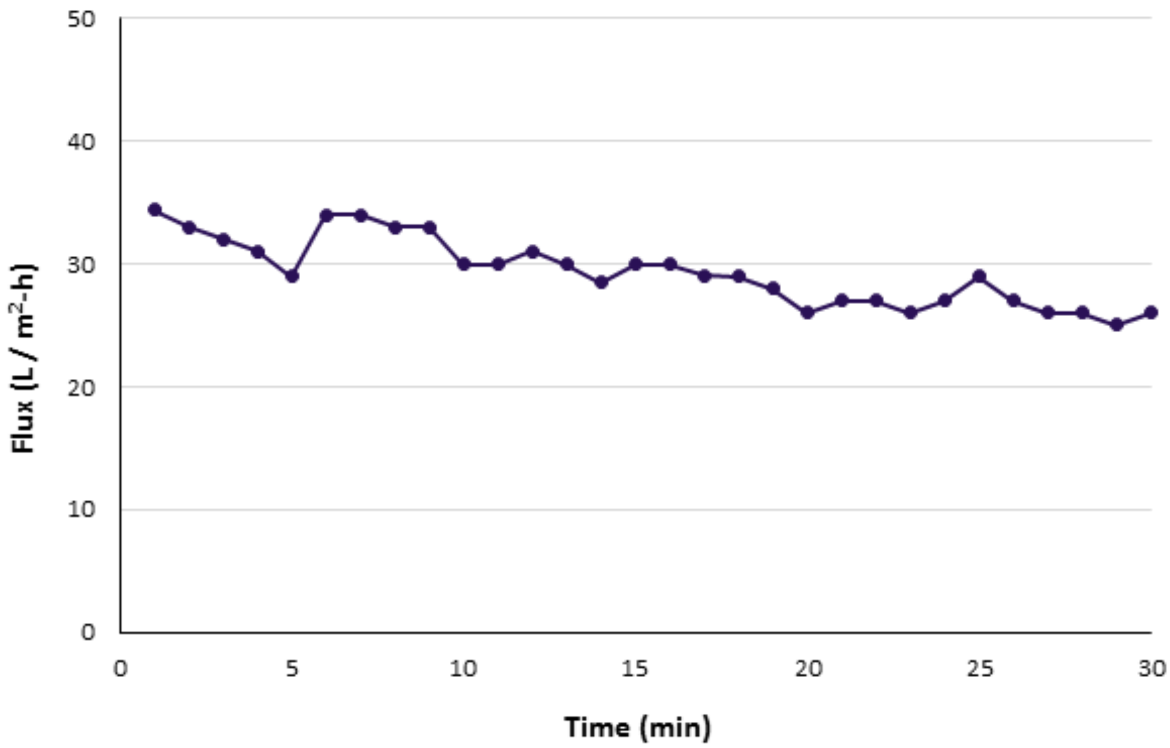

Figure 5 Flux rates for NF-1 at Phase-1

30 samples were taken and analyzed at different periods. The results of the parameters analyzed in the feed, permeate and retentate flows of the NF1 process are given in Table 13 in Annex 3.

For NF and RO processes, if a contaminant's feed concentration, its rejection rate for membrane, and concentrations in permeate are known, its concentration in the concentrate (brine) stream can be estimated by the following mass balance equation.

$$Q_{feed} x C_{feed,i} = (Q_{permeate} x C_{permeate,i}) + (Q_{retentate} x C_{retentate,i})$$

Q_{feed}: Flow of feed stream, L/h

$C_{feed,i}$: Concentration of pollutant i in the feed stream

$Q_{permeate}$: Flow of permeate stream, L/h

$C_{permeate,i}$: The concentration of the pollutant i in the permeate stream

$Q_{retentate}$: Flow of retentate stream, L/h

$C_{retentate,i}$: The concentration of the pollutant i in the retentate stream

In addition to the analyzes carried out for all flows, the concentrations of the relevant parameters were also estimated by using mass balance approach and compared with the measured values. Accordingly, the analyzed and calculated concentrations in the retentate stream of the NF1 process are shown in Figure 6. Relatively slight variations for retentate measured and calculated data might be due to the concentrate circulation mode batch operation which results continues concentration increase in feed. In order to avoid from that for the assessment several samples from the feed was taken at different intervals and the mean value was used as input for calculations. However, this approach may not fully represent the operation conditions and measured and calculated data may vary.

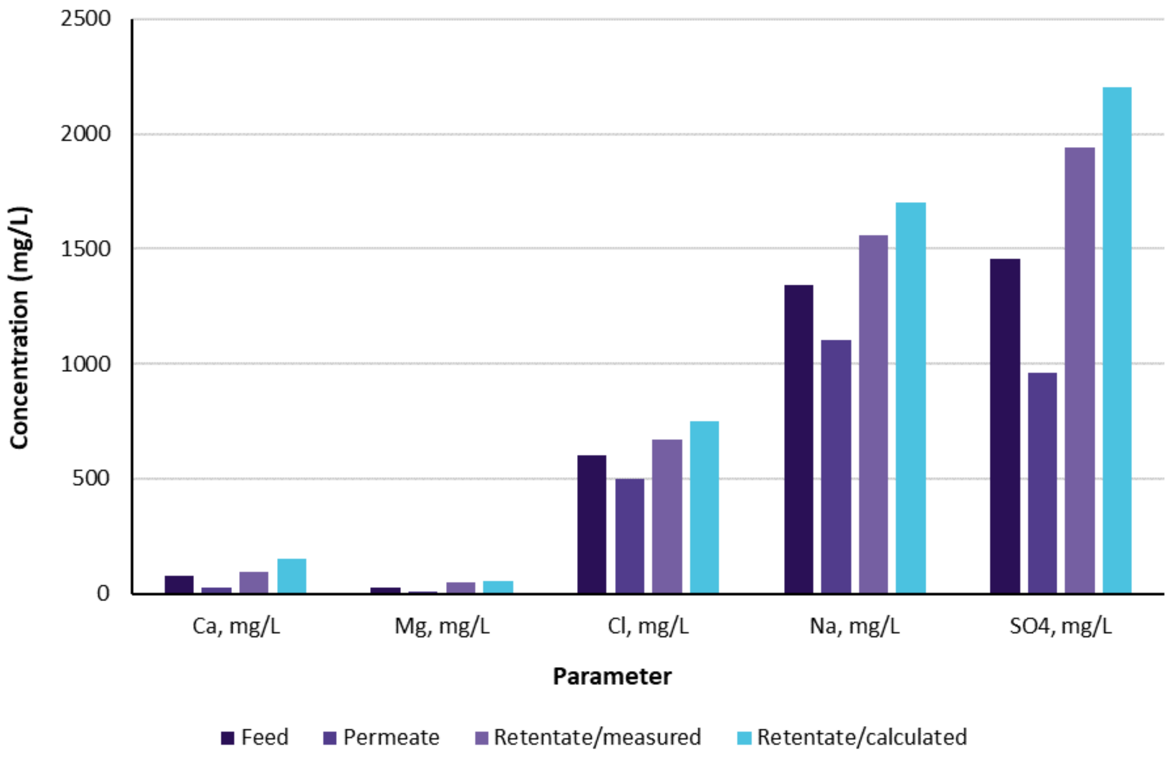

Figure 6 Analyzed and calculated concentrations of ions for NF-1

During the operation, an average TDS rejection of 20% was determined. In accordance with the membrane tests of the membrane producing company, 10% NaCl rejection was obtained at 7.5 bar, with 2000 ppm NaCl solution. Hence, the rejection increases with the increasing feed NaCl concentrations and operating pressure. However, 80% of the salt was recovered by the NF system operated in the presented work.

The average COD, sulfate and total hardness rejections were 24%, 34% and 68%, respectively (Figure 2.6). Since most of the color was removed by ozonation process, the NF1 permeate color remained below the measurement limits. Similarly, COD rejection efficiency was determined to be low in NF-1 since, most of the COD was also removed in the ozonation process, and an average of 40 mg / L COD was detected in the NF permeate.

In general, the results met the expected values. By increasing the recovery, the total water and overall salt recovery would be expected to increase. Hence, it was aimed to increase the recovery up to 80%for the Phase-2 tests and run the system at constant permeate flow rate.

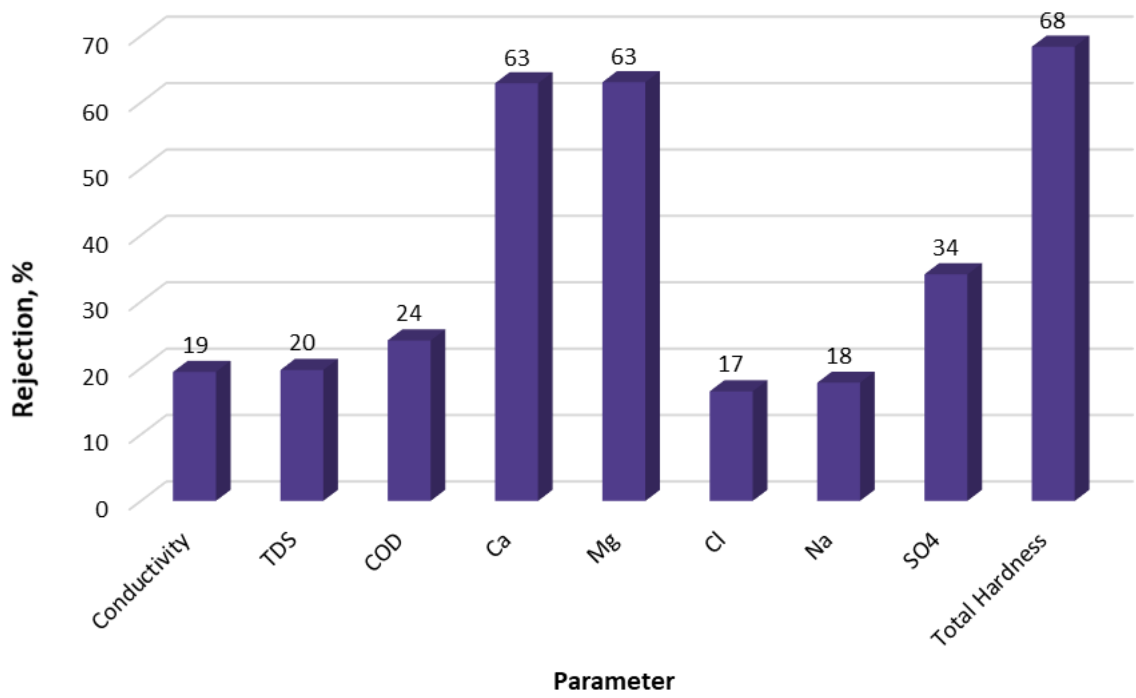

Figure 7 Average rejection efficiencies of NF-1 for Phase-1

2.2.3. Nanofiltration 2 (NF-2)

The NF-2 process was designed to recover additional salts from the reject stream of NF-1 and to recover salts (NaCl) from IEX regeneration stream. The operation was carried out by targeting the permeate flow of 180 L/h. The initial recovery was chosen as 60%. The system was operated in concentrate recycle mode. The feed pressure under these conditions was observed as between 25 and 30 bar. Following to 12 day of operation, the pressure was set at 20 bar. Average permeate flow rate at 10 bar was determined as 340 L/h. This flow rate corresponded to approximately 5.5 LMH. This rate was below the operating fluxes of the membrane. However, due to the increased fouling in operation, the pressure increased and the flux was decreased. The flux trend detected is shown in Figure 8. While, tap water flux of NFG was determined as 59 LMH, the average flux was determined for NF-1 retentate feed stream was 9 LMH. This flux reduction can be explained by the precipitation of Na_2SO_4 in the feed on membrane surface. In addition, since the NF-2 feed stream was the concentrated stream of the NF-1, the pollutant concentrations were higher. The flux observed at the end of the phase decreased by 58% compared to the initial flux. This indicated a serious flux reduction and the need for more frequent chemical cleaning for the membrane.

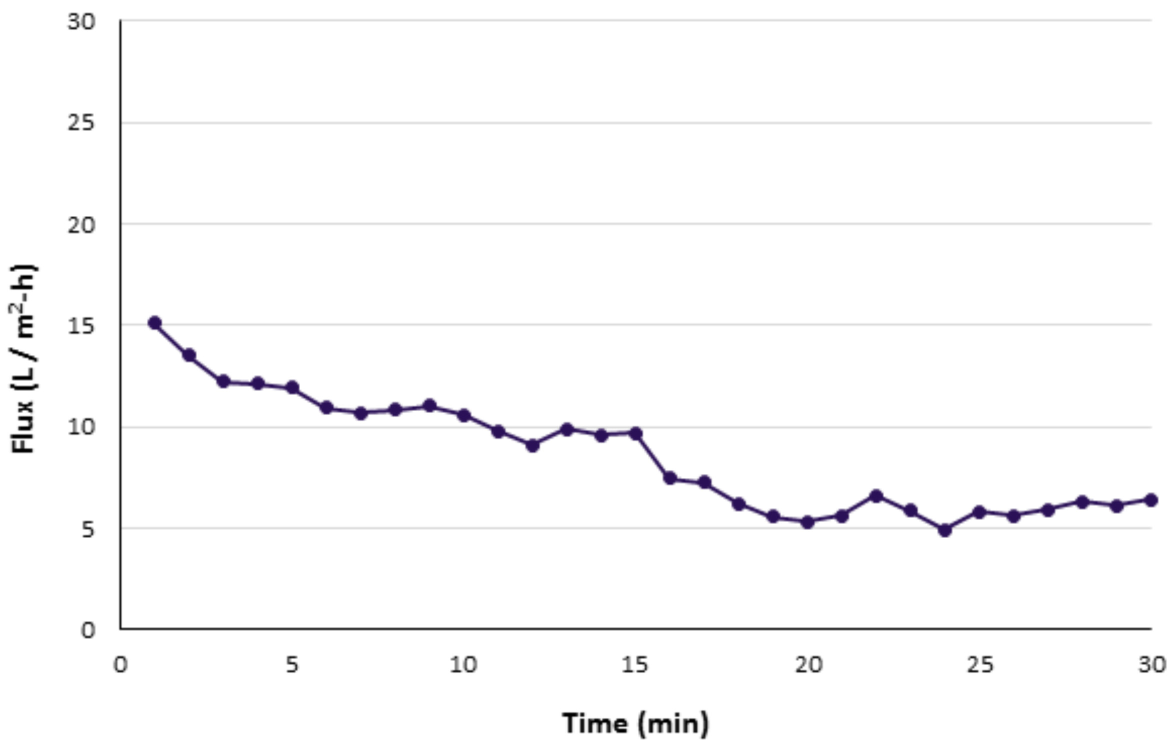

Figure 8 Flux rates for NF2 processes at Phase-1

The permeate and retentate concentrations determined for the NF-2 operation are given in Table 14 in Annex 3. NF-2 process feed concentrations were already given in Table 13 in Annex 3 as NF-1 retentate.

In accordance with the rapid flux decline in NF-2, an extensive pressure increase was observed. It was determined that relatively high concentration of ions present in NF-1 retentate may form compounds which might result in flux decrease. It has been stated that the formation of sulfate scales can result in operational problems and difficulties which may lead to additional costs [10,11]. As an example, during the bench scale test the precipitate remained after drying the NF membrane is shown in Figure 9.

Figure 9 Na_2SO_4 precipitation (predominantly) on membrane surface during lab scale test

The analyzed and calculated concentrations by using mass balance approach in retentate stream of the NF-2 process are shown in Figure 10. Likewise NF-1, due to the precipitation of ions such as Ca, Mg, Cl, Na and SO4 in the form of compounds, some precipitation processes could also take place on the membrane.

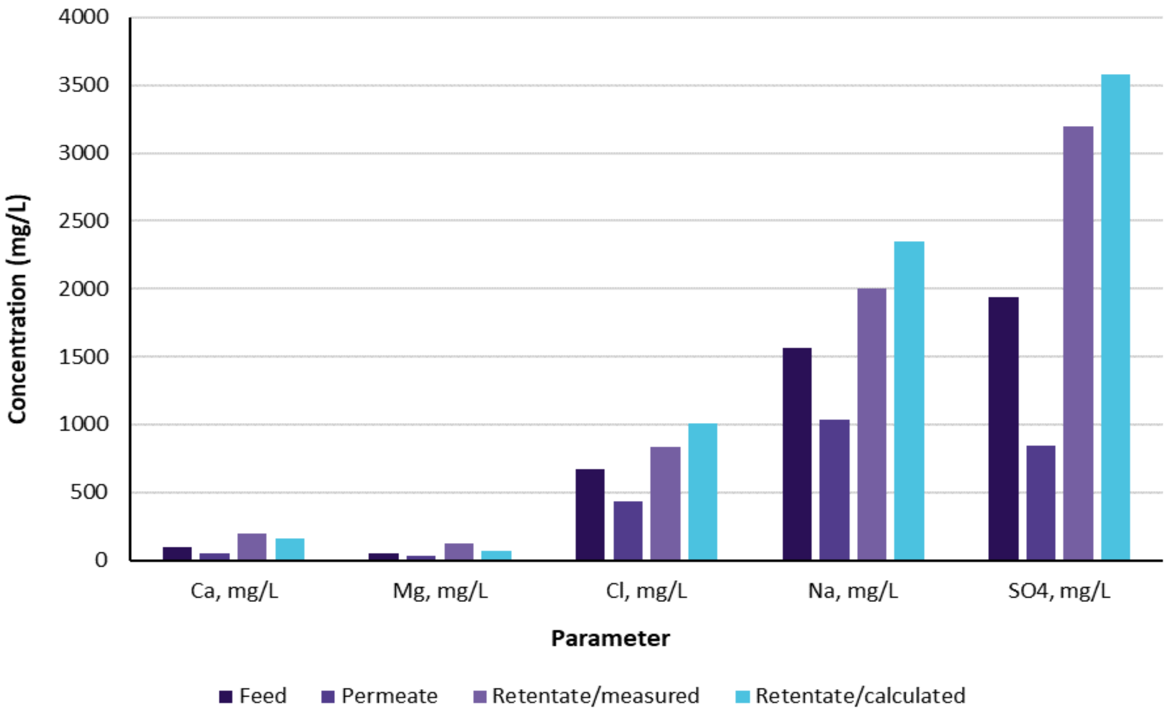

Figure 10 Analyzed and calculated concentrations of ions for NF-2

An average TDS rejection efficiency of 26% was determined. The TDS rejection rate increased due to the increased concentrations of TDS and other pollutants in the feed stream as compared to NF-1 results. The average COD, sulfate and total hardness rejections were 36%, 56% and 57%, respectively (Figure 11).

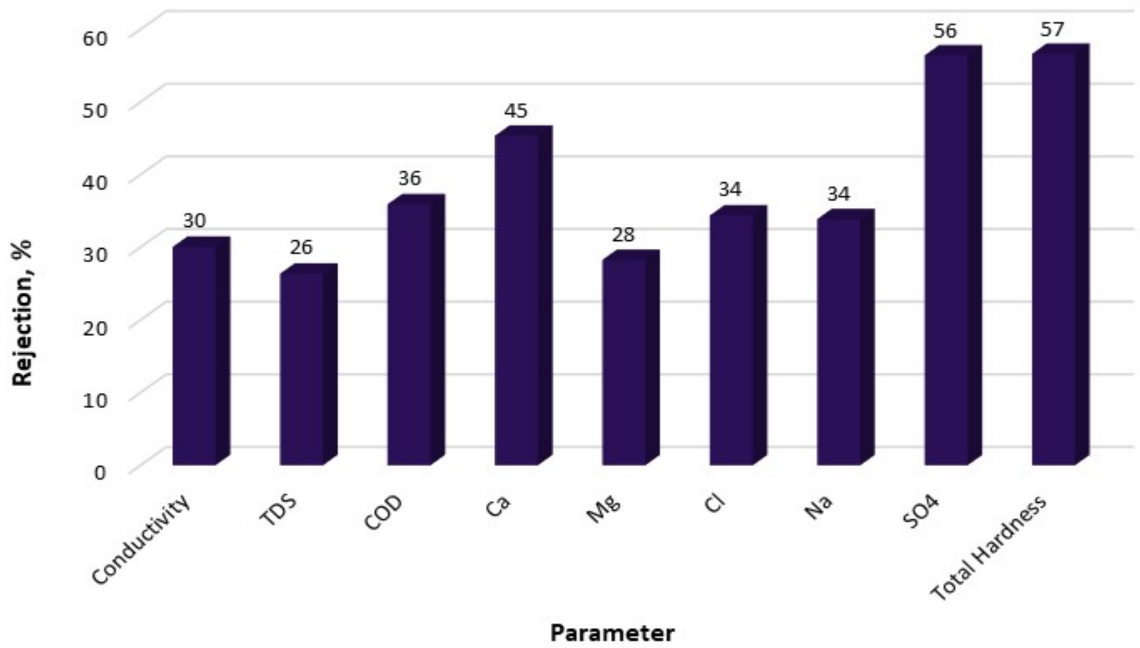

Figure 11 Average rejection efficiencies of NF2 processes for Phase-1

2.2.4. Reverse Osmosis (RO)

The purpose of the RO process is to increase the TDS concentration of the permeate of NF-1 and NF-2. For this purpose, the RO system was operated in concentrate recycle mode with 65-70% recovery. Primarily, the operation was carried out by targeting a permeate flow of 600 L/h. The feed pressure under these conditions was 15 bar.

Pressure increase was observed for RO over time. With the increasing TDS and other ion concentrations in the feed tank, fluxes decrease and pressure increase were detected (Figure 12). Following to 12 day of operation, the feed pressure was set at 30 bar and average permeate flow rate was determined as 235 L/h which corresponded to a flux of approximately 15 LMH. However, the flux decreased considerably in due course. The flux decreased by 82% as compared to the initial flux at the end of the Phase-1. This indicated the need for more frequent chemical cleaning for the membrane. Therefore, additional precautions such as lowering the pH of the feed or removal of relevant ions prior to RO could have been required to prevent precipitation. In accordance, it was assessed that the installation of IEX unit before the RO would enhance the operating conditions with respect to the fouling phenomenon or flux reduction. Hence, this proposed process scheme was investigated in Phase-2.

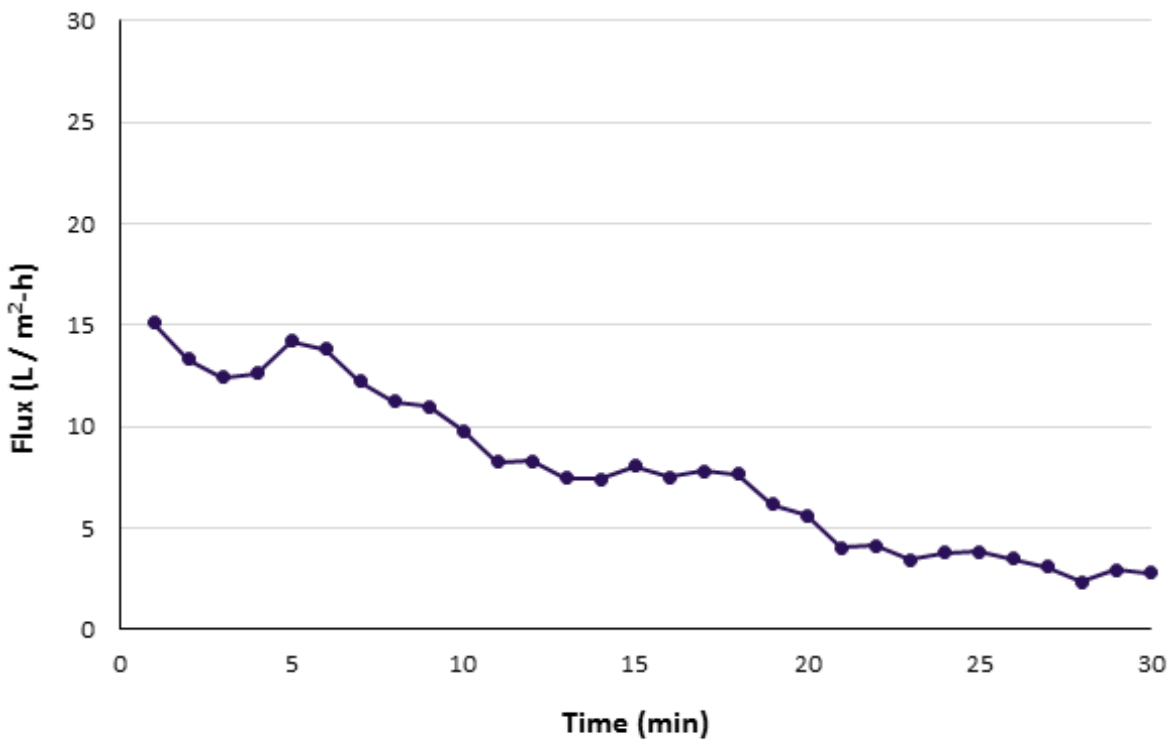

Figure 12 Fluxes for RO processes at Phase-1

The feed, permeate and retentate concentrations determined by the RO operation are given in Table 15Table 20 in Annex 3 for the relevant parameters.

The analyzed and calculated concentrations in the retentate stream of the RO process are shown in Figure 13. As in the case of NF-1 and NF-2 tests, due to the precipitation of ions such as Ca, Mg, Cl, Na and SO_4 in the form of compounds, some precipitation processes taken place on the membrane.

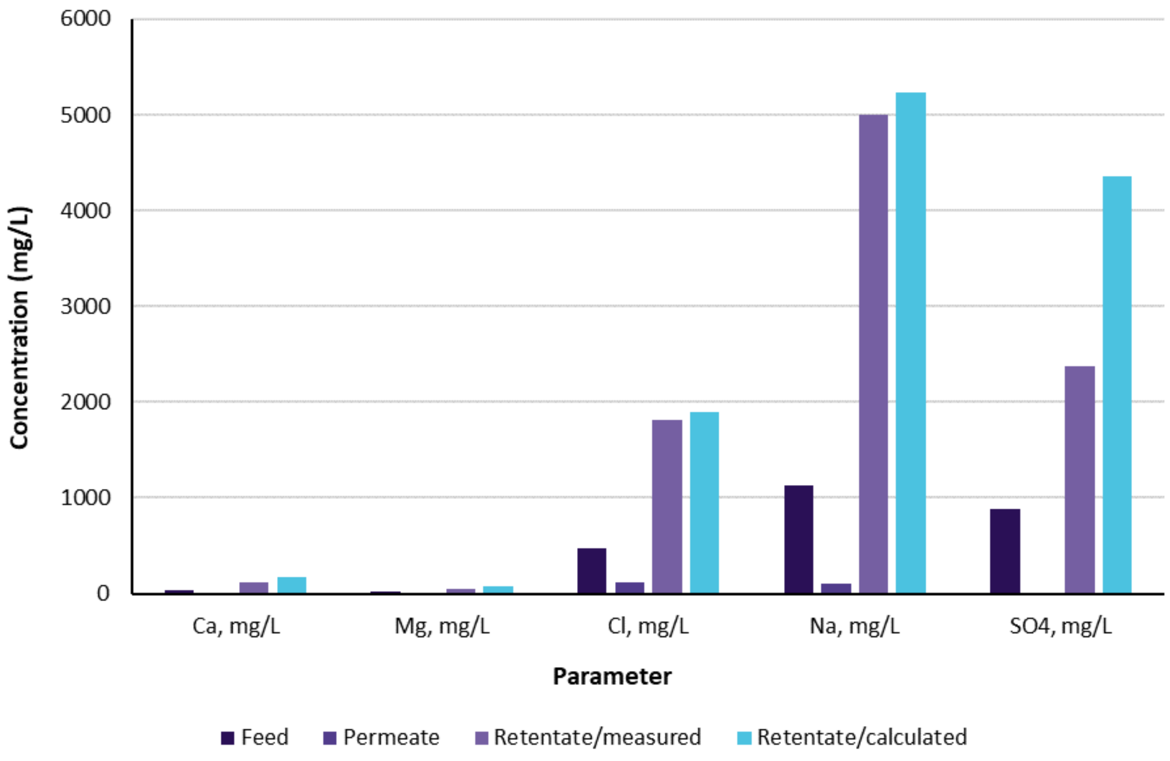

Figure 13 Analyzed and calculated concentrations of ions for RO

An average TDS reject efficiency of 75% was determined which was rather below the expected rejection rate (Figure 14). It was observed that 75% of monovalent ions (Na and Cl) were rejected by the membrane. Especially, in the latest part of the operation, increase in the permeate TDS concentration was observed. The average COD, sulfate and T. hardness rejections were 93%, 99% and 88%, respectively (Figure 14).

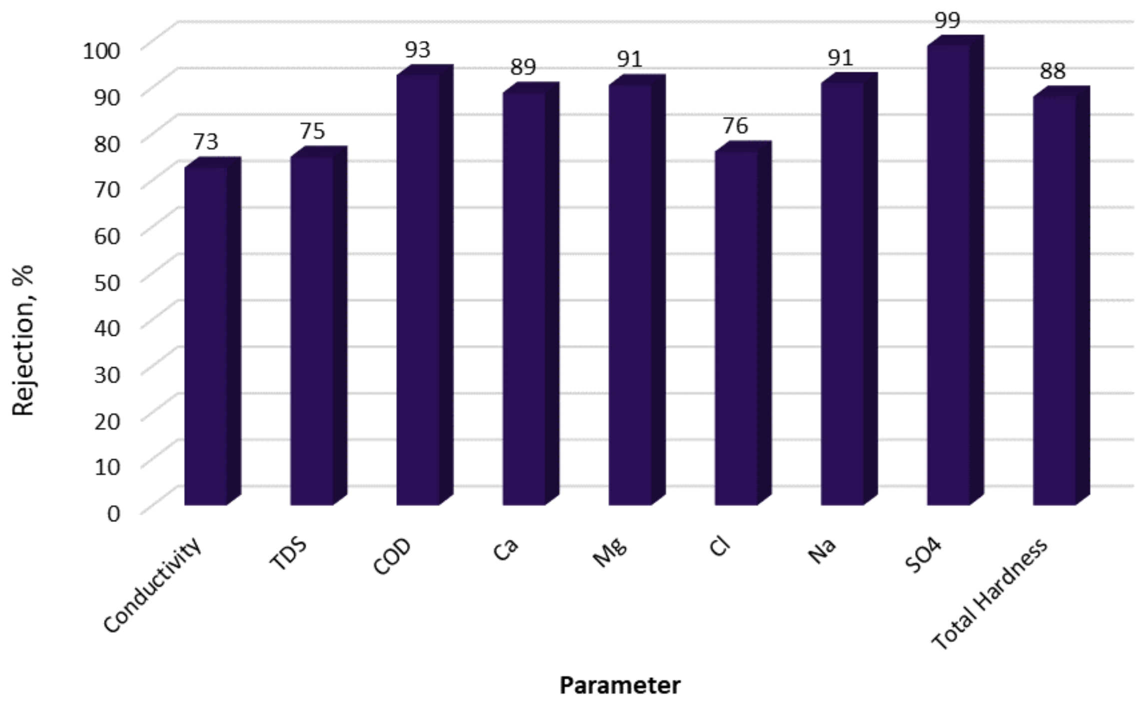

Figure 14 Average rejection efficiencies of RO process during the Phase-1

The applied recipes for dyeing processes require various salt concentrations. In general, dark colors need high salt concentrations (i.e. 40-60 g/L) whereas, much lower salt concentrations can also be used for light colors.

As a result of the Phase-1 operation, the average TDS of brine produced by the RO process was 11 g/L. In this manner, an increase in both water recovery and salt concentration could be expected by increasing the recovery of NF and RO processes.

2.2.5. Ion Exchange (IEX)

The purpose of the IEX process is to remove the Ca^{2+}, Mg^{2+} concentrations of the feed stream. The results of the IEX runs are given in Table 16 in Annex 3. As expected, almost all of the Ca^{2+}, Mg^{2+} were removed.

2.2.6. TPS Phase-1 Operation Results

The overall results obtained from operation of TPS are presented in Figure 15. It should be noted that each treatment unit was operated in a batch mode. The storage tanks placed at input and output streams of the treatment units secured batch operation conditions. The overall input flow rate of 750L/h-cycle for TPS designates the single operation cycle. In this manner, the TPS was run at 3 cycles/day total input flow rate.

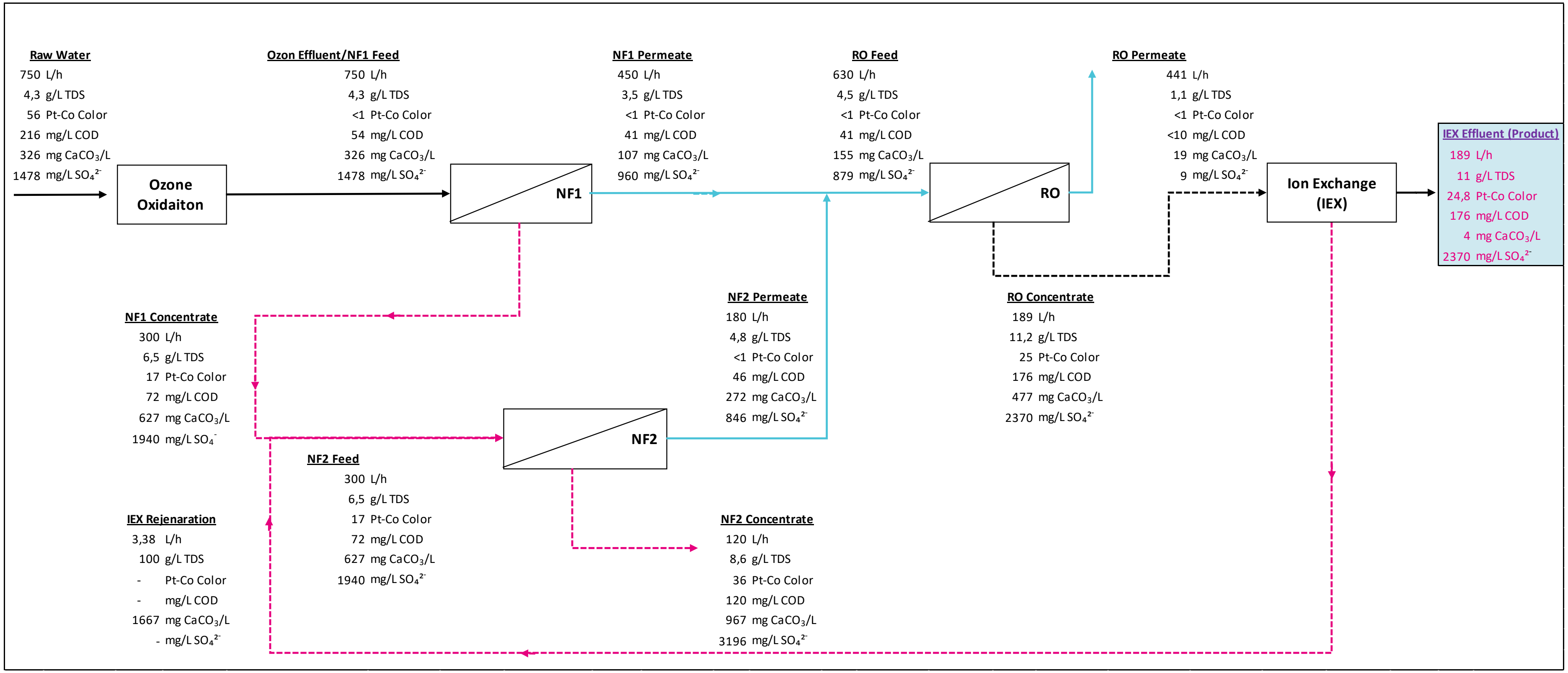

Figure 15 Process design and results

2.3. Phase-2 Results

Phase-2 tests were carried out with a slight modification in the pilot plant flow chart applied for Phase-1. In Phase-2, the resin system was located before the RO unit which was the final step. In addition, the recovery for both membrane systems was set as 80%. The other operating conditions were similar to the phase-1. The operating conditions of the treatment units are given in Table 5.

Table 5 Operating conditions applied for the phase-2 of the systems in TPS

Ozone		NF1		NF2		RO		IEX	
Contact Time, h	3	Number of stages	2	Number of stages	1	Number of stages	2	Operation flow rate, BV/h	2
Ozone dosage, g O_3/h	100	Total elements per stage	2	Total elements per stage	2	Total elements per stage	2	Resin volume, L	150
		Pressure, bar	10	Pressure,bar	10-20	Pressure,bar	20-30	Resin name	Dowex-HCR-S/S
		Recovery,%	80	Recovery,%	80	Recovery,%	80	Resin type	Strong acid cation
		Mode	Concent. Recyle	Mode	Concent. Recyle	Mode	Concent. Recyle	Regeneration cycle, Bed Volume	100
		Each cycle time, min	~20 L/h	Each cycle time, min	~100 L/h	Each cycle time, min	~40 L/h		
		Average flow Feed Permeate Retentate	 3200 2100 1100	Average flow Feed Permeate Retentate	 1300 381 919	Average flow Feed Permeate Retentate	 1700 1100 600		

2.3.1. Ozone Oxidation Unit

The ozone oxidation unit was operated with a contact time of 3 h and an ozone dosage of 100 g O3/h. Subsequently, retentate was passed through the activated carbon column and through the UV system before being fed into the NF-1 feed tank. At the outlet of ozone oxidation unit, 73% COD and 93% of color removal efficiencies were attained (Table 17 in Annex 4). Whereas, COD and color concentrations were on the average 45 mg/L and 8 Pt-Co, respectively.

2.3.2. Nanofiltration 1 (NF-1)

The operation was carried out by targeting the permeate flow of 2000L/h which corresponded to the flux of approximately 55-60 LMH. The feed pressure was observed as 9-10 bar. The system recovery was chosen as 80%. The system was operated in concentrate recycle mode. Although the concentration of pollutants in the feed tank increased with time, no major fluctuations in pollutant rejection efficiencies were observed. Variations in flux for each cycle is shown in Figure 16. Each cycle started at the targeted flux (55-60 LMH) and at the end of the cycle the flux decreased by 36%. This flux reduction can be explained by the increasing concentration of pollutants in the feed tank. At the end of each cycle, flush was applied. Thus, it was possible to start again from the target flux in the next cycle. During this phase, chemical cleaning was not performed.

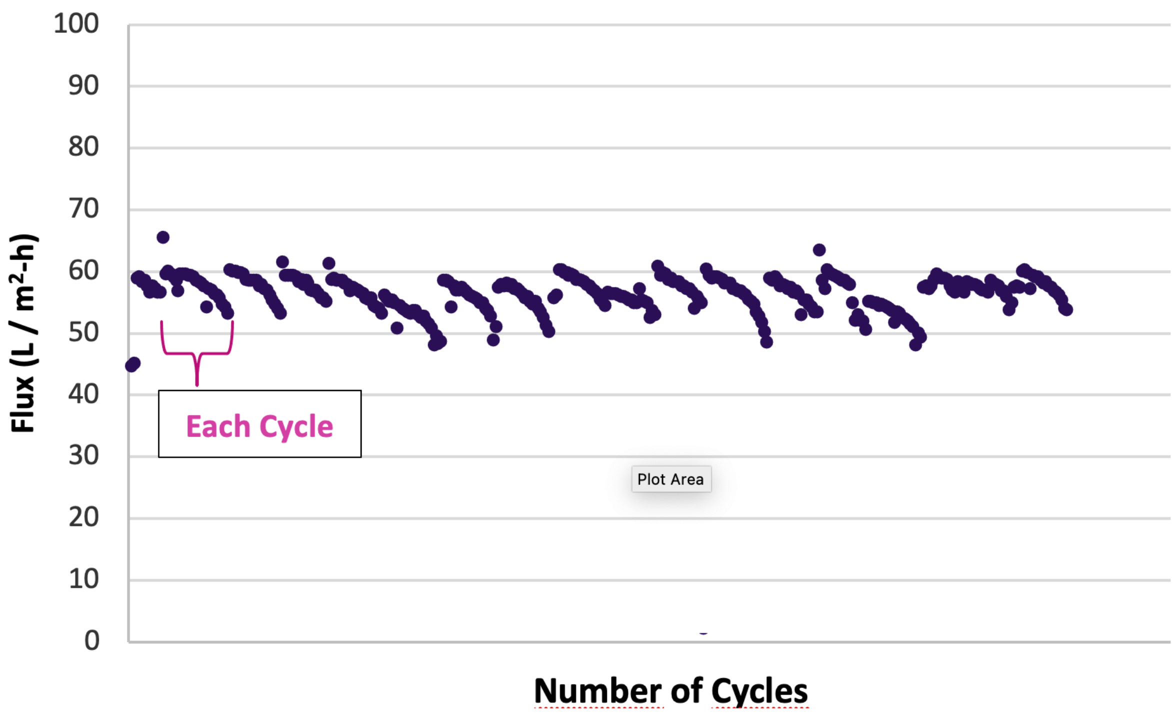

Figure 16 Flux rates for NF-1 at Phase-2

Consequently, the analyzed and calculated concentrations by mass balance in the retentate stream of the NF-1 process are shown in Figure 17. The difference did not exceed 10%. This difference is thought to be due to analysis sensitivity or forming of compounds in the retentate stream.

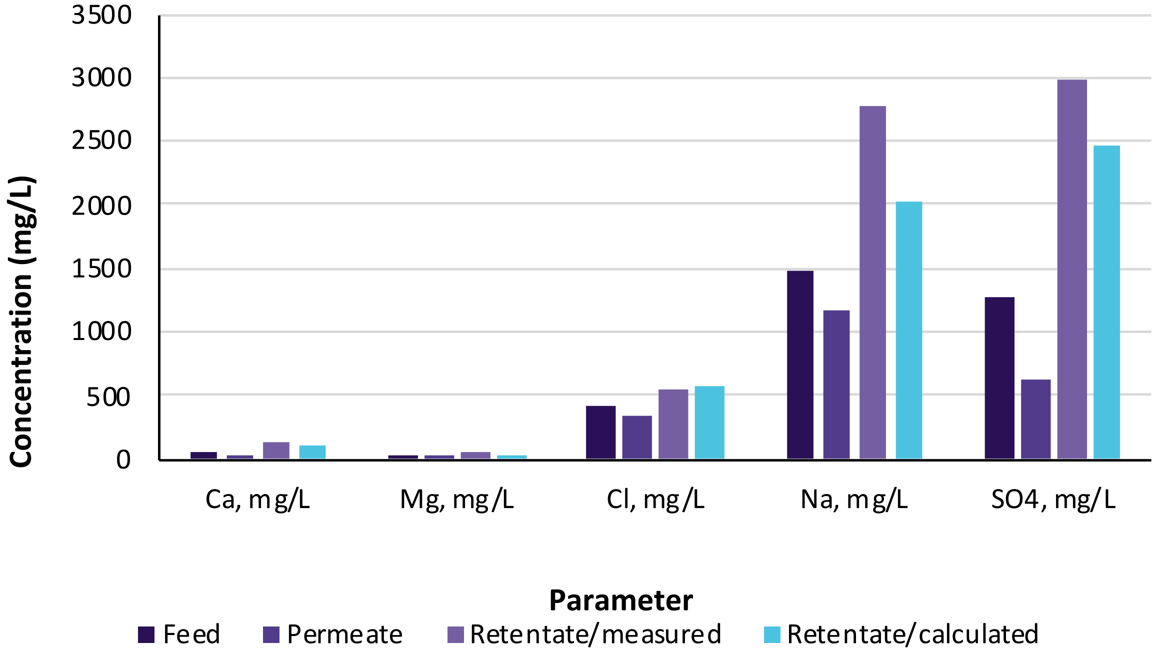

Figure 17 Analyzed and calculated concentrations of ions for NF-1

During the operation of phase 2, an average TDS rejection of 16% was determined and 84% of the salt was recovered by the NF system operated for the presented phase.

The average COD, sulfate and total hardness rejections were 31%, 50% and 39%, respectively (Figure 18). Since, the ozonation process removed most of color, the NF1 permeate color generally below 8 Pt-Co. Similarly, COD rejection efficiency was determined to be low in NF1 since, most of the COD was also removed in the ozonation process, and an average of 31 mg/L COD was detected in the NF permeate. Hence, the anticipated results were obtained. It was also demonstrated that by increasing the recovery, the total water and overall salt recovery were also increased.

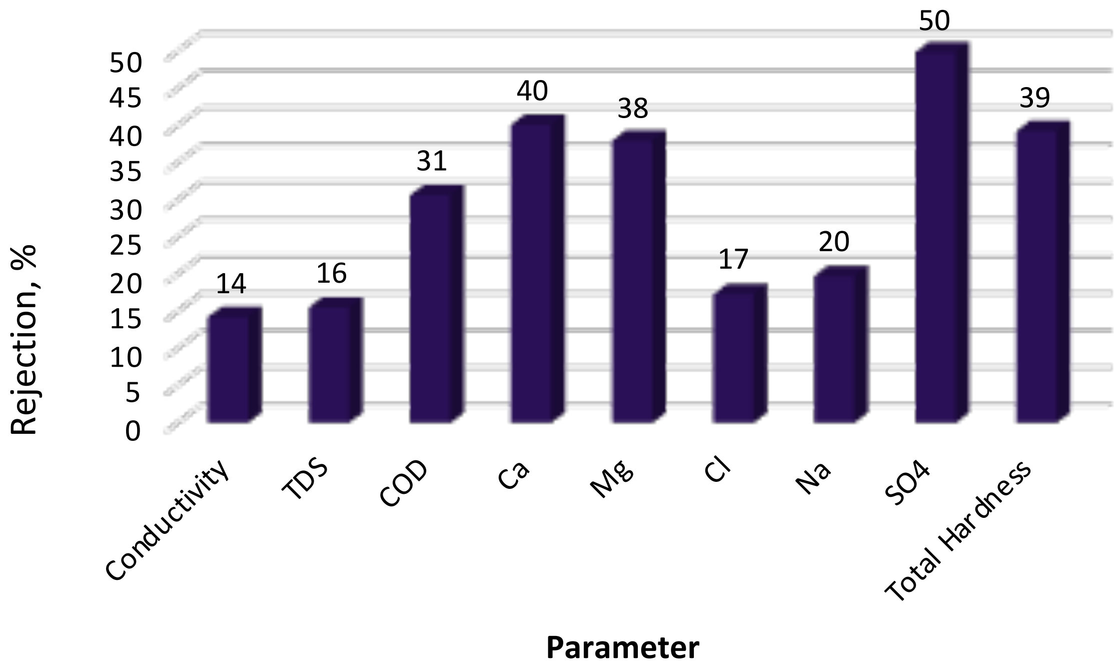

Figure 18 Average rejection efficiencies of NF-1 for Phase-2

2.3.3. Nanofiltration 2 (NF-2)

The permeate flow of 1000 L/h which corresponded to the flux of approximately 55-60 LMH was aimed throughout the operation. The pressure was 9-10 bar. The system recovery was 80%. The system was also operated in concentrate recycle mode. The concentration of pollutants in the feed tank increased, however, pollutant rejection efficiencies stayed almost constant.

Variations of flux is shown in Figure 19. Cycles started at the targeted flux and at the end of the cycles flux decreased by 28% likewise the other NF operations described. At the end of each cycle, a flush was applied. Nevertheless, the initial flux could not be recovered fully. This was due to the high concentrations of different pollutants in the NF2 feed and the scaling potential on membrane surfaces.

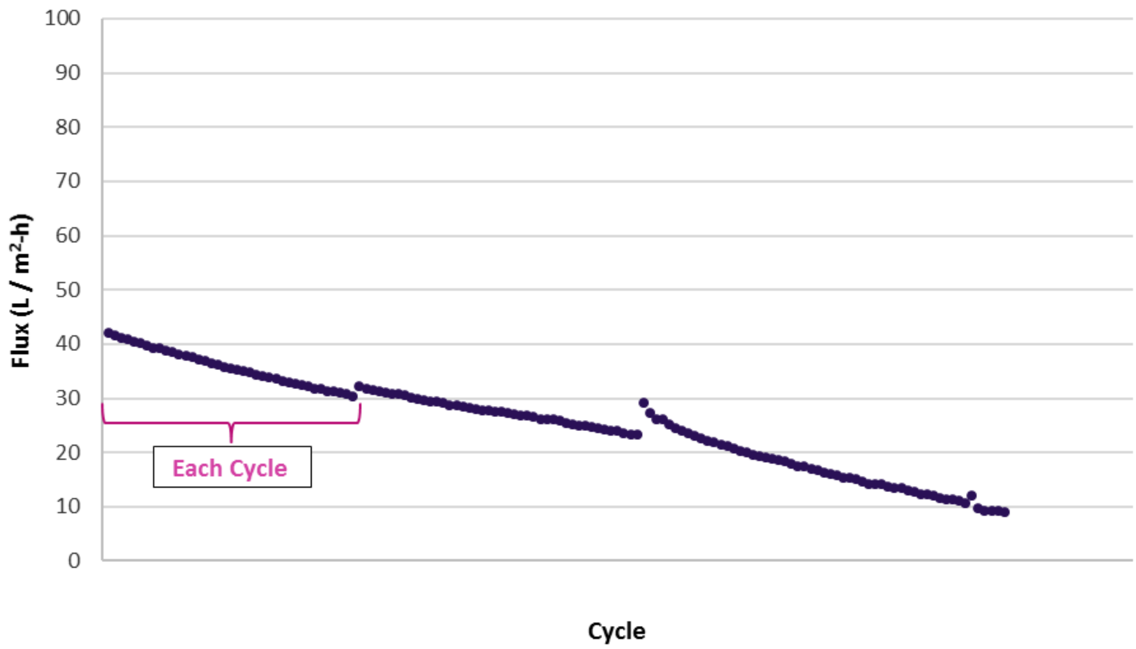

Figure 19 Flux rates for NF2 processes at Phase-2

Accordingly, the analyzed and mass balance calculated concentrations in the retentate stream are shown in Figure 20. The difference did not exceed 10% as in the case of NF-1.

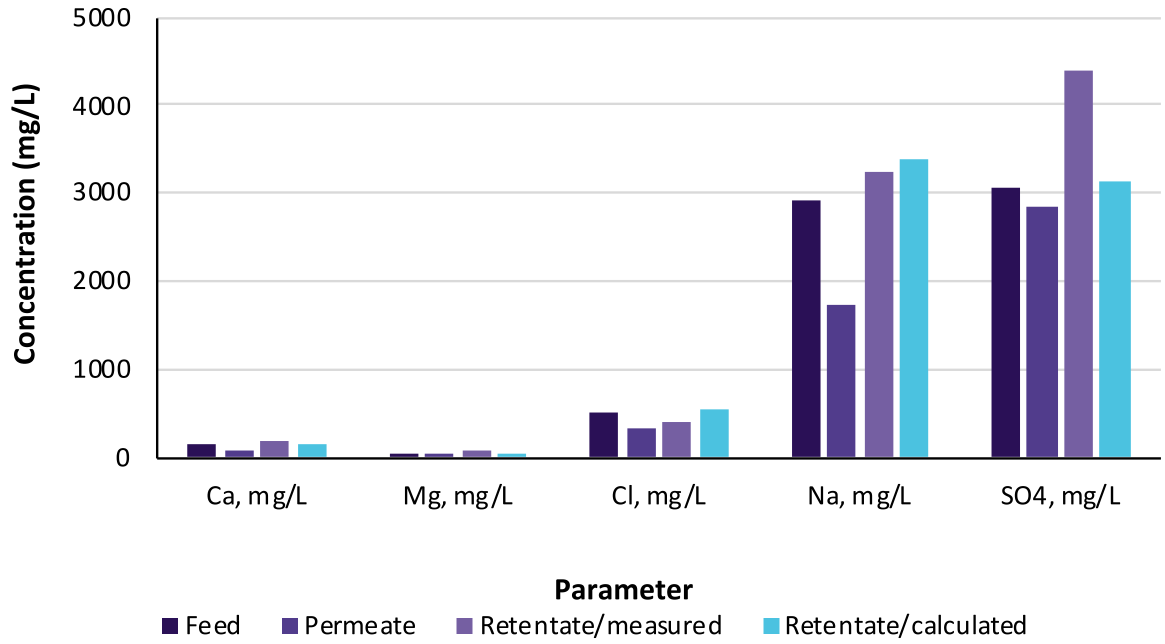

Figure 20 Analyzed and calculated concentrations of ions for NF-2

An average TDS rejection efficiency of 39% was attained. The average COD, sulfate and total hardness rejections were 52%, 54% and 33%, respectively (Figure 21). COD, color, sulfate and total hardness concentrations in NF2 permeate were determined to be 85 mg / L, 14 Pt-Co, 1415 mg / L, 368 mg $CaCO_3$ / L, respectively.

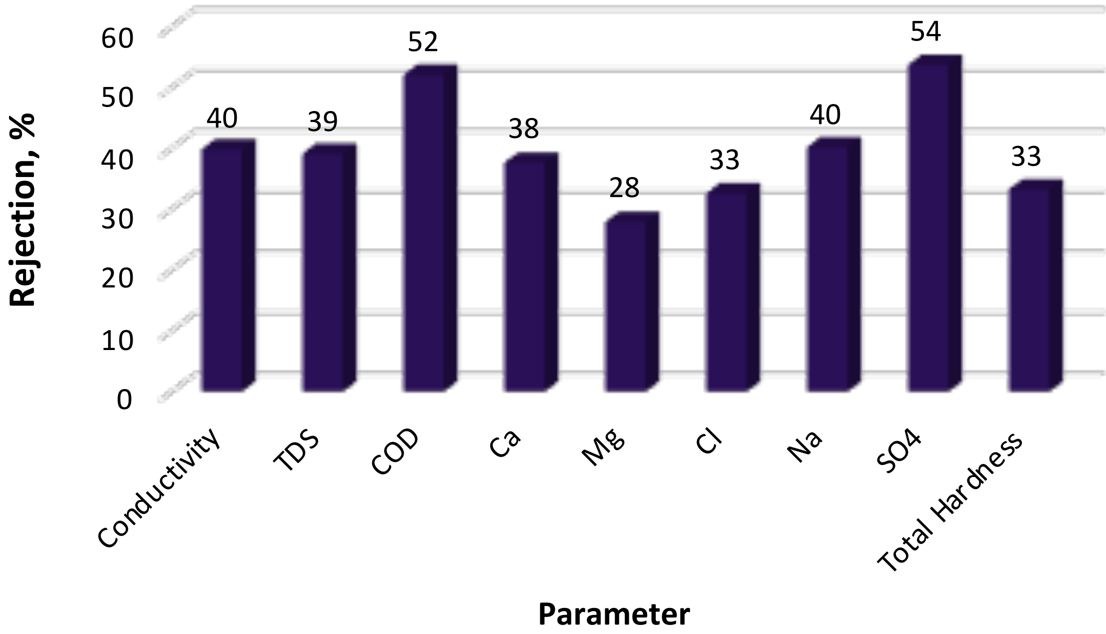

Figure 21 Average rejection efficiencies of NF2 processes for Phase-2

2.3.4. Ion Exchange (IEX)

The purpose of the IEX process is to total hardness of NFs permeate and to prevent of possible scaling potential on RO membranes. For this reason, the IEX process was placed before the RO in Phase-2. The performance of the IEX processes are shown in Table 21 in Annex 4. As in the case of Phase-1 runs the operation was carried out efficiently.

2.3.5. Reverse Osmosis (RO)

The RO system was operated in concentrate recycle mode with 80% recovery. The operation was accomplished with the permeate flow of 900 L/h and with the flux of approximately 30 LMH. The feed pressure was started at 20 bar. The concentration of pollutants increased in the feed tank during operation however no fluctuations in pollutant rejection efficiencies were observed. The fluxes for each cycle are shown in Figure 22. The cycles started at the targeted flux and at the end of the cycle the flux decreased by 71%. This flux reduction can be due to the increasing concentration of TDS in the feed tank. At the end of each cycle, flush was applied. Thus, it was possible to start again with the target flux for the next cycle. During this phase, chemical cleaning was not performed.

A pressure increase was observed over time and at the end of phase-2 operation, the pressure was 30 bar. With the increasing TDS and other ion concentrations in the feed tank, fluxes decreased and pressure increases were observed (Figure 22). This might indicate the need for more frequent chemical cleaning for membranes.

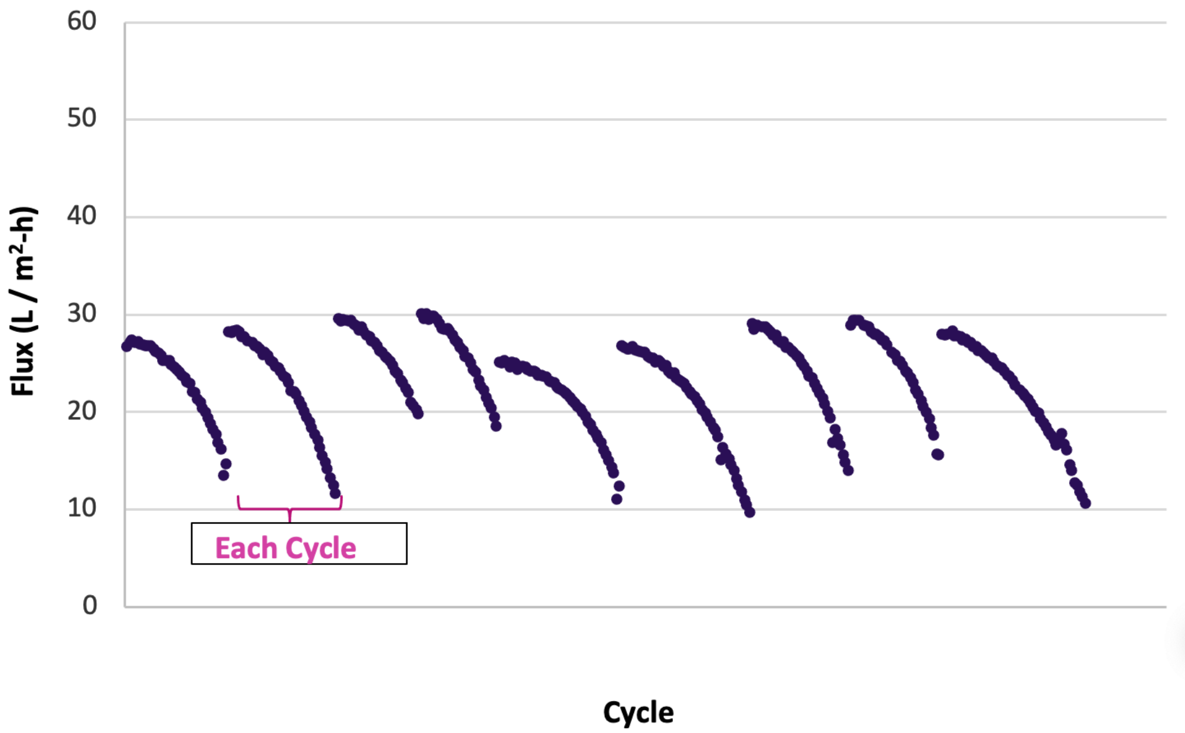

Figure 22 Flux values for RO processes at Phase-2

The analyzed and calculated concentrations in the retentate stream of the RO process are shown in Figure 23.

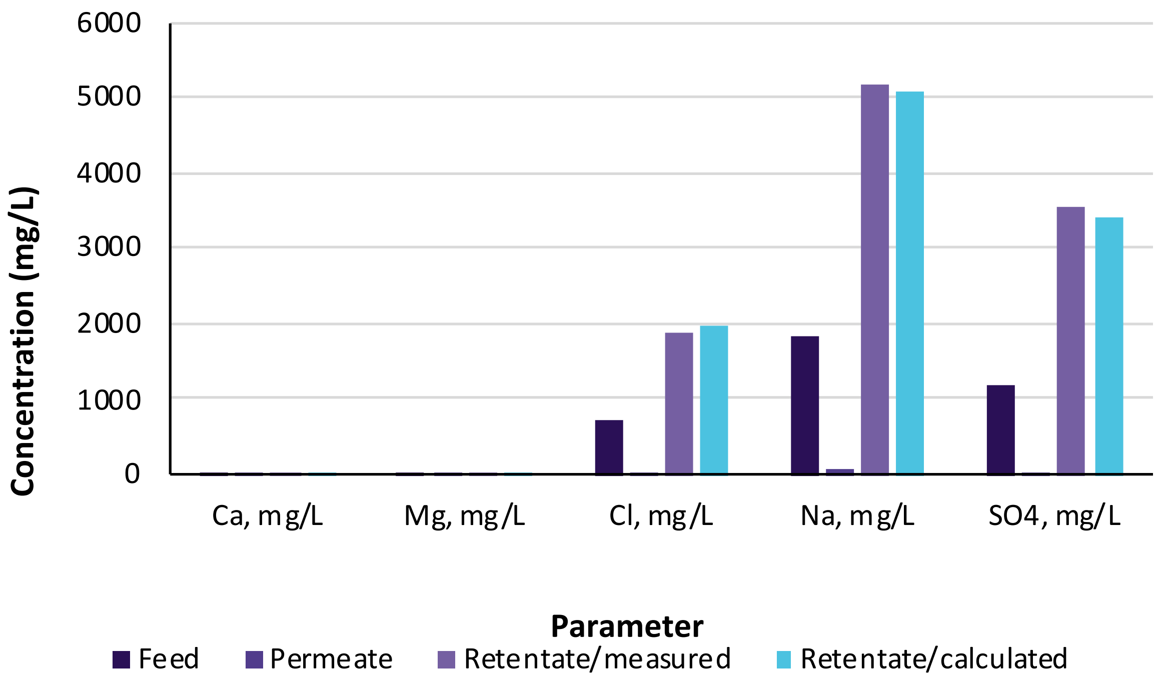

Figure 23 Analyzed and calculated concentrations of ions for RO

High rejection rates were attained for all the parameters. An average TDS rejection efficiency of 97% was determined (Figure 24). It was observed that >96% of monovalent ions (Na and Cl) were rejected by the membrane.

The permeate stream of the RO process can be used for textile process. RO concentrate stream could be recycled for fabric dyeing processes as in the case of Phase-1. As a result of the Phase-2 operation, the average TDS of brine produced by the RO process was 16 g/L. With increasing TDS, the amount of salt used in the dyeing processes would be reduced so that more resources would be saved within the enterprise.

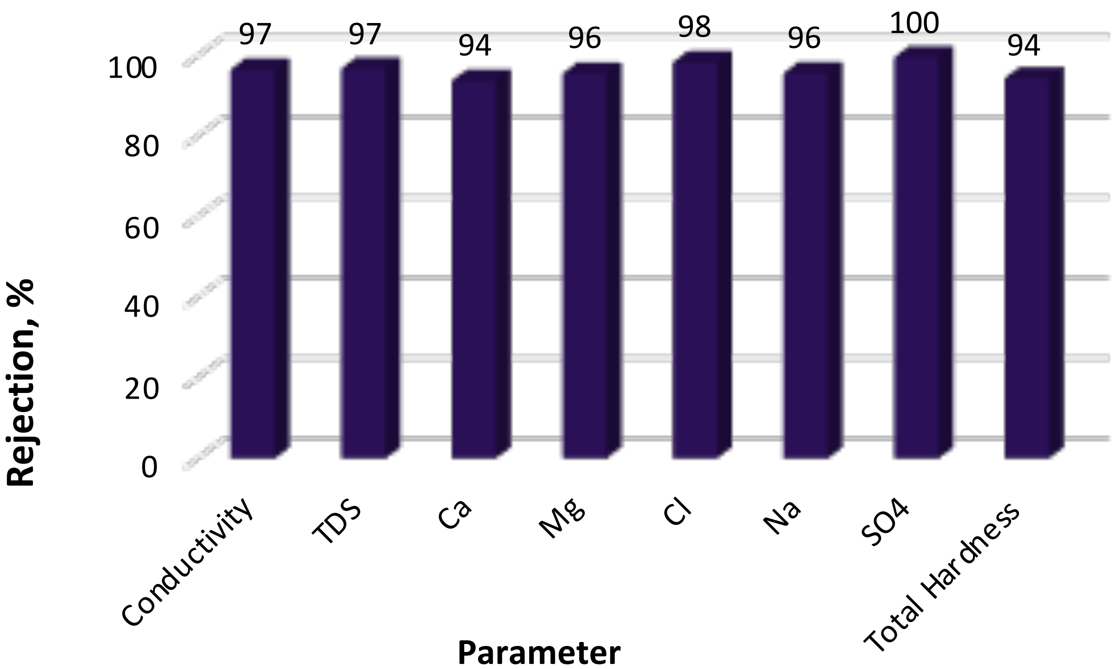

Figure 24 Average rejection efficiencies of RO process during the Phase-2

2.3.6. Processes Scheme for Phase-2

The overall results obtained from operation of TPS for Pase-2 is outlined in Figure 25. As in the case of Phase-1 treatment units were operated as batch. The overall input flow rate of 750L/h-cycle for TPS designated the single operation cycle. In this manner, the TPS was run at 3 cycles/day total input flow rate.

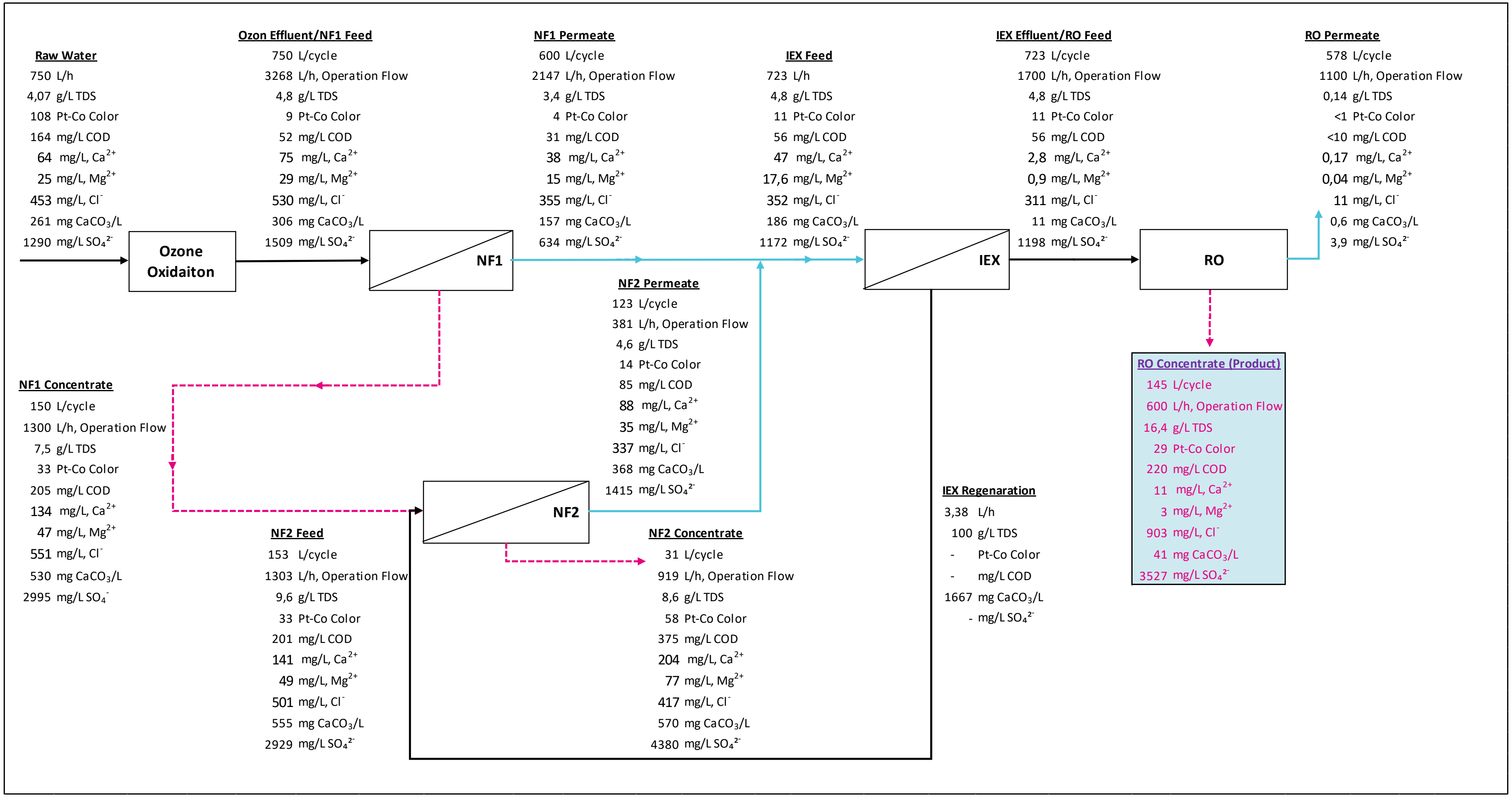

Figure 25 Process design and results

2.4. Fabric Dyeing Tests (in Zorlu Textile)

2.4.1. Dyeing Method and Color Differences

To evaluate the reuse potential of the TPS product, comparative dyeing tests were carried out at Zorlu Textile laboratories based on Zorlu Textile internal procedures defined for laboratory practices. Along these lines, "exhaust dyeing" methodology was practiced by using reactive dyes. Exhaust dyeing is principally a batch process based on long-term reaction of textile material in the bath containing dyestuff, dyeing auxiliaries and chemicals. Dyeing is accomplished in overflow type dyeing machines.

The dyeing performances were evaluated by using the parameter color difference (ΔE) of the samples as compared to the standard dyeing process. The salt concentration of TPS product was 7-8 g/L and 12-16 g/L for Phase-1 and Phase-2, respectively. Dyeing procedure was carried out in a small scale dyeing machine, using flotte ratio of 1:8 (kg:L), including the amounts of dye and Na_2CO_3.

Dyeing tests were conducted by using blue, yellow and red basic reactive dyes and their combinations, light, medium and dark colors tested. Based on the dyeing type (light, medium, dark), NaCl or Na_2SO_4 were added. The process was performed by using TPS salt product and softened water (standard sample) at 60-80 oC.

The calorimetric properties of the samples were determined with Datacolor SP600 Spectrophotometer in terms of CIELab variables. For CIELab system color is expressed as CIE L*, a* and b* values. Where, L* defines lightness, a* is red-green and b* yellow-blue variables. It can also be characterized as color stimuli as L*, C* and h. Where, C* is the difference in chroma and h is the difference in hue [12].Total color differences of fabric samples, which were dyed with TPS product, as compared to the standard sample procedure, calculated using following equation [13].

$$Colour\ difference\ (\Delta E) = \sqrt{\Delta L^2 + \Delta a^2 + \Delta b^2}$$

where ΔL is the color brightness, Δa is the variation between green and red and Δb is the variation between blue and yellow.

If the total ΔE turns out to be less than 1, the result of color matching is considered as acceptable. In Zorlu textile, ΔE <1 are generally acceptable for dyeing operations.

2.4.2. Dyeing Tests Results

Fabric dyeing tests were carried out for three different colors (blue, green and pink) for Phase-1. Characterization of the TPS product is given in Table 6. ΔE, determined for light, medium and dark staining for each color tested are shown in Figure 26 and the test results of fabric samples dyed with using standard procedure and TPS product are shown in Figure 27.

Table 6 TPS product quality parameters for Phase-1

Parameters	Values
TDS, g/L	7-11
Color, Pt-Co	25
COD, mg/L	176
Total Hardness, °F	0,4
SO_4^{2-}, mg/L	2370

The results indicated that apart from light pink for all other colors ΔE<1, so the tests were considered to be successful in general. The best result was observed for dark blue. However, different trends were also observed for light, medium and dark colors. For example, while dark was the best result for blue, the best results for light was green and for medium was pink. This was due to the different recipes applied for different colors in dyeing processes. For instance, blue dyed with metal complex dyes, while pinks were dyed with vinyl sulfone dyes. Especially considering that, green is obtained from blue-yellow mixture and pink color is obtained from red-yellow mixture, the variables increase the ΔE for dye combinations. Among these color groups, it was stated that the most representative color was blue. Blue dyes are considered as more sensitive groups and easily show possible problems and defects.

Figure 26 Fabrics dyed with standard solution and TPS product

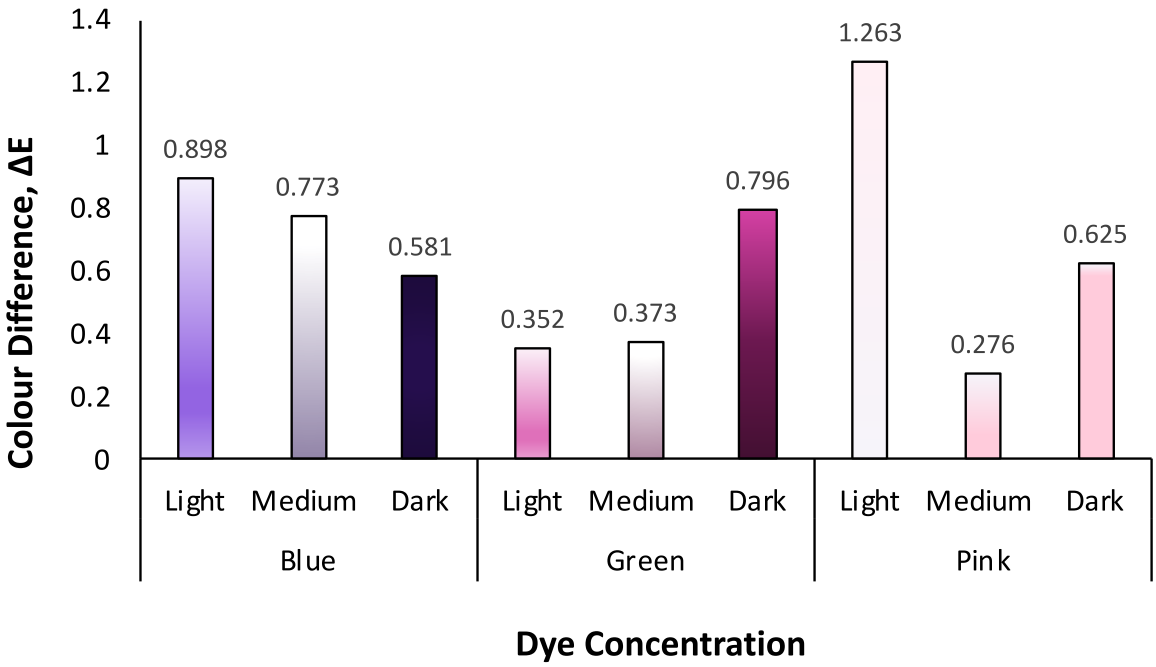

Figure 27 Dyeing test results for Phase-1

Characterization of TPS product for Phase-2 is given in Table 7. For Phase-2, when the IEX was placed before RO operating at recovery of 80%, product ion concentrations increased as compared to Phase-1. Hence, the same product was tested in two different ways to assess the effect of the total hardness for dyeing processes. The first sample had a hardness of 4.1 oF, and the second sample hardness softened to 0 oF. The samples of dark blue fabrics dyed with softened and hard water are presented in Figure 29.

Table 7 TPS product quality parameters for Phase-2

Parameters	Product-1 With hardness	Product-2 No hardness
TDS, g/L	16.4	16.4
Color, Pt-Co	29	29
COD, mg/L	220	220
Total Hardness, °F	4.1	0
SO_4^{2-}, mg/L	3527	3527

Since, blue is representative color, tests were conducted using dark blue dye. ΔE measured for both softened and non-softened TPS product are shown in Figure 28. The test results showed that with the increasing hardness, ΔE also increased, hence, the fabric quality was negatively affected. It can be presumed that up to 5 oF hardness, dyeing can be performed with dark blue colors using TPS product.

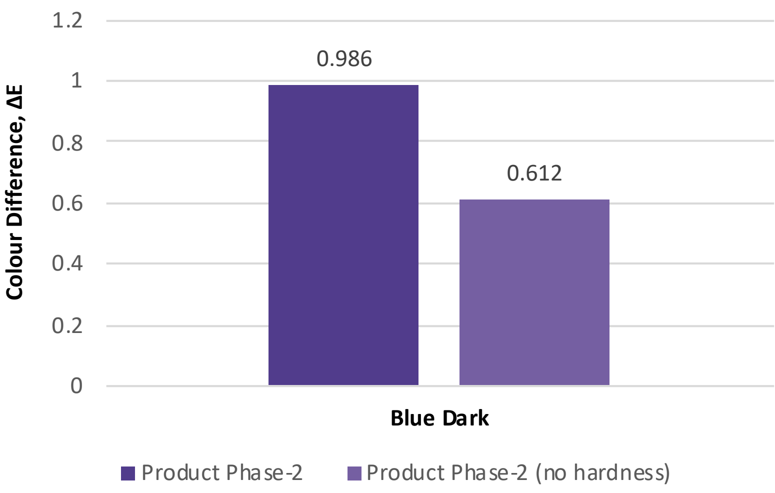

Figure 28 Dyeing test results in Phase-2 for blue dark color

Figure 29 Dark blue dyed fabrics in Phase-2

Investigation of the reusability of recovered brine for dyeing processes for textile industry is considered as a promising study for future applications.

2.5. Assessment of Phase-1 and Phase-2 Operational Schemes of TPS

The operational characteristics, advantages and disadvantages of the both flow schemes conducted for TPS are listed in Table 8 for comparison purposes. The operational features including energy consumption, chemical usage, flush water and salt consumption for regeneration of IEX process are illustrated in Table 9.

Along these lines, Phase-2 scheme appeared to be advantageous from the point of view of obtaining the high TDS of the product stream, relatively high salt and water recovery. Moreover, energy consumption also turned out to be lower for Phase-2. However, dye application properties or potential of the recovered salt solution for Phase-2 was relatively less than Phase-1 due to the presumably higher hardness. The high-energy consumption of Phase-1 for RO operation was attributed to the rapid fouling potential of the RO membranes and operational features and equipment defects encountered for Phase-1. The TPS has presented unique properties for textile sector, especially for Zorlu Textile enterprise brine recovery and reuse. The results could not be compared with any reference technology because there are no such technology used in the textile industry.

Table 8 Evaluation of phase-1 and phase-2 results for treatment and recovery of RO concentrate

Phase-1	Phase-2
Process flow: OX→NFG1→NFG2→RO→**IEX**	**Process flow**: OX→NFG1→NFG2→IEX→**RO**
NFs and RO operated at 60% recovery. ❖ Total water recovery 80-85%. ❖ NF and RO systems efficiently operated ❖ Pollutants and ion concentrations lower in the product (IEX effluent).	NFs and RO operated at 80% recovery. ❖ Total water recovery up to 96%. ❖ NF and RO systems efficiently operated ❖ Pollutants and ion concentrations increased in product stream (RO concentrate) due to increased recovery and flow configuration.
Aimed to remove hardness of product stream for dyeing by placing IEX process after RO	Aimed to remove NF permeate stream hardness and reduce fouling potential for RO. ❖ Despite low ion concentrations at IEX output/RO input, hardness-causing ions in RO concentrate stream (product) slightly increased.
As pH of feed water around 8.5, precipitation observed in samples taken from NF-1 concentrate / NF2 feed.	HCl dosing performed at NF1 inlet to decrease pH to 7.
While NF-1 and NF-2 system operating fluxes at expected levels, RO fluxes detected to be low after start-up. Flux decrease in NF-2 over time observed rapidly due to Na_2SO_4 precipitation	This issue prevented and overcome by acid dosage.

Table 9 Evaluation of phase-1 and phase-2 results for energy and chemical usage

Phase-1	Phase-2
Process flow: OX→NFG1→NFG2→RO→**IEX**	**Process flow:** OX→NFG1→NFG2→IEX→**RO**
Energy consumption (as m^3 TPS input stream) Ozone : 17 kWh/m^3 NF1 : 1.8 kWh/m^3 NF2 : 7.2 kWh/m^3 RO : 7.6 kWh/m^3 IEX : 1 kWh/m^3 Total : 35 kWh/m^3 Cost : 3.7 USD/m^3	**Energy consumption** (as m^3 TPS input stream) Ozone : 15 kWh/m^3 (TPS input) NF1 : 1.0 kWh/m^3 NF2 : 3.3 kWh/m^3 RO : 4.0 kWh/m^3 IEX : 1.7 kWh/m^3 Total : 25 kWh/m^3 Cost : 2.7 USD/m^3
Chemical usage (as m^3 TPS input stream) Antiscalant : 0.025 kg/m^3 HCl : 0.050 kg/m^3 NaCl for IEX regeneration: 45 kg/66 m^3 Antiscalant dosage kept minimum as RO retentate (feed of pilot) water matrix contains antiscalant agents.	**Chemical usage** (as m^3 TPS input stream) Antiscalant : 0.028 kg/m^3 HCl : 0.057 kg/m^3 NaCl for IEX regeneration: 45 kg/66 m^3 Antiscalant dosage kept minimum as RO retentate (feed of pilot) water matrix contains antiscalant agents.
Water consumption for flushes: 436 L/m^3 Water consumption for chemical cleaning : 178 L/m^3 (Flush and chemical cleaning procedure carried out with RO permeate)	Water consumption for flushes: 167 L/m^3 Water consumption for chemical cleaning : 167 L/m^3 (Flush and chemical cleaning procedure carried out with RO permeate)

2.6. Expected Impacts of TPS

TPS is capable of treating about 2.2-2.4 m^3/d of RO retentate discharged from advanced wastewater treatment facilities of Zorlu Textile. The expected outcomes of TPS is given in Table 10. The developed process scheme results in 50-60% of recovery of NaCl for the dyeing processes, whereas the clean water recovery as permeate of the RO treatment unit would be 70-95%. Alternatively, this stream will be reused within the enterprise for various purposes. Hence, by this approach it is anticipated to accomplish efficient recovery of salt solution for dyeing processes.

Table 10 Expected outcomes of TPS

Expected Outcomes	
Feed Salt, g/L	3.2 - 3.6
Recovered Salt, g/L	2.1 - 2.4
Reduction of COD, kg	0.11 – 0.15
Recovered Salt, %	65 - 66
Recovered Process Water,%	59 - 77
Recovered Salt Solution for dyeing processes, %	19 - 25
Total Water Recovery*, %	84 - 96
Generated Waste Stream, %	4 - 16
Reduction of COD, %	~91

* sum of processes water and salt solution for dyeing processes

The other impacts and outcomes of TPS are summarized below.

- Decrease salt consumption of the enterprise by 60%
- Reduction in water consumption by 15%
- The results would have great impacts on the textile industry in achieving resource efficiency and improving sustainability due to the reduced consumption of process inputs, as well as the mitigation of greenhouse gasses accordingly. In this way, it is estimated that considerable decrease for CO2 emissions could be achieved
- Significant improvement of aquatic environments and protection of soil from salinization
- Similar technology and approach can be applied to other sectors of industry which generate saline discharges
- Compliance with the relevant regulations likely to be in force in the near future
- Economic benefits for the enterprise implemented ZLD approach due to the reduction in consumption of salt and water
- Improvements in visibility of the enterprise due to the increased concerns for environmental issues, and also relevant growth in export potential with good market value
- Business opportunities foreseen for the companies involved wastewater treatment and reuse/recovery options
- Creation of new job alternatives for technical personnel in both textile or other relevant enterprises for various sectors including environmental fields (wastewater treatment and reuse companies).

The operation of TPS has provided impacts for the evaluation of sustainability performance for WP7. In addition to that the TPS contributed business plan and opportunities for WP 8.2.1 for providing data.

3. Conclusions

The TPS was operated for about a year at Zorlu Textile Industry in compliance with the objectives of ZERO BRINE project. TPS was designed to perform resilient and modified operation schemes to achieve optimized solutions for brine recovery and reuse for textile sector. Based on the data as well as the experience gained throughout the operation period the following conclusions are worth to emphasize.

The dye tests revealed that Phase-1 (oxidation-NF-RO-IEX) and Phase-2 (oxidation-NF-IEX-RO) recovered salt stream products could be reused for dyeing processes successfully in accordance with Zorlu Textile practices and criteria. Phase-1 operational scheme with the IEX as final step resulted in more secure and reliable product to be reused for dyeing processes at Zorlu Textile. Phase-2 operational scheme with the RO as final step resulted in more efficient operation in terms of reusable water and amount of salt recovery, however, less reliable one for textile dyeing operations as compared to Phase-1 results. It is recommended to perform more dye tests with color/dye types with recovered product. Thus, the criteria for reuse in dyeing process can be determined more precisely.

The only waste stream generated from TPS was NF-2 concentrate. Considering, high content of sulfate in NF-2 concentrate and the fact that Na_2SO_4 and NaCl are used in the textile processes this stream could also be used for dyeing process. The reusability could also be tested following to removal of hardness by IEX. In this way, ZLD concept could possibly be achieved for textile sector.

It is anticipated that relatively high-energy consumption is partially due to the size of TPS, much lower energy consumption rates could be expected for full scale plants.

4. Acknowledgements

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Annex 1 Technical Design of The Textile Pilot System (TPS)

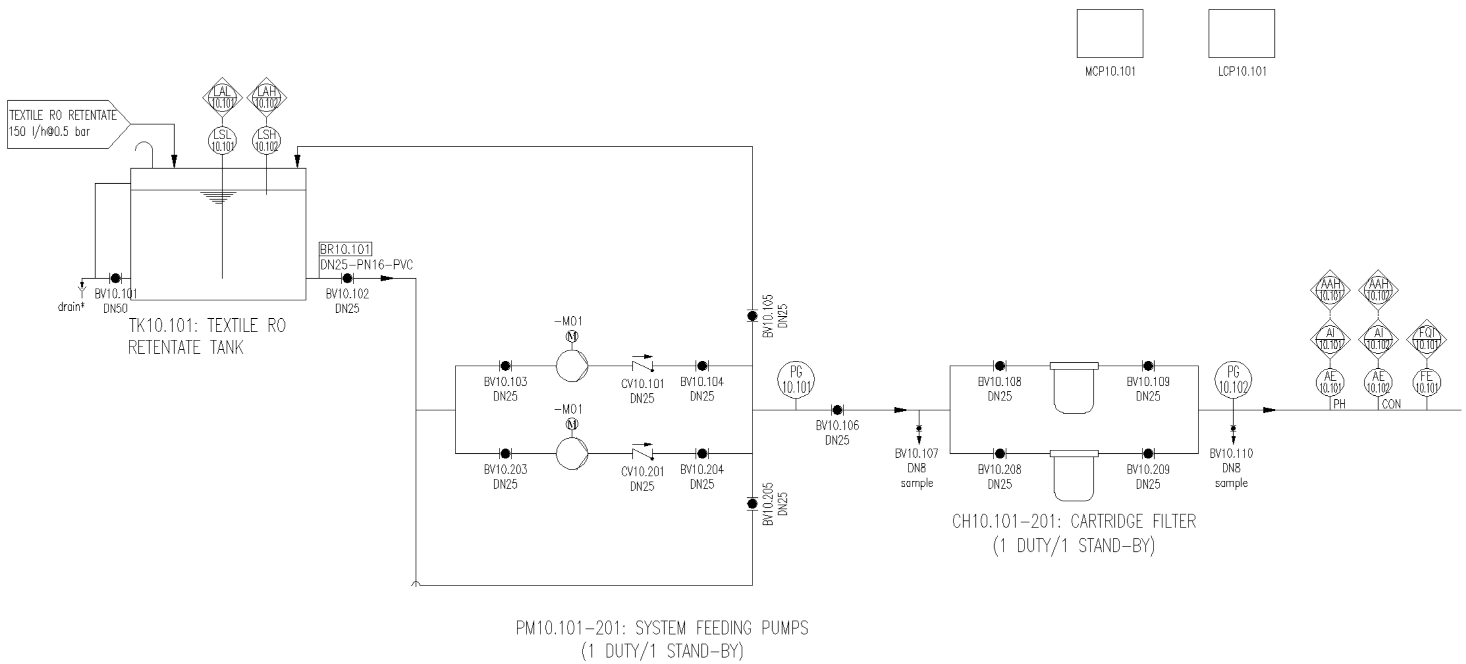
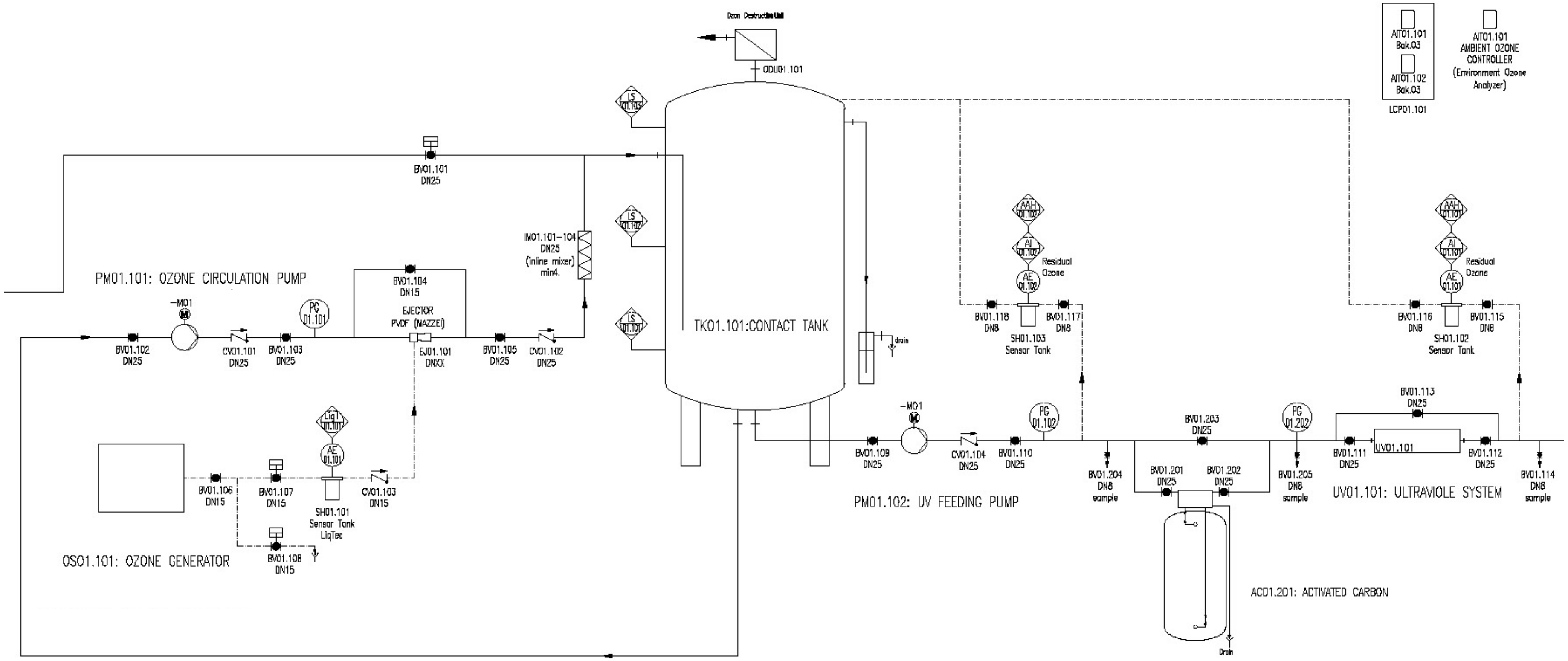
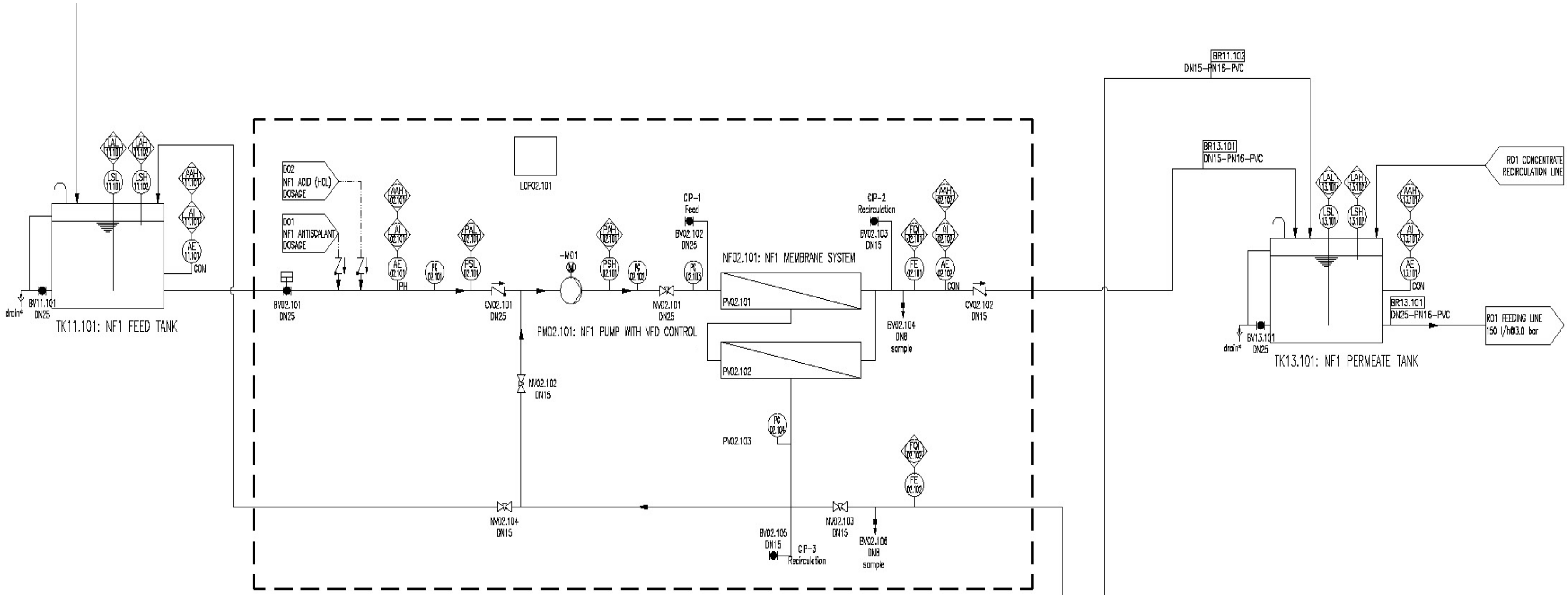


Figure 30 Retentate feeding system (TK-Retentate storage tank, LSH-Level sensor, BV-Valve, CV-Check valve, PG-Manometer, AAH/AL/AE-pH, Conductivity meter, PM-Feed pump, CH-Cartridge filter, MCP- Main control panel, LCP- Local control panel)



Ozon Destructive Unit
ODU01.101
LS 01.103
LS 01.102
LS 01.101
BV01.101 DN25
IM01.101-104 DN25 (inline mixer) min4.
PM01.101: OZONE CIRCULATION PUMP
-M01
PG 01.101
BV01.104 DN15
EJECTOR PVDF (MAZZEI)
BV01.102 DN25
CV01.101 DN25
BV01.103 DN25
EJ01.101 DNXX
BV01.105 DN25
CV01.102 DN25
TK01.101:CONTACT TANK
drain
LIQT 01.101
AE 01.101
BV01.106 DN15
BV01.107 DN15
SH01.101 Sensor Tank LiqTec
CV01.103 DN15
OS01.101: OZONE GENERATOR
BV01.108 DN15
AIT01.101 Bak.03
AIT01.102 Bak.03
LCP01.101
AIT01.101 AMBIENT OZONE CONTROLLER (Environment Ozone Analyzer)
AAH 01.102
AI 01.102
AE 01.102
Residual Ozone
BV01.118 DN8
SH01.103 Sensor Tank
BV01.117 DN8
AAH 01.101
AI 01.101
AE 01.101
Residual Ozone
BV01.116 DN8
SH01.102 Sensor Tank
BV01.115 DN8
-M01
PG 01.102
BV01.109 DN25
CV01.104 DN25
BV01.110 DN25
PM01.102: UV FEEDING PUMP
BV01.204 DN8 sample
BV01.203 DN25
BV01.201 DN25
BV01.202 DN25
PG 01.202
BV01.205 DN8 sample
BV01.113 DN25
BV01.111 DN25
UV01.101
BV01.112 DN25
BV01.114 DN8 sample
UV01.101: ULTRAVIOLE SYSTEM
AC01.201: ACTIVATED CARBON
Drain

a)



TK11.101: NF1 FEED TANK
D02 NF1 ACID (HCL) DOSAGE
D01 NF1 ANTISCALANT DOSAGE
LCP02.101
PM02.101: NF1 PUMP WITH VFD CONTROL
NF02.101: NF1 MEMBRANE SYSTEM
PV02.101
PV02.102
PV02.103
CIP-1 Feed
CIP-2 Recirculation
CIP-3 Recirculation
BR11.102 DN15-PN16-PVC
BR13.101 DN15-PN16-PVC
RO1 CONCENTRATE RECIRCULATION LINE
TK13.101: NF1 PERMEATE TANK
BR13.101 DN25-PN16-PVC
RO1 FEEDING LINE

b)

c)

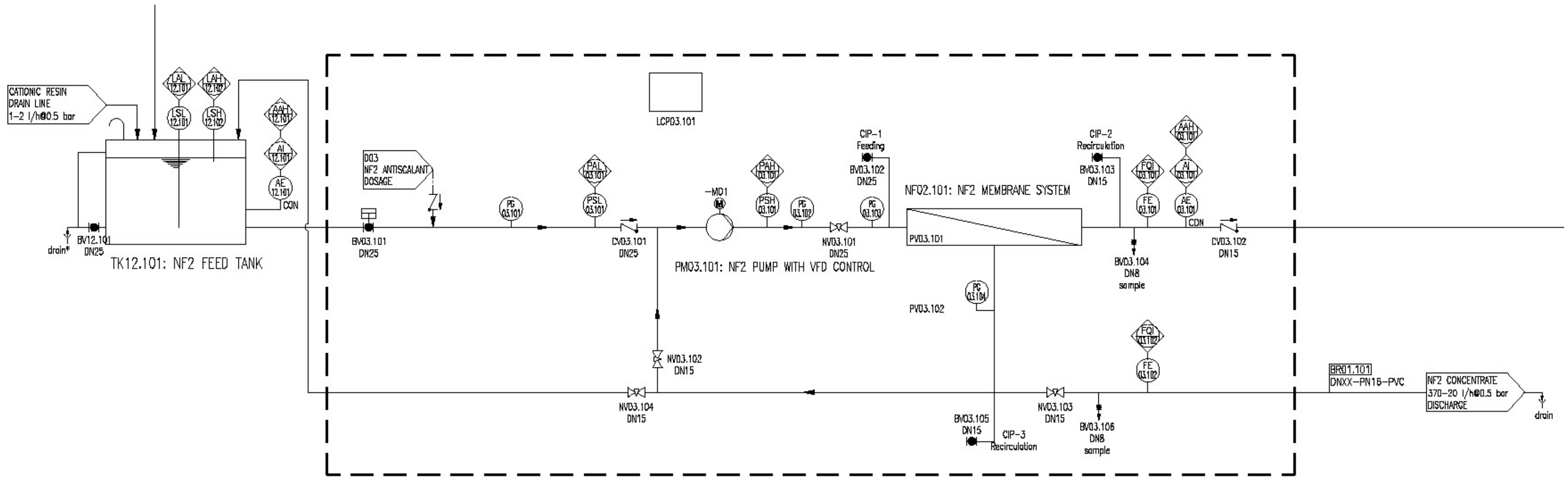


Figure 31 Removal of impurities a) Ozone oxdidation unit (OS-Ozone generator package, TK-Ozone contact tank, ODU-Ozone destruction unit, AC-Activated carbon unit, UV- UV lamp system, AE/SH-Ozone measurement sensor, BV-Valve, CV-Check valve, IM-Inline Mixer, EJ-Enjector, PG-Manometer, AIT- Ambient ozone analyzer, PM-Feed pump, LCP- Local control panel); b) Nanofiltration-1 unit (TK-NF1 feed tank, LSH-Level sensor, BV-Valve, CV-Check valve, PG-Manometer, AAH/AL/AE-pH/Conductivity meter, PM-Feed pump (centrifugal), PV-Nanofiltration membrane, FE-Flow meter, NV-Valve, LCP- Local control panel); c) Nanofiltration-2 unit (TK-NF2 feed tank, LSH-Level sensor, BV-Valve, CV-Check valve, PG-Manometer, AAH/AL/AE-pH/Conductivity meter, PM-Feed pump (centrifugal), PV-Nanofiltration membrane, FE-Flow meter, NV-Valve, LCP-Local control panel)

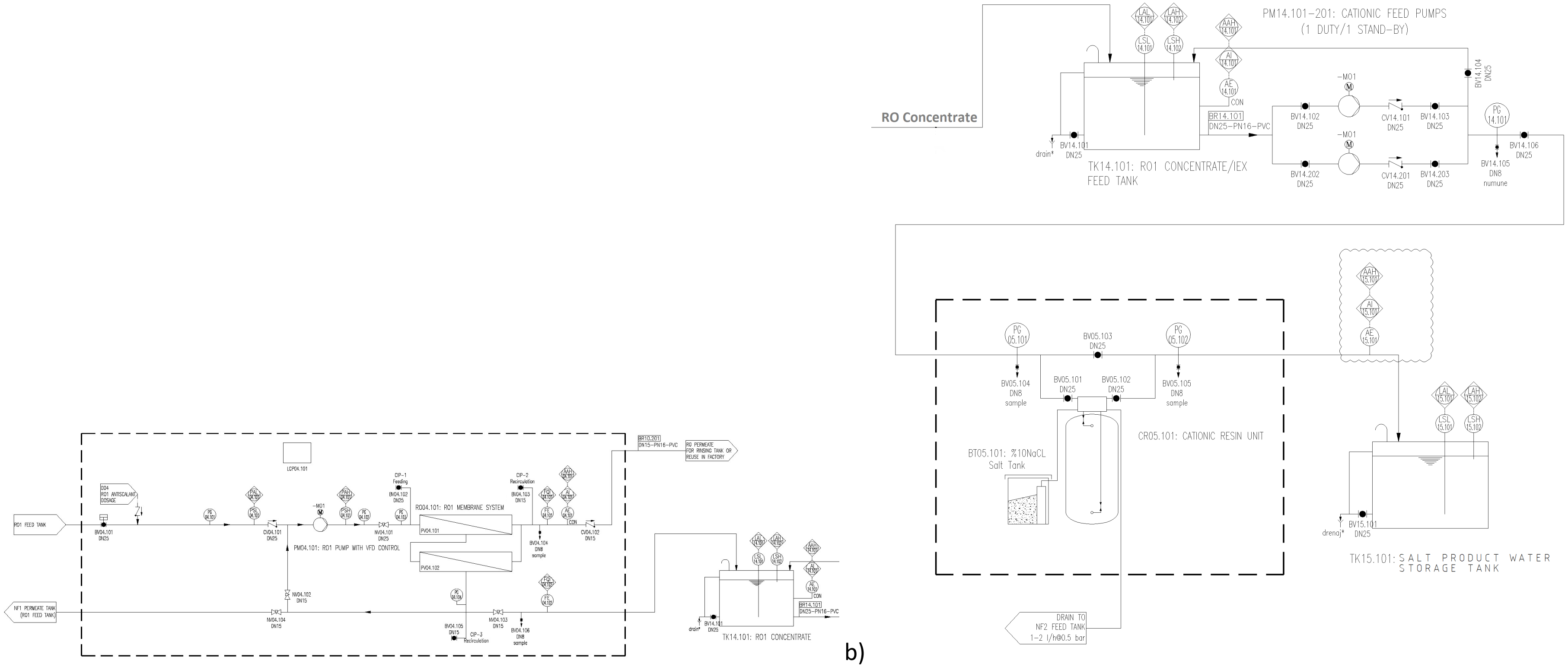
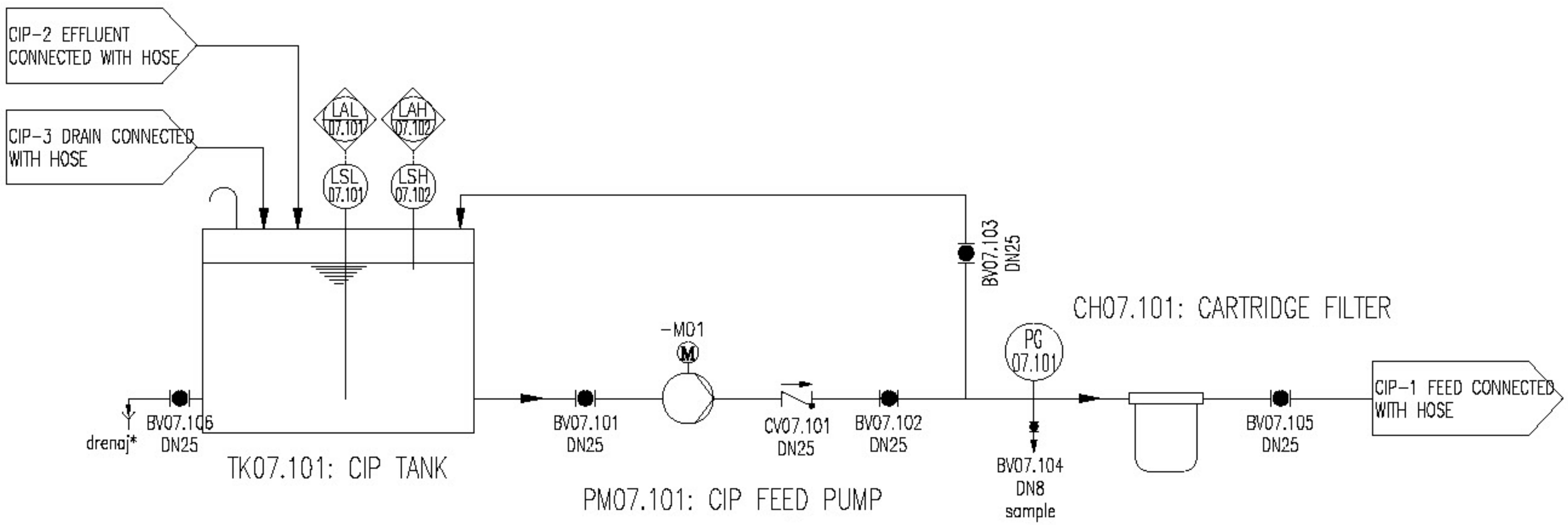
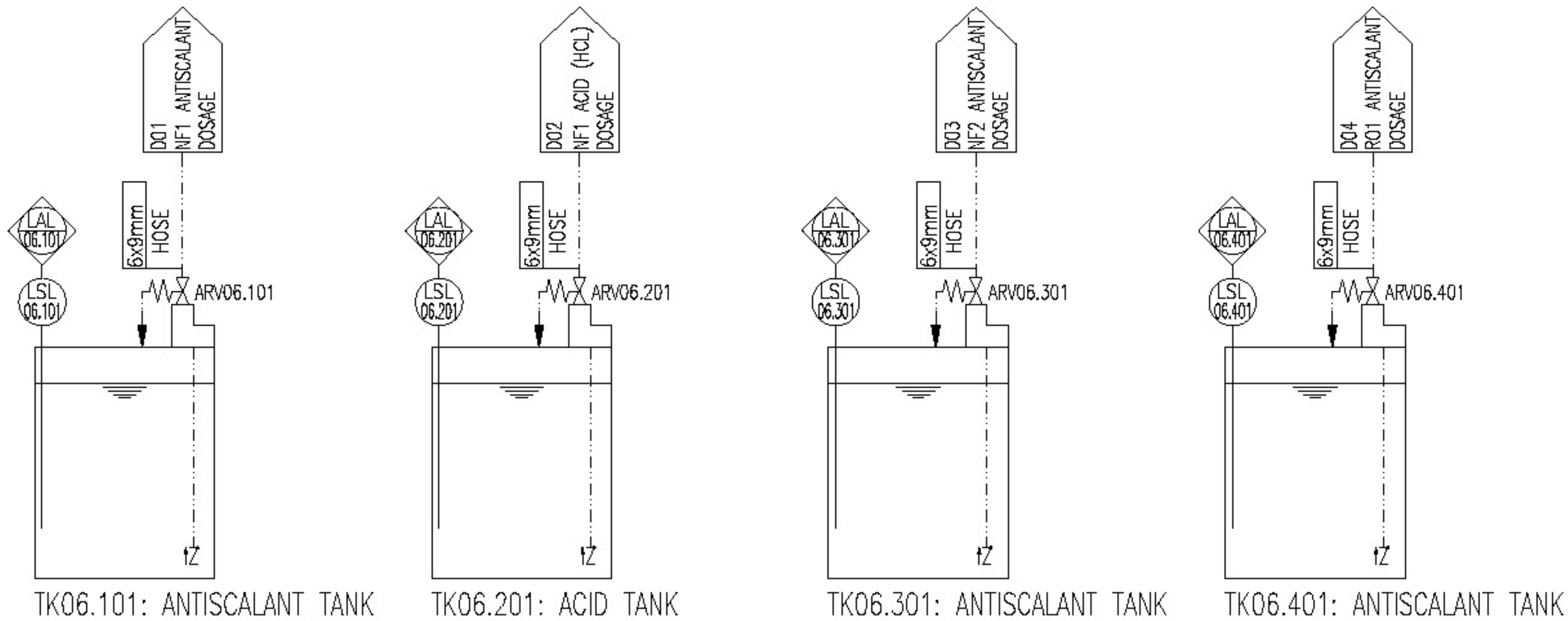
a)  b)

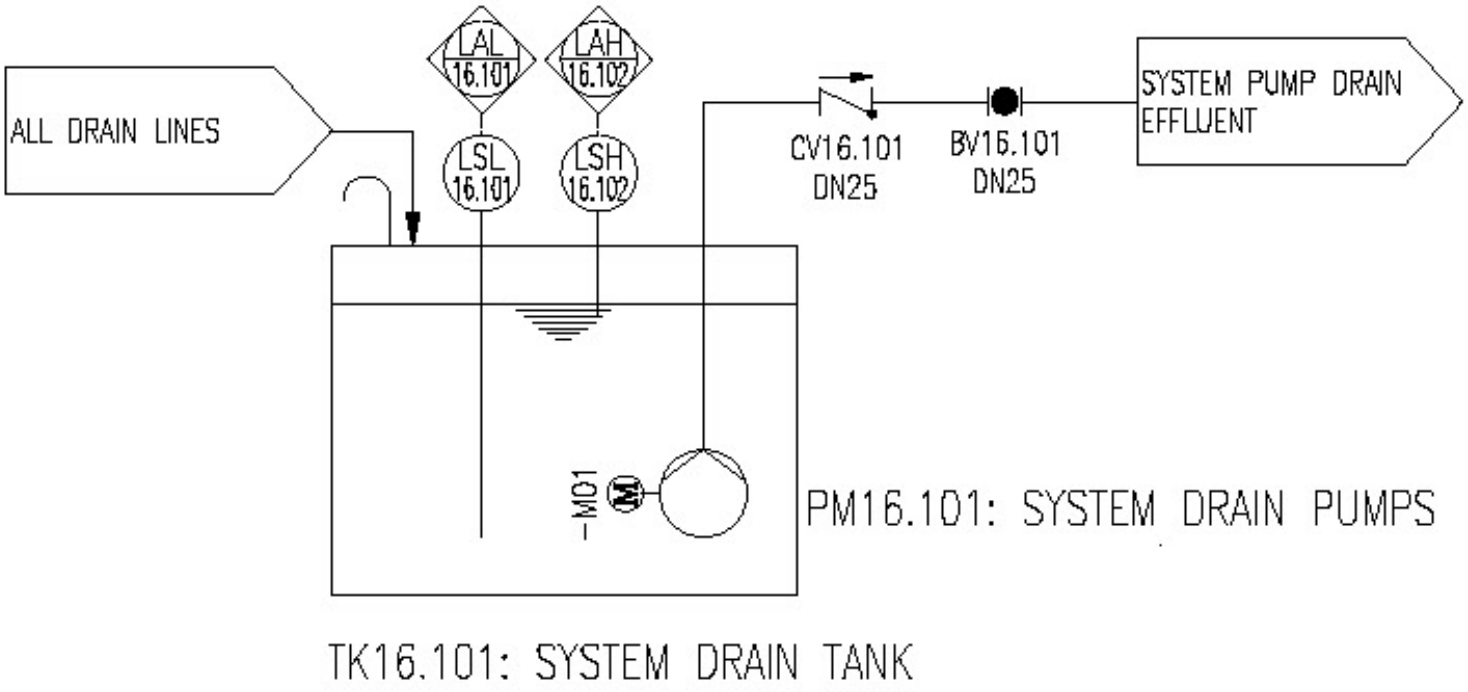
Figure 32 Concentration of the brine and softening a) Reverse osmosis unit (TK-RO feed tank, LSH-Level sensor, BV-Valve, CV-Check valve, PG-Manometer, AAH/AL/AE-pH/Conductivity meter, PM-Feed pump (centrifugal), PV- RO membrane housing, FE-Flow meter, NV-Valve, LCP-Local control panel); b) Ion exchange unit (TK-RO reject tank and salt product water storage tank, LSH-Level sensor, BV-Valve, CV-Check valve, PG-Manometer, AL/AE-Conductivity meter, PM-Feed pump (centrifugal), CR-Ion exchange column, FE-Flow meter, BT-Salt tank, LCP-Local control panel)


CIP-2 EFFLUENT CONNECTED WITH HOSE
CIP-3 DRAIN CONNECTED WITH HOSE
LAL 07.101
LAH 07.102
LSL 07.101
LSH 07.102
BV07.103 DN25
CH07.101: CARTRIDGE FILTER
-M01
M
PG 07.101
CIP-1 FEED CONNECTED WITH HOSE
drenaj*
BV07.106 DN25
TK07.101: CIP TANK
BV07.101 DN25
CV07.101 DN25
BV07.102 DN25
BV07.104 DN8 sample
BV07.105 DN25
PM07.101: CIP FEED PUMP

a)


D01
NF1 ANTISCALANT
DOSAGE
6x9mm
HOSE
LAL
06.101
LSL
06.101
ARV06.101
TK06.101: ANTISCALANT TANK
D02
NF1 ACID (HCL)
DOSAGE
6x9mm
HOSE
LAL
06.201
LSL
06.201
ARV06.201
TK06.201: ACID TANK
D03
NF2 ANTISCALANT
DOSAGE
6x9mm
HOSE
LAL
06.301
LSL
06.301
ARV06.301
TK06.301: ANTISCALANT TANK
D04
RO1 ANTISCALANT
DOSAGE
6x9mm
HOSE
LAL
06.401
LSL
06.401
ARV06.401
TK06.401: ANTISCALANT TANK

b)



c)

Figure 33 Auxillary Units a) CIP unit (TK-CIP tank, LSH-Level sensor, BV-Valve, CV-Check valve, PG-Manometer, PM-Feed pump (centrifugal), CH-Cartridge filter); b) Chemical unit (TK-Anti-scaling and acid tank, LSH-Level sensor, PM-Dosage pumps); c) Drain unit (TK-Drain tank, LSH-Level sensor, PM-Drain pump (Submerged), BV-Valve, CV-Check valve)

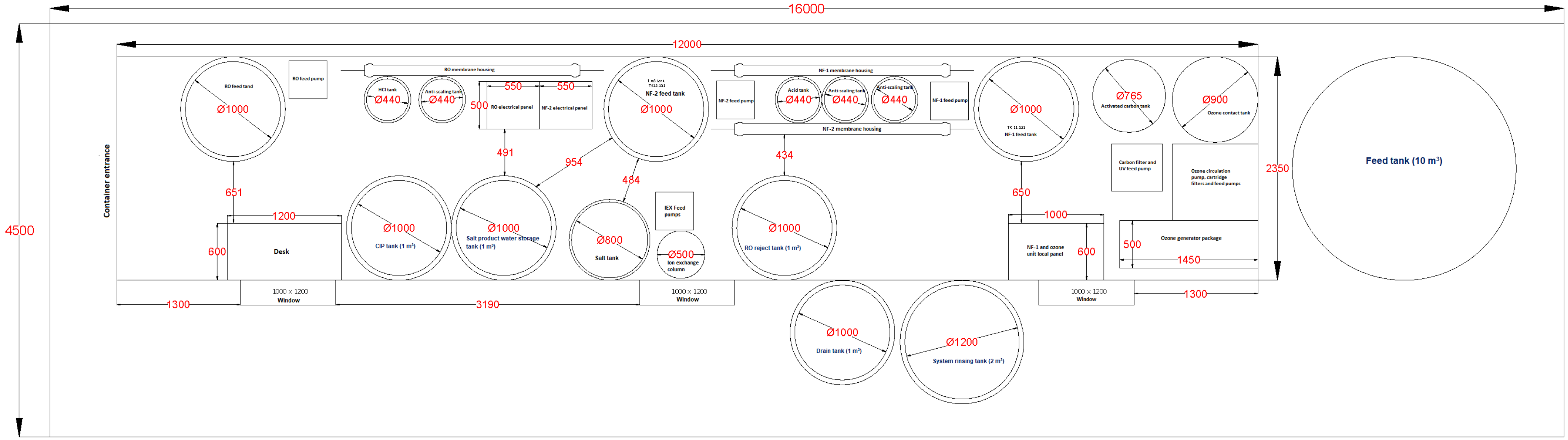


Figure 34 The location of plant units in the container

Annex 2 The composition of the samples collected during the plant start-up

Table 11 The composition of the samples collected during the plant start-up

Process	Sample	pH	Conductivity, µs/cm	TDS, g/L	COD, mg/L	Color, Pt-Co	Ca, mg/L	Mg, mg/L	Cl^{-}, mg/L	SO_4^{2-}, mg/L	T. Hardness, $CaCO_3$ mg/L
Feed Water (1)	**S1**	**9.89**	**9,070**	**4.8**	**344**	**44**	**82**	**32**	**652**	**1,386**	**352**
Ozone (Ozone+AC+UV) Effluent (2)	S1	9.48	8,920	4.8	166	6	82	32	654	1,387	342
	S2	9.65	8,870	4.8	147	4	78	30	643	1,366	345
	S3	9.46	9,080	4.8	139	4	84	34	652	1,392	353
	S4	9.43	9,050	4.8	150	6	83	33	650	1,386	364
	Average	**9.51**	**8,980**	**4.8**	**151**	**5**	**82**	**32**	**650**	**1,383**	**351**
NF1 Permeate (3)	S1	9.59	5,370	3.8	119	1	31	13	515	890	112
	S2	9.62	5,240	3.7	115	2	25	11	524	825	98
	S3	9.56	5,620	3.9	119	1	29	16	502	911	89
	S4	9.53	5,810	4.0	123	2	24	9	523	876	104
	Average	**9.58**	**5,510**	3.9	**119**	**2**	**27**	**12**	**516**	**876**	**101**
NF1 Concentrate (4)	S1	9.52	15,680	6.7	221	22	92	42	711	2,564	662
	S2	9.58	15,170	6.4	238	19	91	51	685	2,785	625
	S3	9.51	15,390	6.5	227	17	101	47	655	2,655	601
	S4	9.45	15,940	6.8	231	14	96	49	664	2,650	641
	Average	**9.52**	**15,545**	**6.6**	**229**	**18**	**95**	**47**	**679**	**2,664**	**632**
NF2 Permeate (6)	S1	9.67	3,750	3.9	114	2	44	39	465	769	205
	S2	9.66	3,970	4.0	105	1	53	42	426	811	193
	S3	9.70	4,460	4.3	96	2	41	29	399	776	214
	S4	9.70	5,310	4.8	120	3	50	34	438	834	220
	Average	**9.68**	**4,373**	**4.2**	**109**	**2**	**47**	**36**	**432**	**798**	**208**

NF2 Concentrate (7)	S1	9.64	14,230	7.8	302	28	178	103	721	5,258	879
	S2	9.64	14,800	8.2	298	25	179	96	621	5,785	863
	S3	9.65	15,310	8.4	286	35	190	127	785	5,478	950
	S4	9.69	15,870	8.8	255	19	183	114	693	5,527	866
	Average	**9.66**	**15,053**	**8.3**	**285**	**27**	**183**	**110**	**705**	**5,512**	**890**
RO Permeate (10)	S1	8.51	141	0.7	19	1	6	1	95	14	18
	S2	8.21	156	0.7	12	2	6	2	104	6	21
	S3	7.62	147	0.6	14	1	6	2	124	9	24
	S4	8.24	710	0.4	19	2	4	2	103	8	16
	Average	**8.15**	**289**	**0.6**	**16**	**2**	**6**	**2**	**107**	**9**	**20**
RO Concentrate (9)	S1	9.65	6,310	9.3	254	19	99	54	1,789	2,058	457
	S2	9.06	7,050	9.7	281	14	112	56	1,848	2,145	502
	S3	9.44	7,560	9.6	245	17	104	49	1,903	1,981	487
	S4	9.56	5,830	9.5	264	13	106	48	1,850	2,204	449
	Average	**9.43**	**6,688**	**9.5**	**261**	**16**	**105**	**52**	**1,848**	**2,097**	**474**
IEX Feed (9)	S1	9.20	5,890	9.1	261	18	102	55	1,799	2,051	457
	S2	8.98	6,630	9.5	274	15	111	57	1,848	2,144	512
	S3	9.53	7,350	9.7	247	16	114	52	1,892	1,971	497
	S4	9.57	6,580	9.6	269	13	106	48	1,851	2,211	439
	Average	**9.32**	**6,613**	**9.5**	**263**	**16**	**108**	**53**	**1,848**	**2,094**	**476**
IEX Effluent (11)	S1	9.53	5,600	9.4	258	20	1	2	1,789	2,051	13
	S2	8.85	6,610	9.7	272	14	2	2	1,858	2,117	13
	S3	9.61	7,350	9.8	244	15	2	2	1,929	2,004	13
	S4	9.66	6,790	9.6	259	7	1	2	1,801	2,147	10
	Average	**9.41**	**6,588**	9.6	**258**	**14**	**2**	**2**	**1,844**	**2,080**	**12**
Product (Salted Water, mixing tank) (11)	**Sample 1**	**9.41**	**6,588**	**9.6**	**258**	**14**	**2**	**2**	**1,844**	**2,080**	**12**

ZERO BRINE

Annex 3 Performance of units in the phase-1

Table 12 Performance of the ozone unit in the Phase-1

Cycle	pH	Conductivity. µs/cm	COD, mg/L	Color Pt-Co	pH	Conductivity. µs/cm	COD, mg/L	Color Pt-Co
OZONE EFFLUENT/ ACTIVATED CARBON INLET					ACTIVATED CARBON EFFLUENT /NF1 FEED			
1	9.16	7,630	153	1	9.13	7,500	51	<1
2	9.17	7,740	134	1	9.09	7,730	61	<1
3	9.30	7,820	133	1	9.33	7,770	45	<1
4	8.02	7,930	125	6	7.80	7,890	48	<1
5	8.08	7,940	144	9	7.64	7,840	55	<1
6	8.13	7,580	141	27	7.71	7,550	54	<1
7	8.10	7,330	164	14	7.90	7,630	63	<1
8	7.98	7,250	141	7	7.73	7,250	54	<1
9	8.15	7,250	133	7	7.86	7,350	51	<1
10	7.99	7,320	144	7	8.02	7,180	55	<1
11	8.04	7,220	144	17	8.06	7,310	55	<1
12	8.54	7,250	131	15	8.05	7,330	50	<1
13	8.27	7,300	125	9	8.10	7,400	48	<1
14	8.51	7,320	160	15	8.29	7,560	65	<1
15	8.64	7,300	157	5	8.24	7,350	68	<1
16	8.32	7,290	159	1	8.21	7,520	61	<1
17	8.00	7,310	151	12	8.21	7,450	58	<1

18	8.26	7,310	144	14	8.12	7,580	55	<1
19	8.08	7,300	128	18	8.01	7,570	49	<1
20	8.34	7,370	125	20	8.06	7,360	48	<1
21	8.43	7,420	125	17	8.34	7,790	48	<1
22	8.16	7,790	128	1	7.34	7,710	49	<1
23	8.12	7,680	133	17	7.86	7,930	51	<1
24	8.21	7,614	138	14	7.96	8	53	<1
25	8.27	7,520	123	13	8.12	7,630	47	<1
26	8.23	7,560	128	9	8.12	7,650	49	<1
27	8.34	7,340	138	7	8.12	7,540	53	<1
28	8.50	7,350	144	10	7.87	7,370	55	<1
29	8.31	6,840	146	8	8.32	7,370	56	<1
30	8.23	6,290	141	9	8.17	7,110	54	<1
Average	**8.33**	**7,405**	**139**	**10**	**8.13**	**7,274**	**54**	<1
Min	**7.98**	**6,290**	**123**	**1**	**7.34**	**8**	**45**	<1
Max	**9.30**	**7,940**	**164**	**27**	**9.33**	**7,930**	**68**	<1

Table 13 Analysis results of feed, permeate and retentate of NF1 processes for Phase 1

Cycle	pH	Conductivity, µs/cm	TDS, g NaCl/L	COD, mg/L	Color Pt-Co	Ca, mg/L	Mg, mg/L	Cl, mg/L	Na, mg/L	SO_4, mg/L	T. Hardness, mg $CaCO_3$/L
NF1 FEED											
1	9.13	7500	4.1	51	<1	78.0	28.0	593	1321	1358	321.0
2	9.09	7730	4.1	61	<1	77.0	30.0	588	1311	1357	314.0
3	9.33	7770	4.1	45	<1	81.0	29.0	586	1302	1393	299.2
4	7.8	7890	4.3	48	<1	82.0	27.0	586	1314	1344	309.0
5	7.64	7840	4.2	55	<1	76.0	27.0	591	1341	1385	298.0
6	7.71	7550	4.2	54	<1	63.0	26.0	589	1338	1344	301.0

7	7.9	7630	4.2	63	<1	56.7	27.2	581	1309	1342	309.0
8	7.73	7250	4.2	54	<1	63.5	26.7	588	1311	1356	315.0
9	7.86	7350	4.2	51	<1	79.3	28.6	600	1321	1462	344.0
10	8.02	7180	4.0	55	<1	79.0	28.7	602	1318	1471	351.0
11	8.06	7310	4.2	55	<1	80.3	28.1	624	1332	1500	355.0
12	8.05	7330	4.2	50	<1	81.5	28.5	627	1329	1486	350.0
13	8.1	7400	4.7	48	<1	80.4	27.4	625	1322	1478	347.4
14	8.29	7560	4.8	65	<1	81.3	26.9	611	1354	1468	348.6
15	8.24	7350	4.7	68	<1	80.9	28.1	612	1365	1475	343.9
16	8.21	7520	4.8	61	<1	80.4	28.0	611	1349	1474	350.2
17	8.21	7450	4.8	58	<1	80.4	28.0	611	1352	1480	347.8
18	8.12	7580	4.9	55	<1	81.7	27.1	612	1349	1478	346.0
19	8.01	7570	4.8	49	<1	81.2	27.9	614	1368	1482	348.3
20	8.06	7360	4.7	48	<1	81.2	28.3	614	1377	1488	349.0
21	8.34	7790	4.3	48	<1	81.9	28.8	631	1373	1563	350.9
22	7.34	7710	4.2	49	<1	79.0	31.0	603	1371	1512	351.0
23	7.86	7930	4.4	51	<1	80.0	29.0	599	1375	1500	350.2
24	7.83	7856	4.3	53	<1	78.0	28.0	586	1336	1508	351.0
25	8.12	7630	4.3	47	<1	77.0	30.0	585	1348	1521	352.0
26	8.12	7650	4.3	49	<1	79.0	28.0	600	1371	1513	350.0
27	8.12	7540	4.4	53	<1	81.0	29.0	598	1389	1518	351.0
28	7.87	7370	4.3	55	<1	80.0	31.0	587	1380	1496	350.0
29	8.32	7370	4.3	56	<1	82.0	30.0	580	1361	1498	349.0
30	8.17	7110	4.1	54	<1	77.0	30.0	597	1324	1490	351.0
Average	**8.12**	**7536**	**4.4**	**54**	**<1**	**78**	**28**	**601**	**1344**	**1458**	**338**
Min	**7.34**	**7110**	**4.0**	**45**	**<1**	**57**	**26**	**580**	**1302**	**1342**	**298**
Max	**9.33**	**7930**	**4.9**	**68**	**<1**	**82**	**31**	**631**	**1389**	**1563**	**355**
NF1 PERMEATE											
1	9.19	6370	3.4	67	1	38.4	12.3	498	1104	985	113.0
2	9.44	7530	4.0	40	1	36.5	13.4	506	985	940	101.0
3	9.52	7220	3.8	38	1	30.3	14.7	505	996	942	98.0
4	7.73	7080	3.8	39	1	29.6	14.5	517	1005	906	87.0
5	8.12	7250	3.8	41	1	31.1	12.8	487	1114	898	85.0
6	7.82	6840	3.7	40	1	27.7	12.0	490	1131	890	93.0
7	7.77	6220	3.4	36	1	26.7	10.5	503	1132	901	96.0
8	7.74	5240	2.8	42	1	14.4	5.8	500	988	913	95.0
9	7.6	5260	2.8	42	1	11.8	3.7	496	933	996	85.0

10	7.61	4770	2.4	42	1	10.7	3.0	503	1005	916	108.0
11	7.45	4730	2.5	41	1	15.3	2.1	495	1037	995	114.0
12	7.84	6070	3.6	39	1	12.9	4.5	497	1088	956	112.0
13	7.42	6100	3.9	40	1	15.5	3.6	506	1124	987	112.5
14	7.79	6210	4.0	38	1	18.4	7.7	519	1136	912	114.8
15	7.65	6150	3.9	37	1	23.1	8.4	521	1128	988	119.4
16	7.73	6490	4.2	38	1	35.8	8.5	528	1182	967	121.1
17	7.72	6690	4.3	41	1	43.4	17.3	523	1133	943	117.9
18	7.86	6680	4.3	40	1	44.2	19.7	506	1128	988	116.6
19	7.68	8190	5.2	38	1	48.9	18.5	505	1154	996	115.0
20	7.78	6930	4.4	37	1	54.9	18.5	517	1163	977	110.0
21	7.95	5920	3.8	40	1	34.9	12.4	515	1169	962	113.5
22	7.64	5720	3.1	40	1	28.4	11.6	510	1165	960	108.4
23	8.05	4940	2.7	40	1	27.4	9.8	511	1166	955	100.0
24	7.9	4988	2.8	41	1	27.5	9.4	489	1158	950	118.0
25	7.21	5810	3.2	41	1	26.6	10.4	490	1150	1006	117.9
26	8	5700	3.2	43	1	25.0	9.8	490	1149	986	110.4
27	7.35	5280	3.1	41	1	27.8	11.0	488	1153	990	98.6
28	7.64	5360	3.1	39	1	31.3	10.5	485	1121	995	97.7
29	7.44	5260	3.0	39	1	33.9	9.3	480	1100	1003	112.4
30	7.53	5150	2.9	40	1	35.5	8.8	476	1138	1008	115.9
Average	**7.87**	**6072**	**3.5**	**41**	**1**	**29**	**10**	**502**	**1105**	**960**	**107**
Min	**7.21**	**4730**	**2.4**	**36**	**1**	**11**	**2**	**476**	**933**	**890**	**85**
Max	**9.52**	**8190**	**5.2**	**67**	**1**	**55**	**20**	**528**	**1182**	**1008**	**121**
NF1 RETENTATE											
1	9.21	9030	5.0	67	3	91.1	48.5	718	1782	1920	733.00
2	9.15	13270	7.3	75	5	90.8	51.5	695	1744	1836	721.00
3	9.24	12240	6.7	71	4	105.5	50.6	699	1625	2113	705.00
4	7.9	12580	6.8	89	8	105.5	48.0	691	1533	1965	685.00
5	7.78	14830	6.6	83	18	88.8	49.1	696	1445	1921	675.00
6	7.79	12730	7.9	77	17	81.1	45.3	688	1658	1889	650.00
7	7.63	12930	7.7	86	12	73.2	50.0	648	1777	1965	650.00
8	7.67	13960	6.5	69	13	78.5	50.4	626	1015	2005	620.00
9	7.56	14090	6.8	68	6	81.0	48.0	679	1138	2106	645.00
10	7.4	15650	6.4	71	20	89.3	48.9	664	1365	1989	621.00
11	7.4	20500	6.3	66	13	92.2	53.3	685	1429	1988	627.50
12	7.67	13820	6.4	73	4	101.1	48.9	692	1552	2078	630.50

13	7.29	10240	6.6	78	7	99.1	47.9	677	1528	1936	636.40
14	7.51	10070	6.4	74	4	96.3	47.6	715	1585	1910	645.00
15	7.25	10720	6.9	67	11	95.4	51.2	702	1568	1895	621.00
16	7.25	10580	6.8	66	23	98.7	49.1	700	1489	1885	590.00
17	7.53	10700	6.8	70	37	103.0	48.6	696	1614	1965	608.00
18	7.64	10350	6.6	71	32	102.1	51.0	688	1621	1833	598.00
19	7.44	10011	6.4	68	55	100.8	47.0	671	1608	1810	594.00
20	7.57	10490	6.7	69	37	99.6	49.5	672	1642	1864	585.00
21	7.85	10730	6.9	65	11	104.0	49.1	686	1694	1893	590.00
22	7.15	9790	6.3	66	31	103.4	34.5	680	1558	1913	555.00
23	7.83	9340	6.0	70	16	105.6	49.0	660	1603	1945	569.00
24	7.82	9321	6.0	71	17	95.1	48.1	643	1544	2098	545.00
25	7.23	9460	6.1	70	18	90.2	49.4	631	1598	2011	530.00
26	7.88	9270	5.9	68	19	90.5	47.5	621	1683	1910	577.00
27	7.6	9670	6.2	73	27	104.1	46.4	619	1650	1913	598.00
28	7.44	9200	5.9	71	20	102.5	56.3	602	1595	1894	615.00
29	7.39	9270	5.9	70	14	103.1	52.2	595	1560	1900	670.00
30	7.24	9540	6.1	70	6	94.3	53.0	605	1610	1854	710.00
Average	**7.71**	**11479**	**6.5**	**72**	**17**	**96**	**49**	**668**	**1560**	**1940**	**627**
Min	**7.15**	**9030**	**5.0**	**65**	**3**	**73**	**35**	**595**	**1015**	**1810**	**530**
Max	**9.24**	**20500**	**7.9**	**89**	**55**	**106**	**56**	**718**	**1782**	**2113**	**733**

Table 14 Analysis results of permeate and retentate of NF2 processes for Phase 1

Cycle	pH	Conductivity, μs/cm	TDS, g NaCl/L	COD, mg/L	Color Pt-Co	Ca, mg/L	Mg, mg/L	Cl, mg/L	Na, mg/L	SO_4, mg/L	T. Hardness, mg $CaCO_3$/L
NF2 PERMEATE											
1	9.5	6960	3.8	63	<1	24.0	16.0	328	936	834	118.50
2	9.6	6780	3.6	40	<1	28.0	13.2	413	1003	823	121.60
3	9.66	6520	3.4	36	<1	33.0	9.4	332	928	736	130.00
4	7.97	6620	3.8	55	<1	28.0	14.4	401	876	721	133.00
5	7.34	6430	3.4	44	<1	31.0	12.2	417	855	798	128.50
6	8.28	7160	4.1	53	<1	29.0	15.0	303	843	751	121.40
7	8.93	5070	2.9	61	<1	21.7	16.7	314	897	784	112.50
8	8.43	6410	3.7	42	<1	21.5	12.4	415	997	875	110.30
9	8.41	5950	3.5	48	<1	13.3	9.1	583	1075	810	113.60
10	8.57	7250	4.2	43	<1	12.6	10.1	690	1146	731	118.90
11	8.7	8210	4.8	39	<1	11.6	8.8	633	1041	720	118.00

12	8.53	9690	5.8	38	<1	27.6	17.4	636	956	750	184.50
13	8.86	7730	4.9	41	<1	27.1	16.2	755	986	713	195.00
14	8.34	7770	5.0	40	<1	24.3	18.4	741	904	801	102.40
15	8.53	8660	5.5	48	<1	21.5	22.1	633	925	880	122.50
16	8.4	10300	6.6	35	<1	36.9	50.6	605	952	890	215.50
17	7.95	12310	7.9	41	<1	85.0	74.2	504	903	850	465.00
18	8.02	12830	8.2	42	<1	114.5	76.3	490	1121	1121	513.00
19	8.42	14470	9.3	52	<1	129.0	77.8	475	1113	1112	554.00
20	8.4	12800	8.2	48	<1	140.8	80.0	456	1244	1101	617.50
21	8.51	8050	5.2	53	<1	113.0	41.0	429	1366	1015	517.50
22	8.05	7930	4.4	53	<1	104.5	44.1	321	1214	1166	525.00
23	8.06	6000	3.3	48	<1	95.5	48.3	289	1121	992	580.00
24	8.11	6650	3.8	43	<1	80.2	52.6	303	1189	823	465.00
25	8.14	6850	3.8	38	<1	74.4	53.5	311	1231	814	373.00
26	8.32	9500	5.4	38	<1	68.7	56.2	297	1189	785	340.80
27	8.13	7150	4.1	44	<1	55.2	51.9	286	1067	766	253.40
28	8.23	6530	3.8	52	<1	43.9	49.2	254	989	733	221.50
29	8.08	6210	3.6	50	<1	37.7	47.2	267	975	751	285.00
30	8.34	6070	3.5	51	<1	32.8	40.1	271	913	725	296.50
Average	**8.43**	**8029**	**4.8**	**46**	**<1**	**52**	**35**	**438**	**1032**	**846**	**272**
Min	**7.34**	**5070**	**2.9**	**35**	**<1**	**12**	**9**	**254**	**843**	**713**	**102**
Max	**9.66**	**14470**	**9.3**	**63**	**<1**	**141**	**80**	**755**	**1366**	**1166**	**618**
NF2 RETENTATE											
1	9.43	10880	6.0	88	65	171.2	75.5	655	2285	1793	740.50
2	9.35	12990	7.2	205	59	163.4	67.8	663	3112	3460	690.00
3	9.27	14200	7.9	208	55	158.6	83.5	782	2975	3280	738.50
4	8.15	15860	8.5	196	51	155.5	80.9	797	3033	3022	720.00
5	7.65	16360	8.2	151	57	164.4	75.6	732	2976	2770	723.00
6	7.92	16110	8.5	133	65	167.0	72.2	703	2800	3160	718.00
7	8.7	13460	7.1	118	44	169.2	77.7	762	2772	3276	745.50
8	8.22	17170	9.1	115	36	186.5	85.7	725	2525	4025	823.40
9	8.46	17300	9.5	110	34	211.0	112.1	836	2147	3743	965.40
10	8.23	20100	11.1	114	32	83.2	110.4	893	1365	3865	650.50
11	8.37	22600	12.4	121	35	74.6	118.5	902	1868	4517	671.20
12	8.39	18050	10.5	118	20	95.9	106.5	955	1399	3018	665.00
13	8.74	16650	8.7	128	18	111.3	99.0	1010	1204	2915	683.40
14	8.18	15480	8.4	116	13	152.6	101.3	1117	1145	3353	791.10

15	8.43	17970	9.9	98	28	163.5	107.1	1273	1020	3217	853.50
16	8.26	19740	10.5	96	23	214.5	125.7	838	1478	3574	1010.00
17	8.12	20000	11.8	103	50	259.2	139.3	803	1586	3436	1204.60
18	7.9	20400	11.1	95	42	278.9	141.5	751	1658	2855	1268.00
19	8.44	24600	13.3	101	65	296.6	151.6	654	1665	3234	1304.00
20	8.48	21200	12.1	95	62	308.1	159.3	526	1777	2809	1418.50
21	8.44	13770	7.8	95	29	240.7	138.0	662	1716	3353	1132.50
22	7.62	12100	6.6	112	20	203.6	118.9	761	1698	3745	990.50
23	8.02	11760	6.7	121	21	200.5	125.7	800	1700	2933	1054.40
24	8.12	11743	6.6	111	20	212.5	133.5	894	1735	3013	1121.30
25	8.08	10138	5.5	98	14	221.6	150.0	893	1759	2812	1100.00
26	8.35	11170	6.4	95	15	230.6	168.2	923	1813	2826	1254.90
27	8.17	11840	6.4	93	21	235.5	175.5	966	1990	2750	1315.50
28	8.18	11480	6.3	100	33	228.4	170.3	989	2057	2834	1217.40
29	8.13	12660	6.8	134	20	220.6	176.6	980	2345	3024	1258.50
30	8.17	12280	6.5	120	19	200.5	180.7	911	2489	3260	1185.40
Average	**8.33**	**15669**	**8.6**	**120**	**36**	**193**	**121**	**838**	**2003**	**3196**	**967**
Min	**7.62**	**10138**	**5.5**	**88**	**13**	**75**	**68**	**526**	**1020**	**4093**	**651**
Max	**9.43**	**24600**	**13.3**	**208**	**65**	**308**	**181**	**1273**	**3112**	**6817**	**1419**

Table 15 Analysis results of feed, permeate and retentate of RO processes for Phase 1

Cycle	pH	Conductivity, µs/cm	TDS, g NaCl/L	COD, mg/L	Color Pt-Co	Ca, mg/L	Mg, mg/L	Cl, mg/L	Na, mg/L	SO_4, mg/L	T. Hardness, mg $CaCO_3$/L
					RO FEED						
1	9.36	6700	3.6	53	<1	30.3	10.2	376	1012	621	119.6
2	9.5	6850	3.6	28	<1	32.1	9.8	388	1022	757	121.3
3	9.68	12750	7.0	74	<1	31.5	11.4	375	989	724	123.5
4	8.64	16330	9.9	35	<1	28.9	13.4	395	990	756	125.0
5	8.15	9370	5.1	44	<1	27.6	15.2	403	1003	705	130.0
6	8.71	9980	5.8	53	<1	24.4	15.8	458	980	695	126.0
7	7.99	5570	3.2	38	<1	31.3	14.3	421	985.6	676	120.0
8	8.03	6050	3.6	44	<1	20.5	10.3	425	1015	746	101.0
9	8.19	6420	3.7	52	<1	18.3	9.2	421	1166	840	75.5
10	7.85	5930	3.5	51	<1	15.7	8.5	459	1118	725	70.4
11	8.06	6310	3.7	48	<1	13.8	6.5	500	1145	670	50.0
12	8.21	7130	4.2	38	<1	22.2	9.6	594	1283	861	85.0
13	7.9	7970	5.1	41	<1	21.3	10.1	504	1246	903	87.4

14	8.07	7390	4.7	38	<1	24.7	11.3	533	1299	986	103.2
15	8.04	7440	4.8	33	<1	30.7	15.0	546	1338	1186	125.0
16	8.08	7220	4.6	30	<1	37.0	18.7	605	1404	1156	173.0
17	7.81	8070	5.2	41	<1	49.8	23.8	665	1440	1164	192.5
18	7.89	7490	4.8	44	<1	51.5	25.5	603	1441	1254	198.6
19	7.87	7200	4.6	40	<1	59.0	27.6	585	1499	1312	214.6
20	8.09	7970	5.1	40	<1	65.2	29.9	560	1447	1458	267.5
21	8.28	6850	4.0	38	<1	37.1	16.6	521	1032	829	142.5
22	7.88	7210	4.0	41	<1	53.2	18.2	488	1020	903	190.0
23	8.07	7240	3.9	37	<1	51.6	16.5	436	996	897	187.5
24	8.1	6350	3.6	33	<1	48.5	18.5	412	1102	855	182.3
25	7.7	6520	3.6	30	<1	46.6	21.6	423	954	842	213.3
26	8.23	6890	3.9	31	<1	48.3	23.3	405	944	810	204.5
27	8	6730	3.9	31	<1	51.4	25.4	398	983	798	221.6
28	7.78	7870	4.6	35	<1	50.2	22.8	388	992	760	215.4
29	8.04	6520	3.8	38	<1	49.5	26.9	375	1004	754	221.7
30	7.9	6170	3.5	41	<1	51.3	31.3	364	973	734	250.5
Average	**8.20**	**7616**	**4.5**	**41**	**<1**	**37**	**17**	**468**	**1127**	**879**	**155**
Min	**7.70**	**5570**	**3.2**	**28**	**0**	**14**	**6**	**364**	**944**	**621**	**50**
Max	**9.68**	**16330**	**9.9**	**74**	**0**	**65**	**31**	**665**	**1499**	**1458**	**268**
RO PERMEATE											
1	8.44	771	0.3	3	<1	4.1	1.2	32	98	9	16
2	8.74	1230	0.5	<10	<1	4.2	1.1	37	103	<10	15
3	8.73	1380	0.7	<10	<1	4.0	1.3	39	101	<10	17
4	8.68	1869	0.8	<10	<1	3.8	1.5	49	89	<10	17
5	7.57	2370	0.2	<10	<1	3.5	1.7	65	92	<10	17
6	8.93	1657	0.7	<10	<1	4.5	2.0	87	91	<10	18
7	8.25	1369	0.6	<10	<1	5.8	2.1	84	99	<10	22
8	8.92	1113	0.4	<10	<1	1.8	0.7	75	82	<10	9
9	9.11	1182	0.5	<10	<1	1.5	0.6	81	92	<10	9
10	9.11	1211	0.5	<10	<1	1.2	0.5	99	72	<10	7
11	9.4	1375	0.5	<10	<1	1.2	0.5	93	88	<10	7
12	9.29	1780	0.7	<10	<1	2.2	0.9	87	93	<10	12
13	9.16	1990	1.3	<10	<1	2.5	0.8	98	95	<10	12
14	9.2	2820	1.8	<10	<1	3.4	1.0	101	98	<10	15
15	9.2	2180	1.4	<10	<1	4.0	1.9	114	101.7	<10	15
16	9.9	2970	1.9	<10	<1	5.2	2.5	137	102	<10	21
17	8.93	2500	1.6	<10	<1	7.3	3.4	177	105.6	<10	31
18	8.9	2490	1.6	<10	<1	7.5	3.2	199	110	<10	30
19	9.02	2400	1.5	<10	<1	7.9	3.9	195	103	<10	35
20	9.19	2450	1.6	<10	<1	8.5	4.0	197	97	<10	34

21	9.13	2300	1.5	<10	<1	4.8	2.2	186	99	<10	20
22	8.62	3230	1.7	<10	<1	3.9	1.8	160	96	<10	24
23	8.12	3001	2.1	<10	<1	4.1	2.1	143	103	<10	21
24	8.11	2021	1.1	<10	<1	4.4	2.2	131	112	<10	22
25	7.96	1923	1.1	<10	<1	4.5	0.9	110	121	<10	18
26	8.58	2008	1.1	<10	<1	4.1	1.2	109	133	<10	16
27	8.38	1971	1.1	<10	<1	3.9	1.1	110	128	<10	22
28	8.37	2840	1.6	<10	<1	3.7	1.1	112	114	<10	25
29	8.42	3030	1.7	<10	<1	3.8	1.0	114	121	<10	16
30	8.28	2890	1.6	<10	<1	4.1	0.9	121	129	<10	18
Average	**8.75**	**2077**	**1.1**	**3**	**<1**	**4**	**2**	**111**	**102**	**9**	**19**
Min	**7.57**	**771**	**0.2**	**3**	**<1**	**1**	**0**	**32**	**72**	**9**	**7**
Max	**9.90**	**3230**	**2.1**	**3**	**<1**	**8**	**4**	**199**	**133**	**9**	**35**
RO RETENTATE (PRODUCT FOR DYEING PROCESSES)											
1	9.47	20340	11.3	67	23	144.5	51.0	2121	5136	804	575.0
2	9.72	21330	11.9	16	14	131.2	53.3	2234	5003	1220	550.0
3	9.23	19260	10.7	137	21	121.6	48.4	2005	4988	1587	505.5
4	8.48	19620	10.9	135	23	127.0	36.5	2439	4975	2003	463.2
5	8.47	21420	11.9	144	13	133.6	24.3	2876	4853	2132	430.1
6	8.57	19800	11.0	158	16	146.5	45.8	3123	4544	2850	550.1
7	8.26	21600	12.0	141	11	155.8	60.3	3644	5176	3418	575.0
8	8.44	18540	10.3	166	11	136.5	50.6	2826	5790	3513	530.5
9	8.33	19440	10.8	178	19	104.0	46.6	2278	6538	3667	402.5
10	8.24	19440	10.8	163	14	87.9	35.7	2654	6254	3100	360.5
11	8.57	19800	11.0	144	18	44.0	22.0	2563	6899	2190	170.0
12	8.66	19080	10.6	183	14	56.6	25.5	2167	5965	2123	275.0
13	8.45	19980	11.1	211	10	63.5	29.0	2145	5178	2301	275.5
14	8.6	20160	11.2	224	17	70.2	32.3	2046	5259	2465	302.4
15	8.57	20700	11.5	218	19	82.5	37.0	2072	5395.6	2547	372.5
16	8.67	21960	12.2	210	22	92.0	44.3	2147	5447	2121	401.0
17	8.41	19260	10.7	221	34	114.6	55.5	1787	5417.6	2527	554.0
18	8.41	20160	11.2	236	35	133.2	64.0	1163	5481	3746	603.0
19	8.52	20700	11.5	204	46	142.3	66.5	1079	5106	3188	636.0
20	8.60	21060	11.7	198	46	149.6	70.5	1156	4983	3035	640.0
21	8.62	19980	11.1	187	35	153.4	71.1	1184	4039	2998	670.0
22	8.53	19440	10.8	208	38	132.0	68.9	1034	4123	2398	612.3
23	8.13	19080	10.6	219	41	121.0	67.7	985	4008	2221	580.1
24	8.12	19620	10.9	201	38	118.5	66.5	988	4120	2165	550.4
25	8.37	19440	10.8	196	25	115.4	65.5	923	4060	2067	551.5
26	8.64	19980	11.1	192	25	105.2	60.2	975	4178	1988	525.0

27	8.77	21780	12.1	188	25	100.1	49.4	903	4004	1865	450.2
28	8.79	21600	12.0	175	23	95.7	45.3	896	3980	1877	421.1
29	8.64	21600	12.0	170	31	98.2	40.1	980	4387	1566	414.2
30	8.67	20160	11.2	182	38	85.5	35.0	1034	4888	1433	365.5
Average	**8.60**	**20211**	**11.2**	**176**	**25**	**112**	**49**	**1814**	**5006**	**2370**	**477**
Min	**8.12**	**18540**	**10.3**	**16**	**10**	**44**	**22**	**896**	**3980**	**4093**	**170**
Max	**9.72**	**21960**	**12.2**	**236**	**46**	**156**	**71**	**3644**	**6899**	**6817**	**670**

Table 16 Performance of the IEX in the phase-1

Cycle	pH	Conductivity	TDS	Ca	Mg	Total Hardness
	-	µs/cm	g NaCl/L	mg/L	mg/L	mg $CaCO_3$/L
			IEX FEED (RO RETENTATE)			
1	9.47	20,340	11.3	145	51.0	575
2	9.72	21,330	11.9	131	53.3	550
3	9.23	19,260	10.7	122	48.4	506
4	8.48	19,620	10.9	127	36.5	463
5	8.47	21,420	11.9	134	24.3	430
6	8.57	19,800	11.0	147	45.8	550
7	8.26	21,600	12.0	156	60.3	575
8	8.44	18,540	10.3	137	50.6	531
9	8.33	19,440	10.8	104	46.6	403
10	8.24	19,440	10.8	88	35.7	361
11	8.57	19,800	11.0	44	22.0	170
12	8.66	19,080	10.6	57	25.5	275
13	8.45	19,980	11.1	63	29.0	276
14	8.6	20,160	11.2	70	32.3	302
15	8.57	20,700	11.5	83	37.0	373
16	8.67	21,960	12.2	92	44.3	401
17	8.41	19,260	10.7	115	55.5	554
18	8.41	20,160	11.2	133	64.0	603
19	8.52	20,700	11.5	142	66.5	636
20	8.60	21,060	11.7	150	70.5	640
21	8.62	19,980	11.1	153	71.1	670
22	8.53	19,440	10.8	132	68.9	612
23	8.13	19,080	10.6	121	67.7	580
24	8.12	19,620	10.9	119	66.5	550
25	8.37	19,440	10.8	115	65.5	552
26	8.64	19,980	11.1	105	60.2	525
27	8.77	21,780	12.1	100	49.4	450
28	8.79	21,600	12.0	96	45.3	421

29	8.64	21,600	12.0	98	40.1	414
30	8.67	20,160	11.2	86	35.0	366
Average	**8.6**	20,211	11.2	**112**	**49.0**	**477**
Min	**8.1**	18,540	10.3	**44**	**22.0**	**170**
Max	**9.7**	21,960	12.2	**156**	**71.1**	**670**
IEX EFFLUENT (PRODUCT)						
1	9.7	20,640	11.5	0.08	0.14	2.5
2	9.83	21,030	11.7	0.05	0.25	2.8
3	9.98	19,560	10.9	0.10	0.65	4.5
4	8.9	19,420	10.8	0.07	0.41	3.8
5	8.66	21,820	12.1	0.10	0.29	2.4
6	8.95	19,807	11.0	0.09	0.90	4.1
7	8.78	21,540	12.0	0.11	0.10	0.5
8	8.72	18,847	10.5	0.12	0.96	3.2
9	8.73	19,580	10.9	0.16	0.20	0.8
10	8.59	19,429	10.8	0.14	0.55	2.1
11	8.65	19,893	11.1	0.18	0.27	0.6
12	8.86	19,367	10.8	0.30	0.30	1.1
13	8.7	19,412	10.8	0.07	1.20	5.8
14	8.74	20,635	11.5	0.24	1.40	6.9
15	8.73	20,102	11.2	0.08	1.05	3.6
16	8.75	22,147	12.3	0.17	0.85	6.9
17	8.73	19,160	10.6	0.39	0.42	1.5
18	8.78	20,100	11.2	0.45	0.98	7.9
19	8.86	20,214	11.2	0.65	0.47	4.1
20	8.95	21,014	11.7	0.16	0.23	1.8
21	8.98	20,147	11.2	0.16	0.24	3.8
22	8.69	18,965	10.5	0.47	0.85	3.0
23	9.24	19,780	11.0	0.29	1.08	3.7
24	8.6	19,325	10.7	0.68	1.36	13.2
25	8.45	19,635	10.9	0.80	2.10	9.8
26	8.51	19,429	10.8	1.20	1.21	4.3
27	8.72	21,547	12.0	1.50	0.54	8.6
28	8.44	21,621	12.0	0.08	0.37	4.7
29	8.52	21,896	12.2	0.90	0.89	9.2
30	8.66	20,321	11.3	0.14	0.85	3.4
Average	**8.8**	20,213	11.2	**0.33**	**0.70**	**4.3**
Min	**8.4**	18,847	10.5	**0.05**	**0.10**	**0.5**
Max	**10.0**	22,147	12.3	**1.50**	**2.10**	**13.2**

Annex 4 Performance of units in the phase-2

Table 17 Performance of the ozone unit in the phase-2

Cycle	pH	Conductivity	COD	Color
	-	µs/cm	mg/L	Pt-Co
OZONE FEED				
1	8.70	6,190	164	108
2	8.70	6,190	164	108
3	8.70	6,190	164	108
4	8.70	6,190	164	108
5	8.70	6,190	164	108
6	8.70	6,190	164	108
7	8.70	6,190	164	108
8	8.70	6,190	164	108
9	8.70	6,190	164	108
10	8.70	6,190	164	108
11	8.70	6,190	164	108
12	8.70	6,190	164	108
13	8.70	6,190	164	108
14	8.70	6,190	164	108
15	8.70	6,190	164	108
16	8.70	6,190	164	108
17	8.70	6,190	164	108
18	8.70	6,190	164	108
19	8.70	6,190	164	108
20	8.70	6,190	164	108
21	8.70	6,190	164	108
22	8.70	6,190	164	108
23	8.70	6,190	164	108
24	8.70	6,190	164	108
Average	8.70	6,190	**164**	**108**
Min	8.70	6,190	**164**	**108**
Max	8.70	6,190	**164**	**108**
ACTIVE CARBON FEED				
1	8.38	6,040	112	55

2	8.54	6,010	127	56
3	8.34	6,460	114	57
4	8.40	6,780	131	61
5	8.65	5,830	121	46
6	7.97	5,930	104	10
7	7.97	5,960	108	9
8	7.94	6,020	101	10
9	7.94	6,020	101	10
10	7.94	6,020	101	10
11	7.91	6,640	95	11
12	7.85	6,630	98	11
13	7.98	6,650	96	42
14	8.11	6,450	112	13
15	7.89	6,720	100	15
16	8.11	6,970	105	15
17	7.89	6,910	103	18
18	7.77	6,920	101	13
19	7.99	7,010	102	51
20	7.94	6,710	101	65
21	8.02	6,640	102	22
22	7.97	6,620	102	27
23	8.18	6,690	102	42
24	8.25	6,650	102	57
Average	8.08	6,470	**106**	**30**
Min	7.77	5,830	**95**	**9**
Max	8.65	7,010	**131**	**65**
		ACTIVATED CARBON EFFLUENT /NF1 FEED		
1	8.37	5,920	38	13
2	8.58	5,820	46	12
3	8.56	6,400	50	11
4	8.50	6,680	61	11
5	8.58	5,830	63	4
6	8.62	5,840	49	5
7	8.30	5,920	65	8
8	8.54	5,960	44	3
9	8.54	5,960	44	3
10	8.54	5,960	44	3
11	8.37	6,630	34	3
12	8.38	6,590	44	7
13	8.28	6,690	38	5
14	8.39	6,640	39	2

15	8.39	6,650	43	5
16	8.39	6,950	41	6
17	8.39	6,880	39	13
18	8.18	6,900	40	4
19	8.01	6,930	38	6
20	8.22	6,760	36	12
21	8.20	6,730	43	15
22	7.98	6,670	45	13
23	7.89	6,800	47	19
24	7.95	6,690	39	5
Average	8.34	6,450	**45**	**8**
Min	7.89	5,820	**34**	**2**
Max	8.62	6,950	**65**	**19**

Table 18 Analysis results of feed, permeate and retentate of NF1 processes for Phase 2

Cycle	pH	Conductivity	TDS	COD	Color	Ca	Mg	Cl	Na	SO_4	Total Hardness
	-	µs/cm	g NaCl/L	mg/L	Pt-Co	mg/L	mg/L	mg/L	mg/L	mg/L	mg $CaCO_3$/L
					NF1 FEED						
1	8.37	5,920	4.0	38	13	67.8	24.8	458	1,413	1,283	271
2	8.58	5,820	3.9	46	12	60.5	24.5	454	1,318	1,336	252
3	8.56	6,400	4.0	50	11	58.5	24.7	439	1,286	1,298	248
4	8.50	6,680	4.1	61	11	57.0	24.4	428	1,376	1,268	243
5	8.58	5,830	4.1	63	4	57.6	24.9	437	1,357	1,300	246
6	8.62	5,840	4.0	49	5	57.8	23.6	418	1,286	1,189	241
7	8.30	5,920	4.0	65	8	66.7	24.3	416	1,453	1,181	267
8	8.54	5,960	4.0	44	3	65.4	24.1	417	2,321	1,243	262
9	8.54	5,960	4.0	44	3	65.3	24.1	417	2,321	1,243	262
10	8.54	5,960	4.0	44	3	65.6	24.4	408	1,496	1,240	264
11	8.37	6,630	4.1	34	3	66.7	23.9	412	1,421	1,234	265
12	8.38	6,590	4.1	44	7	66.2	23.7	425	1,256	1,281	263
13	8.28	6,690	4.1	38	5	68.3	24.1	432	1,426	1,288	270
14	8.39	6,640	4.1	39	2	68.4	24.3	420	1,368	1,262	271
15	8.39	6,650	4.1	43	5	68.3	24.7	412	1,449	1,232	272
16	8.39	6,950	4.1	41	6	66.1	23.4	422	1,664	1,246	261
17	8.39	6,880	4.1	39	13	64.6	22.3	418	1,447	1,252	253
18	8.18	6,900	4.1	40	4	64.1	22.2	442	1,378	1,276	251
19	8.01	6,930	4.1	38	6	64.3	22.8	439	1,365	1,281	254
20	8.22	6,760	4.2	36	12	64.1	23.1	432	1,398	1,279	255

21	8.20	6,730	4.2	43	15	64.3	22.5	434	1,347	1,283	253
22	7.98	6,670	4.1	45	13	64.7	23.4	442	1,389	1,289	258
23	7.89	6,800	4.2	47	19	64.5	24.5	443	1,365	1,285	262
24	7.95	6,690	4.1	39	5	64.0	23.9	451	1,398	1,279	258
Average	**8.34**	**6,450**	**4.1**	**45**	**8**	**64**	**24**	**430**	**1,471**	**1,265**	**258**
Min	**7.89**	**5,820**	**3.9**	**34**	**2**	**57**	**22**	**408**	**1,256**	**1,181**	**241**
Max	**8.62**	**6,950**	**4.2**	**65**	**19**	**68**	**25**	**458**	**2,321**	**1,336**	**272**
NF1 PERMEATE											
1	7.59	4,870	3.4	32	3	39.7	15.2	346	1,137	577	161
2	7.37	5,170	3.5	34	5	36.7	15.8	394	1,119	669	157
3	7.28	5,550	3.5	40	7	33.9	14.9	374	1,152	584	146
4	7.67	5,900	3.6	45	5	35.2	15.7	378	1,153	659	152
5	7.40	5,010	3.5	38	3	32.0	13.9	392	1,123	509	137
6	7.62	4,920	3.4	27	3	33.0	13.5	344	1,008	505	138
7	7.22	5,410	3.7	45	3	42.1	16.8	342	1,245	796	174
8	8.31	4,950	3.3	33	1	35.5	13.9	345	1,657	580	146
9	8.31	4,950	3.3	33	1	35.5	13.9	354	1,657	580	146
10	8.31	4,950	3.3	33	1	38.7	15.5	362	1,083	604	160
11	7.27	5,720	3.5	29	2	40.7	15.5	352	1,170	542	165
12	7.25	5,590	3.4	27	3	39.5	14.9	363	1,088	520	160
13	7.31	6,870	3.2	20	3	44.9	12.3	378	1,104	404	163
14	7.84	5,990	3.7	26	1	45.8	17.1	342	1,143	754	185
15	7.56	4,770	2.9	29	2	38.4	14.8	342	1,024	754	157
16	7.84	5,980	3.5	30	4	38.5	14.7	340	1,138	751	157
17	7.56	5,730	3.4	33	7	38.3	14.1	340	1,262	732	154
18	7.25	5,820	3.4	27	3	40.8	14.8	341	1,214	716	163
19	7.71	6,020	3.5	26	5	39.6	14.4	343	1,148	698	158
20	7.27	5,840	3.6	28	7	38.7	13.9	354	1,167	654	154
21	7.21	5,360	3.3	27	2	39.1	14.6	352	1,181	648	158
22	7.83	5,730	3.5	25	8	38.6	15.1	354	1,116	703	159
23	7.39	5,880	3.6	28	3	39.4	14.9	349	1,121	633	160
24	7.48	5,740	3.5	27	2	38.3	14.6	351	1,109	630	156
Average	**7.58**	**5,530**	**3.4**	**31**	**4**	**38**	**15**	**355**	**1,180**	**634**	**157**
Min	**7.21**	**4,770**	**2.9**	**20**	**1**	**32**	**12**	**340**	**1,008**	**404**	**137**
Max	**8.31**	**6,870**	**3.7**	**45**	**8**	**46**	**17**	**394**	**1,657**	**796**	**185**
NF1 RETENTATE											
1	7.70	9,950	7.2	164	15	116.6	42.5	552	2,606	2,553	466
2	7.19	10,620	7.3	238	27	120.5	47.6	623	2,677	2,958	497
3	7.25	11,420	7.5	265	40	119.3	48.1	606	2,665	2,838	496
4	7.37	11,370	7.2	278	50	97.0	39.6	581	2,341	2,475	405
5	7.21	10,530	7.6	299	70	117.4	47.6	633	2,352	2,841	489

6	7.59	10,330	7.0	232	51	117.4	44.2	538	2,621	2,731	475
7	7.07	11,940	8.5	345	53	163.9	59.4	625	3,027	3,680	654
8	8.01	11,140	7.1	208	38	140.9	52.9	450	3,013	3,074	570
9	8.01	11,140	7.1	208	38	141.0	52.9	450	3,013	3,074	570
10	8.01	11,140	7.1	208	38	129.1	45.7	603	2,778	2,774	510
11	7.16	11,550	7.4	151	18	130.0	43.8	581	2,809	2,679	505
12	7.20	11,480	7.3	130	15	123.3	42.3	579	2,566	2,662	482
13	7.14	13,120	8.4	247	60	173.1	57.3	591	3,044	3,499	668
14	7.53	12,430	8.0	254	40	156.6	51.6	526	2,823	3,131	603
15	7.40	12,070	7.6	173	16	137.7	44.5	526	2,521	3,131	527
16	7.53	12,330	7.5	198	16	122.0	40.8	526	2,664	3,123	473
17	7.40	12,250	7.5	186	21	139.1	46.5	528	2,956	3,117	539
18	7.14	11,920	7.3	171	22	139.2	46.9	524	2,896	3,149	540
19	7.60	12,990	7.9	154	22	139.9	46.4	521	2,834	3,062	540
20	7.15	13,120	8.4	165	26	138.4	46.5	532	2,906	3,099	537
21	7.12	10,410	6.6	171	22	139.9	45.6	533	2,871	3,049	537
22	7.61	11,800	7.5	169	38	141.9	46.4	532	2,866	3,051	545
23	7.16	12,680	8.1	155	34	140.9	45.7	539	2,874	3,059	540
24	7.35	11,900	7.6	159	32	140.1	47.7	534	2,879	3,083	546
Average	**7.41**	**11,651**	**7.5**	**205**	**33**	**134**	**47**	**551**	**2,775**	**2,995**	**530**
Min	**7.07**	**9,950**	**6.6**	**130**	**15**	**97**	**40**	**450**	**2,341**	**2,475**	**405**
Max	**8.01**	**13,120**	**8.5**	**345**	**70**	**173**	**59**	**633**	**3,044**	**3,680**	**668**

Table 19 Analysis results of feed, permeate and retentate of NF2 processes for Phase 2

Cycle	pH	Conductivity	TDS	COD	Color	Ca	Mg	Cl	Na	SO_4	Total Hardness
	-	µs/cm	g NaCl/L	mg/L	Pt-Co	mg/L	mg/L	mg/L	mg/L	mg/L	mg $CaCO_3$/L
NF2 FEED											
1	8.01	11,140	7.09	208	38	141	53	450	3,013	3,074	570
2	7.60	12,990	7.94	154	22	140	46	521	2,834	3,062	540
3	7.61	11,800	7.50	169	38	142	46	531	2,866	3,051	545
Average	**7.74**	**11,977**	**7.5**	**177**	**33**	**141**	**49**	**501**	**2,904**	**3,062**	**552**
Min	**7.60**	**11,140**	**7.1**	**154**	**22**	**140**	**46**	**450**	**2,834**	**3,051**	**540**
Max	**8.01**	**12,990**	**7.9**	**208**	**38**	**142**	**53**	**532**	**3,013**	**3,074**	**570**
NF2 PERMEATE											
1	8.02	7,840	5.4	89	9	102.7	40.3	318	1,938	1,363	436
2	7.97	8,060	4.8	83	11	85.2	31.3	339	1,664	1,436	342
3	8.17	5,690	3.5	82	22	75.5	33.5	355	1,602	1,445	326
Average	**8.05**	**7,197**	**4.6**	**85**	**14**	**88**	**35**	**337**	**1,735**	**1,415**	**368**

Min	**7.97**	**5,690**	**3.5**	**82**	**9**	**76**	**31**	**318**	**1,602**	**1,363**	**326**
Max	**8.17**	**8,060**	**5.4**	**89**	**22**	**103**	**40**	**355**	**1,938**	**1,445**	**436**
					NF2 RETENTATE						
1	7.85	12,450	8.9	385	69	209	83	411	3,289	4,506	100
2	7.85	14,530	9.0	377	67	200	76	422	3,226	4,344	815
3	8.73	13,510	8.0	364	39	201	71	417	3,255	4,289	796
Average	**8.14**	**13,497**	**8.6**	**375**	**58**	**204**	**77**	**417**	**3,257**	**4,380**	**570**
Min	**7.85**	**12,450**	**8.0**	**364**	**39**	**200**	**71**	**411**	**3,226**	**4,093**	**100**
Max	**8.73**	**14,530**	**9.0**	**385**	**69**	**209**	**83**	**422**	**3,289**	**6,817**	**815**

Table 20 Analysis results of feed, permeate and retentate of RO processes for Phase 2

Cycle	pH	Conductivity	TDS	COD	Color	Ca	Mg	Cl	Na	SO_4	Total Hardness
	-	µs/cm	g NaCl/L	mg/L	Pt-Co	mg/L	mg/L	mg/L	mg/L	mg/L	mg $CaCO_3$/L
					RO FEED						
1	8.54	5,900	4.1	32	6	2.4	0.8	317	1643	771	9.2
2	8.22	6,240	4.3	40	5	2.3	0.8	365	1802	1380	9.0
3	7.88	7,340	4.7	52	5	2.4	1.0	368	1757	922	9.8
4	7.95	7,390	4.5	48	6	2.1	0.9	340	1658	899	8.8
5	8.14	6,130	4.3	43	6	2.2	0.9	332	1634	789	9.0
6	8.06	6,290	4.4	39	7	2.3	0.9	338	1,794	791	9.4
7	7.85	5,910	4.1	46	7	1.9	0.8	288	3,037	781	7.9
8	8.09	6,360	4.4	57	11	2.4	0.9	309	1,540	809	9.9
9	8.25	8,200	5.7	73	17	4.8	1.7	260	2,247	2,274	18.9
10	8.03	7,410	5.1	63	10	3.5	1.2	318	1,657	1,551	13.7
11	8.02	8,310	5.2	72	10	3.4	1.1	361	1,968	1,307	13.2
12	8.03	8,110	5.1	54	11	3.2	1.0	339	1,782	1,179	12.0
13	7.91	7,320	4.5	44	10	2.4	0.7	313	1,674	1,016	8.7
14	8.11	6,700	4.1	50	7	2.2	0.6	292	1,578	942	8.0
15	8.16	7,110	4.4	31	8	2.3	0.7	292	1,711	942	8.5
16	8.11	7,710	4.6	33	8	2.9	0.7	293	1,901	976	10.3
17	8.16	9,100	5.5	36	11	3.6	0.9	290	2,140	998	12.9
18	7.86	8,440	5.1	47	10	2.8	0.8	294	1,754	2,611	10.4
19	8.15	9,030	5.4	51	11	3.1	0.7	298	1,711	1,047	10.7
20	8.01	7,590	4.7	43	10	2.9	0.8	290	1,705	1,088	10.5
21	8.04	7,190	4.5	54	13	3.0	0.7	288	1,788	1,071	10.3
22	8.16	8,200	5.1	50	11	3.0	0.8	295	1,996	2,497	10.9
23	7.92	7,420	4.6	46	7	3.1	0.7	298	1,813	1,049	10.7
24	8.33	7,510	4.7	50	13	2.9	0.7	294	1,801	1,055	10.3

Average	**8.08**	**7,371**	**4.7**	**48**	**9**	**2.8**	**0.9**	**311**	**1,837**	**1,198**	**11**
Min	**7.85**	**5,900**	**4.1**	**31**	**5**	**1.9**	**0.6**	**260**	**1,540**	**771**	**8**
Max	**8.54**	**9,100**	**5.7**	**73**	**17**	**4.8**	**1.7**	**368**	**3,037**	**2,611**	**19**
RO PERMEATE											
1	7.28	175	0.1	<LOD	<1	0.25	0.14	15	<LOD	8	1.2
2	7.47	197	0.1	<LOD	<1	0.22	0.06	16	<LOD	5	0.8
3	6.40	157	0.1	<LOD	<1	0.19	0.04	12	<LOD	4	0.6
4	7.70	428	0.2	<LOD	<1	0.23	0.09	39	<LOD	10	1.0
5	7.38	176	0.1	<LOD	<1	0.15	0.04	14	<LOD	4	0.5
6	7.95	153	0.1	<LOD	<1	0.12	0.03	11	<LOD	3	0.4
7	7.72	124	0.2	<LOD	<1	0.22	0.03	15	<LOD	3	0.7
8	7.59	170	0.1	<LOD	<1	0.14	0.03	9	<LOD	2	0.5
9	7.65	133	0.1	<LOD	<1	0.27	0.07	7	<LOD	3	1.0
10	7.65	133	0.1	<LOD	<1	0.26	0.04	10	<LOD	8	0.8
11	7.53	195	0.1	<LOD	<1	0.19	0.04	9	<LOD	4	0.6
12	7.35	179	0.1	<LOD	<1	0.11	0.02	8	<LOD	2	0.4
13	7.10	170	0.1	<LOD	<1	0.17	0.03	8	<LOD	2	0.5
14	7.54	203	0.1	<LOD	<1	0.10	0.02	8	<LOD	2	0.3
15	7.56	185	0.1	<LOD	<1	0.11	0.02	8	<LOD	2	0.4
16	7.54	197	0.1	<LOD	<1	0.15	0.01	8	<LOD	2	0.4
17	7.56	240	0.1	<LOD	<1	0.18	0.02	8	<LOD	3	0.5
18	7.01	661	0.4	<LOD	<1	0.11	0.04	8	<LOD	4	0.4
19	7.76	433	0.2	<LOD	<1	0.18	0.02	8	<LOD	4	0.5
20	7.45	285	0.2	<LOD	<1	0.15	0.03	8	<LOD	3	0.5
21	8.03	398	0.2	<LOD	<1	0.21	0.02	7	<LOD	4	0.6
22	8.50	359	0.2	<LOD	<1	0.16	0.02	8	<LOD	3	0.5
23	7.85	320	0.2	<LOD	<1	0.11	0.04	8	<LOD	3	0.4
24	9.17	306	0.2	<LOD	<1	0.12	0.02	8	<LOD	3	0.4
Average	**7.61**	**249**	**0.1**	<LOD	<1	**0.17**	**0.04**	**11**	<LOD	**4**	**0.6**
Min	**6.40**	**124**	**0.1**	<LOD	<1	**0.10**	**0.01**	**7**	<LOD	**2**	**0.3**
Max	**9.17**	**661**	**0.4**	<LOD	<1	**0.27**	**0.14**	**39**	<LOD	**10**	**1.2**
RO RETENTATE											
1	8.31	22,871	16	330	50	9	3.3	921	4,987	2,876	35.8
2	8.20	23,290	16	315	51	9	3.2	1,059	4,913	3,124	34.7
3	7.80	25,202	16	320	50	9	3.8	1,068	4,865	2,754	38.2
4	7.90	25,938	16	335	49	8	3.4	986	4,833	2,912	34.2
5	7.90	22,916	16	335	49	8	3.5	963	4,821	3,345	34.9
6	7.90	22,678	16	335	49	9	3.5	981	4,850	3,289	36.3
7	7.90	23,176	16	335	49	7	3.0	834	4,890	4,429	30.7
8	7.90	23,088	16	335	49	9	3.7	896	4,946	4,429	38.4
9	7.90	23,099	16	335	49	18	6.8	753	5,121	4,429	73.4

10	7.90	23,238	16	335	49	13	4.8	921	5,613	4,899	53.1
11	8.03	26,509	17	152	17	13	4.5	1,048	4,799	3,516	50.9
12	8.01	27,478	17	161	11	12	3.9	982	4,478	2,734	46.2
13	7.93	28,211	17	135	31	9	2.7	907	4,095	2,547	33.7
14	8.16	28,117	17	185	15	8	2.5	846	4,550	2,646	31.0
15	8.12	26,364	16	133	9	9	2.7	846	5,562	2,646	32.8
16	8.16	27,423	16	129	9	11	2.8	850	5,641	2,734	39.5
17	8.12	27,184	16	136	12	14	3.7	841	5,725	2,689	49.9
18	8.01	27,467	17	133	10	11	3.3	854	5,634	3,654	40.1
19	8.09	28,062	17	129	16	12	2.9	865	5,548	3,987	41.2
20	8.08	27,227	17	132	11	11	3.2	840	5,789	4,236	40.5
21	8.12	26,390	16	138	14	11	2.8	834	5,633	4,498	39.9
22	8.21	26,314	16	131	18	11	3.3	856	5,686	4,321	42.0
23	8.08	27,169	17	135	15	12	2.9	863	5,543	3,987	41.3
24	8.23	26,817	17	129	20	11	2.9	853	5,698	3,956	39.6
Average	**8.04**	**25,676**	**16**	**220**	**29**	**11**	**3.5**	**903**	**5,176**	**3,527**	**41**
Min	**7.80**	**22,678**	**16**	**129**	**9**	**7**	**2.5**	**753**	**4,095**	**4,093**	**31**
Max	**8.31**	**28,211**	**17**	**335**	**51**	**18**	**6.8**	**1,068**	**5,789**	**6,817**	**73**

Table 21 Performance of the IEX in the phase-2

Cycle	pH	Conductivity	TDS	Ca	Mg	Total Hardness
	-	µs/cm	g NaCl/L	mg/L	mg/L	mg $CaCO_3$/L
			IEX FEED (NF PERMEATE)			
1	8.33	6,000	4.1	54	20.7	221
2	7.94	6,430	4.4	41	17.4	175
3	7.77	7,340	4.7	38	16.9	164
4	7.80	7,250	4.4	35	15.4	150
5	7.90	6,130	4.3	33	14.0	139
6	7.95	6,430	4.5	33	13.6	137
7	7.64	5,570	3.8	39	15.7	163
8	8.20	6,560	4.5	37	14.5	152
9	8.14	8,230	5.7	85	34.0	353
10	7.74	7,120	4.9	46	18.1	190
11	7.93	8,460	5.3	41	16.2	170
12	7.87	7,620	4.7	40	15.5	165
13	7.83	7,270	4.5	45	16.9	182
14	8.05	7,170	4.4	46	17.1	185
15	7.96	7,030	4.3	39	15.1	161

16	8.05	7,750	4.6	38	14.7	155
17	7.96	8,830	7.3	87	14.4	148
18	7.78	8,170	4.9	40	14.1	217
19	8.06	9,420	5.7	46	28.5	232
20	7.81	7,640	4.7	41	16.4	170
21	8.05	6,410	3.9	43	15.5	170
22	8.15	8,830	5.6	90	26.8	334
23	7.65	7,380	4.6	43	14.8	169
24	8.30	7,470	4.6	41	15.7	167
Average	8.0	7,355	4.8	47	17.6	186
Min	7.6	5,570	3.8	33	13.6	137
Max	8.3	9,420	7.3	90	34.0	353
IEX EFFLUENT (RO FEED)						
1	8.54	5,900	4.1	2.36	0.82	9.2
2	8.22	6,240	4.3	2.27	0.80	9.0
3	7.88	7,340	4.7	2.36	0.96	9.8
4	7.95	7,390	4.5	2.11	0.86	8.8
5	8.14	6,130	4.3	2.17	0.87	9.0
6	8.06	6,290	4.4	2.30	0.88	9.4
7	7.85	5,910	4.1	1.92	0.76	7.9
8	8.09	6,360	4.4	2.45	0.92	9.9
9	8.25	8,200	5.7	4.78	1.70	18.9
10	8.03	7,410	5.1	3.51	1.20	13.7
11	8.02	8,310	5.2	3.42	1.12	13.2
12	8.03	8,110	5.1	3.18	0.97	12.0
13	7.91	7,320	4.5	2.36	0.68	8.7
14	8.11	6,700	4.1	2.19	0.62	8.0
15	8.16	7,110	4.4	2.31	0.66	8.5
16	8.11	7,710	4.6	2.94	0.71	10.3
17	8.16	9,100	5.5	3.64	0.93	12.9
18	7.86	8,440	5.1	2.80	0.82	10.4
19	8.15	9,030	5.4	3.10	0.72	10.7
20	8.01	7,590	4.7	2.90	0.79	10.5
21	8.04	7,190	4.5	3.00	0.69	10.3
22	8.16	8,200	5.1	3.00	0.82	10.9
23	7.92	7,420	4.6	3.10	0.72	10.7
24	8.33	7,510	4.7	2.90	0.73	10.3
Average	8.1	7,371	4.7	2.79	0.87	10.5
Min	7.9	5,900	4.1	1.92	0.62	7.9
Max	8.5	9,100	5.7	4.78	1.70	18.9