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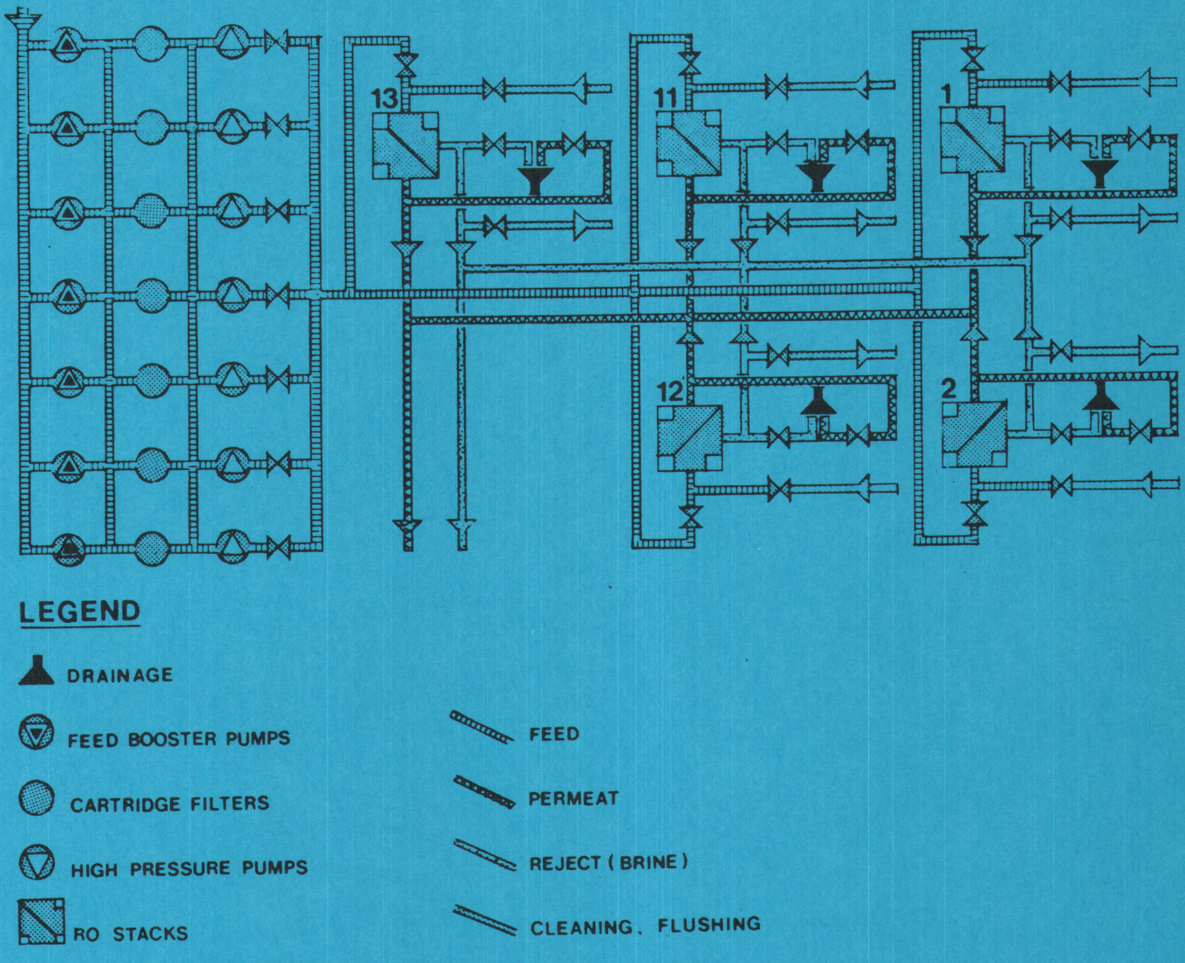

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Drifterfarenheter under de två första åren vid Buwayb vattenverk med omvänd osmos.

Bernt Ericsson, D. Sc. (Chem. Eng.)

Stockholm
May 1983

THE INITIAL TWO-YEAR OPERATION OF THE BUWAYB WATER TREATMENT PLANT

by

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INTRODUCTION

Water demand for the City of Riyadh has increased rapidly over recent years in line with population growth. To meet the increased demand, an extensive water expansion and quality improvement scheme was undertaken. An integral part of the scheme, which has been reviewed by Ghulaigah and Ericsson[1] was the extensive use of demineralization to improve the quality of the brackish supply. At the time of conception, the scheme incorporated the largest demineralization complex in the world in total capacity and included some of the largest individual reverse osmosis plants planned.

The Buwayb Water Treatment Plant forms part of the overall scheme. It was designed to produce 59,000 m^3/day of blended water, with a dissolved solids content of less than 500 mg/l from a hot brackish supply abstracted from deep wells in the Minur aquifer. In order to achieve this, the plant incorporates a reverse osmosis plant with an output capacity of 45,000 m^3/day, along with a lime/soda softening pretreatment stage.

The plant was brought into operation in October 1979, and has been providing water to supply since that date. Initially, the pretreatment stage was operated and the reverse osmosis plant was brought into use in stages during 1980, until it was fully operational in September of that year. In December 1980, process performance tests were carried out on the whole plant to demonstrate that the process operated as intended.

During the period of construction, various laboratory and pilot studies were carried out. The laboratory studies showed the actual water analysis to be different from that anticipated and they indicated that process modifications would be required. These were investigated and demonstrated by pilot work and subsequently incorporated in the full-size plant.

This paper describes the operation of the plant from startup, and compares actual performance with predictions made at design stage and those made following treatability and pilot trials. Results of the process performance tests are presented.

The operation of each process unit is discussed, particular emphasis being placed on the behavior of the reverse osmosis elements, both at pilot and full scale. Various operational aspects are also discussed, both in a general sense and with specific reference to the requirements of this large reverse osmosis plant.

Description of the Buwayb Treatment Plant and Process

The Buwayb Water Treatment Plant consists of a bank of 10 evaporative cooling towers, 6 sludge recirculation-type clarifiers (5 duty, 1 standby), 8 pairs of rapid gravity sand filters (1 upflow, 1 downflow per pair), 13 stacks of reverse osmosis vessels (11 or 12 duty, 1 standby) and all associated chemical dosing, handling and storage equipment, mixing, blending and storage tanks, pumping station and power station. It has been described in some detail by Finlay and Ferguson.[2]

It was designed to accept 70,000 m^3/d of hot brackish water from 18 deep wells in the Buwayb field, to cool it, reduce its calcium and silica concentrations by lime softening in conjunction with sodium aluminate/ferric chloride coagulation and remove the suspended solids by clarification and sand filtration prior to desalination by reverse osmosis. Facilities are provided for a certain amount of the cooled water to bypass the softening and desalination stages and for it to be blended with the desalinated water to produce 59,000 m^3/d of final blended water with the desired Total Dissolved Solids (TDS) of 500 mg/l. This bypass stream receives only flocculation with ferric chloride and sand filtration prior to final blending. The blended

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water receives pH correction and chlorination before being pumped into supply. A flow sketch of the treatment process is shown in Figure 1.

The raw well water is delivered to 10 forced-draft cooling towers. There is a loss, caused by evaporation, of approximately 3,000 m^3/d. The remaining 67,000 m^3/d of cooled water is then split: 49,000 m^3/d is fed to the lime/soda softening treatment process, while 18,000 m^3/d is delivered to the bypass rapid-gravity filters, preceded by ferric chloride dosing and flocculation. The lime/soda softening plant, comprising chemical dosing, six sludge recirculation clarifiers and six double (upflow and downflow) filters, is sized to treat the entire 67,000 m^3/d to a 500 mg/l total hardness (as $CaCO_3$) standard if required.

When softening 49,000 m^3/d of cooled water, approximately 2000 m^3/d of calcium carbonate sludge is discharged and 47,000 m^3/d of softened, clarified and filtered water is available for delivery in the reverse osmosis plant. After acidification, chlorination and softening, the water is treated by reverse osmosis to produce 41,000 m^3/d of permeate and 6000 m^3/d of concentrate for disposal. The permeate is blended with the 18,000 m^3/d of filtered bypass water to provide 59,000 m^3/d of water for supply to Riyadh after final pH correction and disinfection. Provision is made for adjusting the proportion of permeate and bypass water to maintain a constant quality of blended water. Up to 45,000 m^3/d of permeate can be produced while still retaining one reverse osmosis stack on standby. When operating in this mode, the bypass would be reduced to 14,000 m^3/d.

Basis of Design

The treatment process was designed to treat a water that was predicted to have a temperature of 50 to 55°C and the following, more relevant, constituents: 160 mg/l temporary hardness as $CaCO_3$, 465 mg/l permanent hardness as $CaCO_3$, 170 mg/l calcium, 450 mg/l sulphate, 25 mg/l silica and a TDS of 1400 mg/l. The full, anticipated analysis of the raw well water is given in Table I.

The water was required to be treated to have a final TDS not greater than 500 mg/l and, further, any water losses after cooling were to be restricted to 10 percent.

In order to achieve the required TDS concentration, a reverse osmosis plant was incorporated into the overall scheme. This RO plant uses spirally-wound cellulose acetate membranes.

The calcium and sulphate concentrations in the predicted raw water were such that, when concentrated on the reject side of the RO membrane, to the degree dictated by the water loss restrictions, their concentrations would exceed the solubility product by an unacceptably large amount and calcium sulphate would precipitate on the membranes. Similarly, the level of silica in the raw water was such that it would be liable to precipitate on the concentrate side of the membranes.

Hence, either the calcium or the sulphate concentrations had to be reduced, as did the silica content, to prevent such deposition of solids. The solution chosen was to precipitate the calcium associated with the bicarbonate alkalinity with lime and to coagulate the silica and precipitated calcium carbonate with ferric chloride and sodium aluminate. The whole reaction was to be carried out in sludge-recirculation-type clarifiers in which the surplus calcium carbonate sludge is removed from concentrator hoppers in the base of the tanks and clarified water is collected in radial troughs and led away for final "polishing" on the sand filters. Prior to filtration, the pH of the clarified water was to be depressed with acid to ensure complete precipitation of the aluminium coagulant and to prevent calcium carbonate from depositing on the media.

The sand filters each comprise an upflow unit containing 3 to 5 mm of sand, followed by a downflow unit containing 0.6 to 1.18 mm sand.

The process was designed such that the filtered water had a calcium content not greater than 130 mg/l and a silica content not greater than 20 mg/l. The filtration step was also designed to reduce residual aluminum and iron concentration to less than 0.05 mg/l and to produce a water with a turbidity of less than 1 NTU, all of which assists in reducing the risk of fouling the RO membranes.

It is also necessary to reduce the pH of the feed water to around pH 5 to minimize hydrolysis of the membranes and, to this end, a further dose of acid is added after filtration. Small doses of chlorine (to prevent biologial attack of the membranes) and sodium hexametaphosphate (an additional safeguard against precipitation of sparingly soluble salts) are also added to the RO feed water.

The reverse osmosis plant consists of a 3-pass system in 13 separate streams (one standby). It has a total water recovery of 87.5 percent at design operating flow and pressure.

The permeate is blended with the filtered bypass water prior to the addition of sodium carbonate to raise the pH to between 7.5 and 8.0, and chlorine for final disinfection.

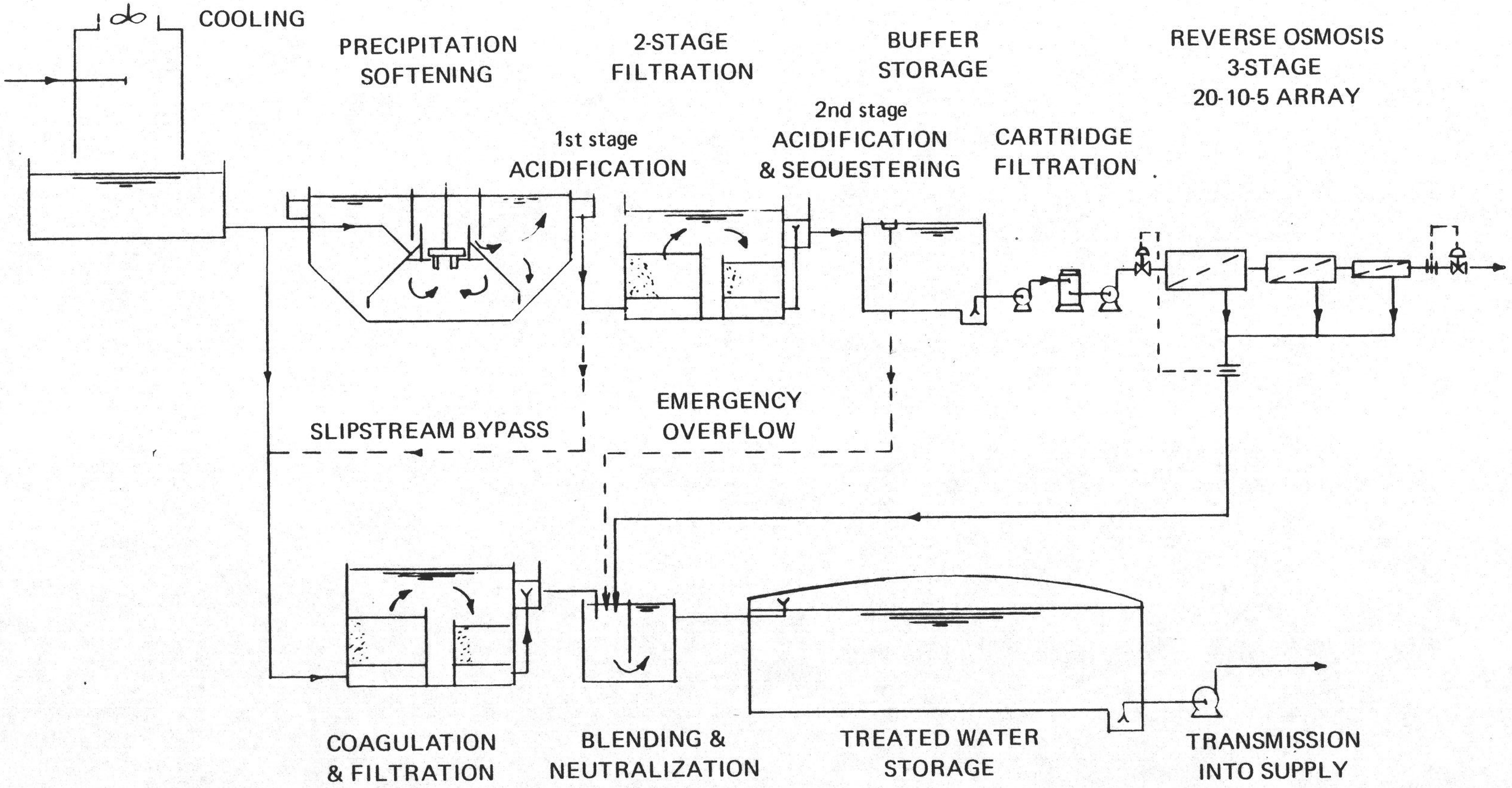

Figure 1 PROCESS FLOW DIAGRAM – BUWAYB WATER TREATMENT PLANT

Provision was also made to dose sodium carbonate to the clarifiers for the partial removal of permanent hardness in the event of the RO plant being off-stream. Under such conditions, it is required that the total hardness should be reduced to 500 mg/l as $CaCO_3$.

TABLE I

SHOWING THE COMPARISON BETWEEN DESIGN ANALYSIS AND ACTUAL ANALYSIS OF EARLY WATER SAMPLES AND COMPARING PRETREATMENT DOSAGES

	Design Analysis of Raw Water	Actual Analysis of Raw Water (Well 54)
Temp	50-55	65-70
pH	7.0	6.9
Alk	160	133
TH	625	816
Ca	170	207
Mg	48	72
Na		154
	196	
K		85
Cl	300	385
SO_4	45	562
SiO_2	25	35
TDS	1400	1610

Pre-treatment Doses		
Hydrated lime	170	140
Sodium carbonate	None	100
Ferric chloride	10	10
Sodium aluminate	10	15

All values in mg/l except temperature (°C) and pH.
Alk and TH expressed as Calcium Carbonate.

Process Performance Data

Laboratory and Pilot Plant Investigations

Throughout the construction period of the main plant and the development of the well field, a series of laboratory and pilot plant investigations was undertaken. These investigations had to obtain the following:

- Analysis of the actual well water, to compare it with that used for design and hence to determine if any process changes were required, and to investigate these on laboratory scale

- Operating information on the lime/soda softening process on a pilot scale that could be used to enable commissioning of the main plant to proceed more smoothly

- Operating information on the reverse osmosis process to confirm theoretical predictions and to determine if any process changes were indicated.

In March of 1979, a pilot plant was installed at wellhead 54. The plant included all the process units of the full-size plant and had a capacity of 10 m^3/hr. The plant was operated at this wellhead until August 1979. During this period, the plant was used primarily to obtain information on the lime/soda softening and filtration stages in preparation for commissioning of the main plant. The analytical information obtained at this site was also used to prepare revised process performance prediction for the main plant. This was supplemented by laboratory investigations from other wells as they became available.

As soon as the pretreatment stage of the main plant had been commissioned, the pilot plant was moved to the main site. Work then concentrated on the reverse osmosis stage. The performance of the plant was monitored carefully both to compare actual performance with theoretical predictions and to establish if further process changes were required.

Laboratory Investigations

The first samples of water became available from well 54. It soon became apparent that the water temperature at around 65°C was higher than expected and that the chemical composition was different from that used for design. Generally, the bicarbonate alkalinity was somewhat lower than expected, while the permanent hardness, calcium, sulphate, silica and TDS were all higher than expected, the latter being, in some cases, over 1600 mg/l. The average analysis of several early samples from well 54 is shown in Table I together with the design analysis.

The actual analysis indicated that changes would be required in the treatment process. Sodium carbonate would now be required to reduce the calcium content to the desired level and the dosages of ferric chloride and sodium aluminate required modification to remove a greater amount of silica. In addition, on reworking the design calculations of the RO stage, it was clear that the production of 59,000 m^3/d of water with TDS of 500 mg/l could no longer be achieved. Either quantity or quality had to be reduced and the broad options lay between producing around 50,000 m^3/d at 500 mg/l or 59,000 at around 685 mg/l. The client decided to opt for the latter. A comparison between the design analysis and proposed pretreatment scheme and the revised scheme based on actual analyses from well 54 is shown on Table I.

As the wellfield was developed, more samples became available and, as these were analyzed, it soon became apparent that, while some local variations did exist, the water was generally very similar to the original samples from well 54. Many samples were subjected to treatability tests using the revised pretreatment scheme and all responded satisfactorily. Analytical data and results of these treatability tests from several samples are shown on Table II. As a result of this work, it was possible to firm up the pretreatment dosages for the main plant. In fact, no revisions of the scheme indicated by the first samples were required.

TABLE II

SHOWING ANALYTICAL DATA AND TREATABILITY TESTS ON VARIOUS SAMPLES FROM DIFFERENT WELLS

Samples:	1	2	3	4	5	6	7	Average
pH	8.0	7.9	8.0	7.9	7.9	8.0	7.6	7.9
Alk	140	144	143	140	130	123	124	135
TH	860	860	820	830	830	870	880	850
Ca	220	220	210	208	204	212	208	212
Mg	75	75	72	75	78	82	87	78
Na	190	141	160	164	135	162	190	163
K	42	46	42	49	45	45	44	45
Cl	370	390	358	370	370	390	400	378
So_4	585	540	533	500	500	524	625	544
SiO_2	32	34	34	36	35	36	38	35
TDS	1607	1612	1500	1607	1544	1533	1533	1580

Analysis after treatment with 140 mg/l lime, 100 mg/l sodium carbonate, 15 mg/l sodium aluminate and 10 mg/l ferric chloride coagulants, locculation, settlement pH correction with acid and sand filtration.

Samples:	1	2	3	4	5	6	7	Average
pH	7.2	7.4	6.9	7.0			6.8	7.0
Alk	54	32	30	56			18	38
TH	620	570	590	590			617	597
Ca	132	128	128	128			134	130
Mg	70	60	65	65			68	66
SO_4	574	567	560	523			650	575
SiO_2	24	20	19	19			18	20

All values in mg/l except temperature (°C) and pH.
Alk and TH expressed as Calcium Carbonate.

Pilot Plant Investigations

The pilot plant was first used in the wellfield (at well 54) to establish the operating regime of the main plant at start-up when it was intended to operate the pretreatment plant without the reverse osmosis stage. In this mode of operation, which can of course occur during any period of total RO shutdown, the plant is required to produce water with a total hardness of around 500 mg/l (as $CaCO_3$). To achieve this requires much higher doses of lime and sodium carbonate than during periods of normal operation. It was established on pilot scale that dosing with 130 – 140 mg/l of hydrated lime, 270 – 290 mg/l of sodium carbonate, 10 mg/l of ferric chloride and 16 mg/l of sodium aluminate prior to clarification, neutralization and filtration, gave satisfactory treatment. Results from typical tests during this phase of the work are shown on Table III. During this period the reverse osmosis section of the pilot plant was only operated for very short periods and no significant information was obtained.

TABLE III

TYPICAL RESULTS OF PILOT WORK ON PRETREATMENT OPERATION

	Raw Water	Cooled Water	Softened Water
Temp	68	28	–
pH	6.28	7.72	9.12
Alkalinity	138	134	20
TH	840	900	510
Ca	212	224	92
Mg	75	83	68
Na	120	140	230
K	206	193	234
Cl	400	430	420
SO_4	635	691	670
SiO_2	40	50	17.5
TDS	1770	1886	1750

PRETREATMENT DOSAGES	
Hydrated Lime	124
Sodium Carbonate	274
Ferric Chloride	15
Sodium Aluminate	10

All values in mg/l except temperature (°C) and pH.
ALK and TH expressed as Calcium Carbonate.

In November of 1979, after commissioning of the pretreatment plant, the pilot plant was moved to the main site and the emphasis of the work was switched to the reverse osmosis plant. Feed for the pilot plant was taken from the reservoir on the main plant. This provided a reliable long-term supply, which enabled over 5,000 hours of operation to be logged. The pilot plant itself was an exact model of the main stacks, comprising three banks, each operating at

50-percent recovery. Eight-inch elements, identical to those on the main plant, were fitted in the first bank. The other two banks used four-inch elements of the same configuration. The main purpose of the work was to confirm that the process design procedures used at design stage were valid, particularly in relation to permeate quality and flux as functions of time. The opportunity was also taken to monitor performance and identify any specific process modifications or cleaning procedures that may have been required. The test work was extremely useful and very successful, particularly in terms of verifying design methods. Typical results are shown on Table IV for operation after 300, 2210 and 4470 hours. This shows a comparison between the permeate and concentrate compositions analyzed and those predicted using the design procedures developed by the contractor. As can be seen, very close agreement was obtained, which verified that the design procedures and the assumptions made regarding flux and rejection decline are essentially sound.

Some cleaning trials were attempted but no really useful information was obtained since it became clear that the elements were not subjected to any significant fouling.

Both the laboratory and pilot scale studies were invaluable in providing information that assisted with the commissioning and operation of the main plant.

TABLE IV

SHOWING COMPARISON BETWEEN MEASURED AND PREDICTED PERMEATE COMPOSITIONS FROM PILOT PLANT

Hours Run:	**300**		**2210**		**4470**	
	Observed	**Predicted**	**Observed**	**Predicted**	**Observed**	**Predicted**
PERMEATE						
pH	5.4		5.7		5.3	
Alk	4	1	4	2	2	3
TH	9	7	14	12	14	12
Ca	2		4	3	4	4
Mg	1	1	1	1	1	1
Na	21	20	31	35	31	38
K	11	15	7	15	7	17
Cl	38	37	60	71	64	80
SO_4	10	1	6	2	17	1
SiO_2	1	3	1	5	5	7
TDS	76	78	118	133	129	151
CONCENTRATE						
pH	4.24		5.6		4.36	
Alk	0	2	6	27	0	26
Ca	516	505	1036	106	1020	1016
Mg	2200	1764	1900	2044	1800	1832
Na	778	780	340	255	300	231
Cl	2590	3447	2500	2698	2859	2849
SO_4	4850	4514	4400	4379	4853	4763
SiO_2	114	122	121	102	142	136
TDS	1060	10530	11290	10780	11680	11385

Process Results From the Full-scale Plant

The lime/soda softening plant was commissioned over a period of three weeks in October 1979, using 140 mg/l of lime, 260 mg/l sodium carbonate, 15 mg/l sodium aluminate (Ferric chloride was not available at startup.), 5 cooling towers, 3 clarifiers and 4 filters to treat the available flow of 38,000 m^3/d. Stable floc blankets were established in the clarifiers during this time and filtered water with a pH of around 7, clear and colorless and with a total hardness of around 500 mg/l was produced and supplied to Riyadh. The plant continued to operate in this manner, except for the introduction of ferric chloride, until the Reverse Osmosis plant was brought on stream some twelve months later. At this point, it was no longer necessary to reduce the total hardness to 500 mg/l but only to 620 mg/l, (as $CaCO_3$) coinciding with a calcium content of approximately 130 mg/l. It was, therefore, possible to reduce the sodium carbonate dose but all other chemical dosages were kept the same.

In order to demonstrate that the whole process operated as intended, a formal process test was carried out in December 1980. The flow available to the plant at that time was 55,300 m^3/day (that is, somewhat less than full design flow). Therefore, in order to demonstrate the process effectively, the plant was operated with a reduced number of process units, each unit operating at or near full design rate. For example, nine reverse osmosis stacks were operated as opposed to the eleven that would have been required at full flow. Fortuitously, the division of flows during the tests was such that each stream was in the same proportion as the design condition. This was not the case in a further process test that was carried out in September 1981. At that time, the flow to the plant had dropped to 39,600 m^3/day, a figure that does not conveniently subdivide into integers of units at full flow. In this case, the RO stacks were operated at full output, which left the balance of bypass water somewhat lower in proportion than design, thus producing a blend of lower TDS than at design. In this case, it was necessary to recalculate the blend back to design conditions.

Results collected during both of these tests are shown in Tables V and VI. It can be seen that, in both cases, the analysis of the filtered softened water and permeate are extremely close to those predicted from laboratory and pilot work and from the contractor's process design techniques. The final blended water is also seen to be well within the revised 685 mg/l limit.

Since the RO plant has been in operation, daily records of all the relevant operating data have been kept for each stack. In addition to providing a plant management tool that can be used to initiate cleaning procedures, etc., or detect leaks, the information provides yet another means of comparing actual performance with predicted performance. Operating data for one of the stacks (this is typical of all others) is shown in Figures 2 and 3. The data has been corrected to the standard conditions used by the element manufacturer to specify his product. It can be seen that, in terms of both rejection (Figure 2) and flux (Figure 3), the elements started and remain somewhat higher than anticipated and are aging almost exactly at the rate anticipated.

Operation and Maintenance

In addition to the construction of the plant, the contractor, Ames Crosta Babcock, also has a contract for technical supervision of the operation of the plant and the provision of certain spares and consumables for a period of five years. The technical management team is under the administrative supervision of Riyadh Water Works Department, which provides all other staff on the plant.

TABLE V

SHOWING RESULTS FROM MAIN RO PLANT OPERATION DURING PROCESS TESTS AND COMPARISON WITH THEORETICAL PREDICTION

December 1980

	Permeate		Blend	
	Analyzed	**Predicted**	**Analyzed**	**Predicted**
Alkalinity	4	3	45	65
Total Hardness	18	12	285	262
Calcium	4	4	72	67
Magnesium	2	1	26	24
Sodium	24	32	78	79
Potassium	7	16	21	25
Sulphate	10	2	192	170
Chloride	56	67	160	170
Silica	3	5	11	14
TDS at 180°C	128	132	604	611

September 1981

	Permeate		Blend	
	Analyzed	**Predicted**	**Analyzed**	**Predicted**
Alkalinity	4	3	26	31
Total Hardness	17	14	176	209
Calcium	4	4	44	52
Magnesium	2	2	16	20
Sodium	40	38	72	72
Potassium	8	18	16	25
Sulphate	12	2	109	138
Chloride	67	80	130	153
Silica	2	4	9	11
TDS at 180°C	142	150	438	490

TABLE VI

SHOWING RESULTS FROM MAIN PLANT DURING PROCESS TESTS

December 1980

	Raw Water	Softened Water	Permeate	Blend
pH	8.0	6.8	5.6	7.6
Alkalinity	134	29	4	45
Total Hardness	830	595	18	285
Calcium	208	140	4	72
Magnesium	75	59	2	26
Sodium	150	220	24	78
Potassium	45	45	7	21
Chloride	405	400	56	160
Sulphate	552	547	10	192
Silica	37	16	3	11
TDS at 180°C	1620	1516	128	604

September 1980

	Raw Water	Softened Water	Permeate	Blend
pH	7.7	6.9	7.6	7.2
Alkalinity	119	18	3	26
Total Hardness	833	615	17	176
Calcium	206	138	4	44
Magnesium	77	2	2	16
Sodium	180	237	411	72
Potassium	47	47	8	16
Chloride	385	395	67	130
Sulphate	574	562	13	110
Silica	33	14	5	9
TDS at 180°C	1614	1526	142	438*

*When re-calculated for the design flow ratios of permeate and by-pass, the TDS value is 590 mg/l.

The management team comprises nine persons, as follows:

- Plant Manager (1)
- Plant Chemist (1)
- Process Engineers (2)
- Electrical Engineers (2)
- Mechanical Engineers (2)
- Administration/Accountant (1)

The process plant is operated on a 24-hour basis, using a team of around 20 operators. Other staff members are engaged in duties associated with running and maintaining the site. All staff live in a purpose-built village that is adjacent to the plant.

When discussing the operation and maintenance of the plant over the last two years or so, it is convenient to make a broad division between those features associated with a large process plant in a somewhat remote area and these associated with the Buwayb plant specifically and, in particular, those relating to the reverse osmosis plant, which is relatively novel on this scale. Some of these are discussed below.

General

The Buwayb plant is approximately 80 km from Riyadh and, while road communications are good, it is essentially a self-contained facility. It uses tonnage quantities of bulk chemicals, and requires constant preventive maintenance with all that entails in terms of spares and consumable items. These can range from large items, such as bearings for diesel generators, to parts for domestic plumbing systems. In this regard, it is little different from other process plants and it has been necessary to set up systems and storage procedures with suitable re-order levels to maintain an assured supply of all items. Bulk chemicals and oil are among the most critical items and, apart from shortage of some key chemicals at the commissioning stage, which delayed startup for a few weeks, the continuity of supply has been maintained.

Generally, the systems for supply and stores have worked well and at no time has a plant shut-down been caused by a lack of spares or consumables, apart from the specific case mentioned above. In some instances, it was necessary at a very early stage to revise stock levels for items that were being consumed faster than expected. (Particular cases that come to mind are diaphragms for dosing pumps and various parts of the analytical and other measuring instruments and, surprisingly, electric bulbs of various types.)

Another major area that is common to many plants is the setting up of proper working, reporting, operating, and safety procedures, including the permit-to-work system, etc. These systems are vital to such a plant that has high-voltage electrical supplies, some large rotating machinery, noxious and corrosive chemicals, high pressure pipes and many large water-retaining structures.

General systems were introduced on plant startup, based on known design and layout parameters, and these have been modified and refined over the past two years as the need for specific requirements has arisen.

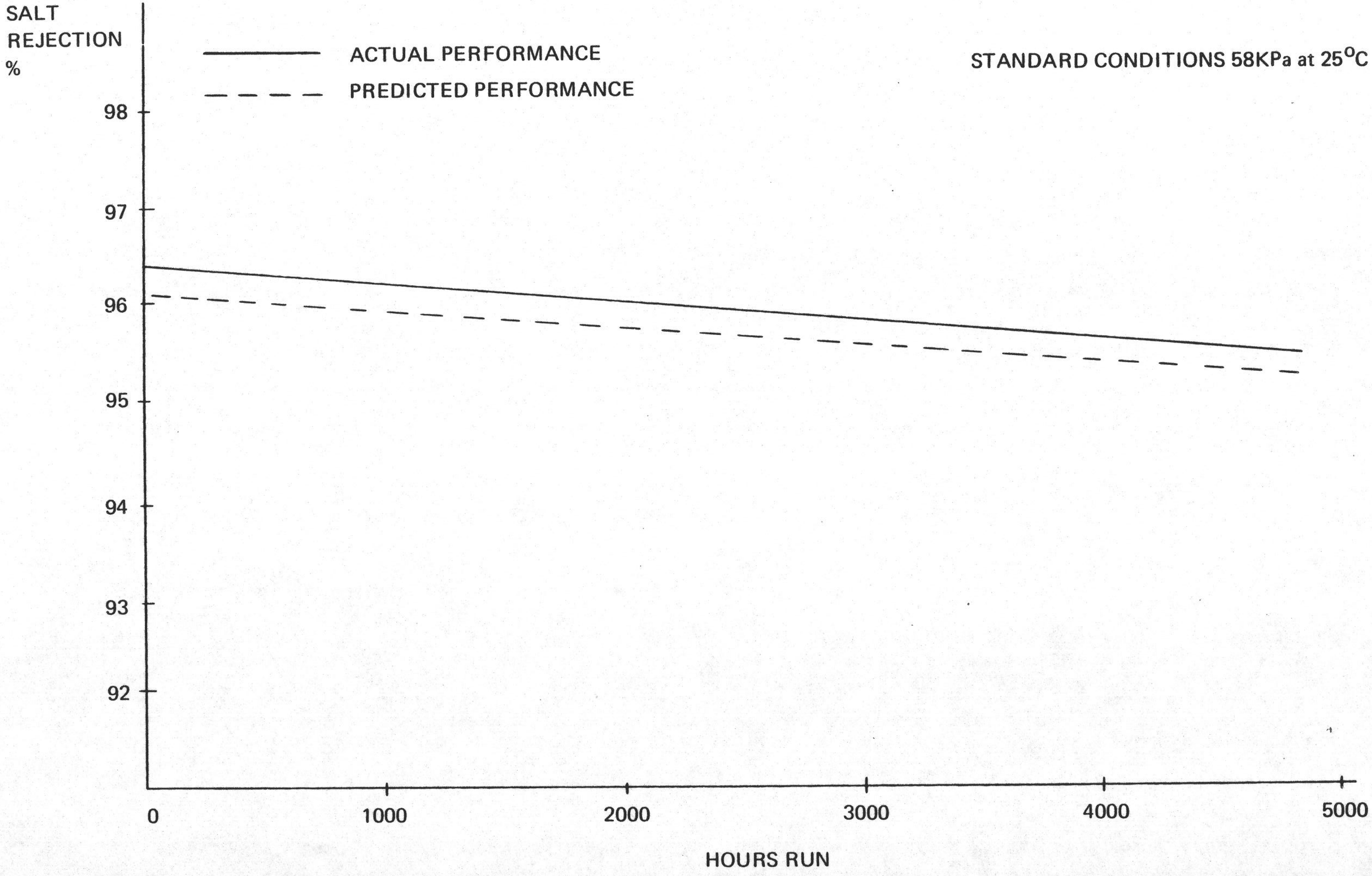

Figure 2 STANDARDIZED REJECTION VERSUS TIME FOR TYPICAL STACK ON MAIN PLANT

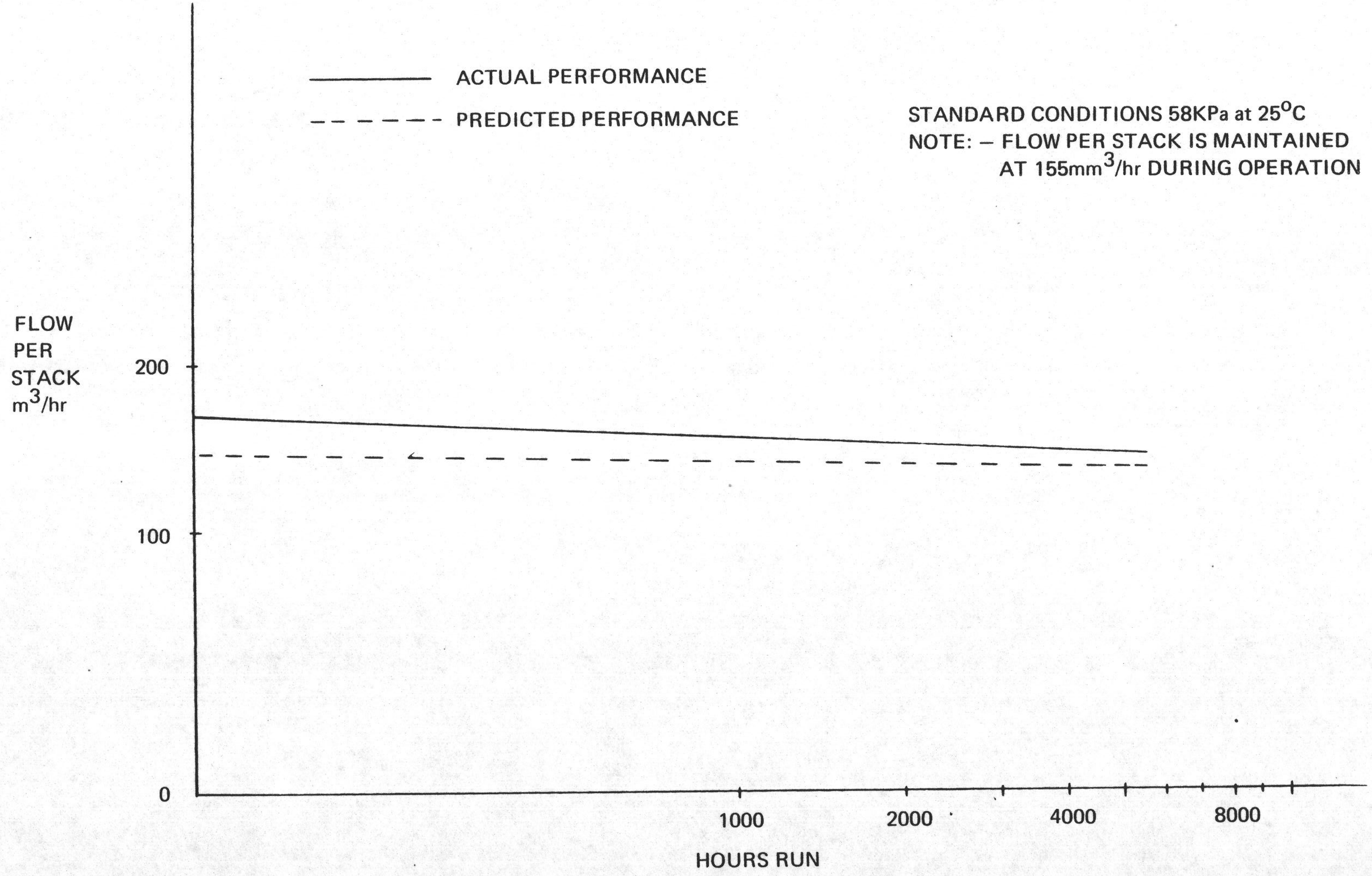

Figure 3 STANDARDIZED FLUX VERSUS TIME FOR TYPICAL STACK ON MAIN PLANT

In addition, consideration must be given to leave scheduling, transportation, visas, medical care, domestic arrangements, etc., associated with recruiting and keeping a team of qualified specialists, sometimes with families, in an isolated community. These considerations have, in fact, assumed considerable importance and should not be overlooked or underestimated.

Those aspects of operation and maintenance considered above, along with many others are, as mentioned previously, not specific to Buwayb but common to virtually any process plant in a similar location, managed and operated in the same way. There are, however, several interesting aspects specific to Buwayb and similar Water/RO plants that have arisen during the last two years. These are dealt with below.

Specific Aspects

When looking at the aspects of O&M specific to Buwayb, it is convenient to consider various sections of the plant separately and, in particular, those areas where it took some time to establish reliable and practical routines.

Cooling Towers — In addition to cooling the water, the cooling towers also serve to assist in iron removal by oxidation. This was recognized at the design stage. In practice, the water analysis is such that approximately 10 kg/day of iron oxide is precipitated in the cooling towers. Some of this collects in the sumps at the bottom, the remainder on the packing. There is, therefore, a need for regular planned cleaning of the towers and this is being done at about 9-month intervals. This was recognized at the design stage.

Chemical Handling — The chemical-handling plant was subject to the normal debugging operations experienced on a plant of this size and it took sometime to establish regular planned procedures with an acceptable level of unplanned maintenance. A good deal of the initial difficulties were caused by the fact that the chemicals arrived in a form that was not completely compatible with the handling equipment. A simple but significant example is that some bagged chemicals come in fiber bags, while the splitters were designed for paper sacks. Some modifications to equipment and operation were required to achieve a stable regime.

Clarifiers/Softeners — This type of clarifier, which is relatively highly rated and extremely effective in operation, does need familiarization for optimum operation. As expected, it took some time to establish correct desludging and operating procedures. One particular area where care is required is in the relationship between the coolers and the clarifiers. Sudden temperature changes, caused by switching out towers and/or fans can cause thermal shocks that disturb the sludge blanket. Coordinated action is required when switching towers and clarifiers to maintain optimum operation. The clarifiers have been rotated for occasional planned cleaning.

Filters — The filters have required no special operational requirements. They are backwashed regularly on a time basis and have consistently produced water of exceptional clarity.

Blending System/RO Feed Tank — As will be seen from the flow diagram, the plant is designed to blend either softened water or slipstream water with the RO permeate prior to discharge. This area did cause operational difficulties when the plant was started when an attempt was made to run the system in more or less of an exact balance. This is extremely difficult since, often, irregular backwashing of the filters or returns of backwash supernatant can cause fluctuations in the flow to the RO feed tank.

In extreme cases the tank could drain right down and activate the low-level probes, thus switching off all the RO plant. Since it takes some time (say, 1 to 2 hours) to put the plant back on stream, it is extremely inconvenient if this condition can occur on a regular basis. Consequently, the operation was changed to allow a constant slight excess of filtered softened water to overflow from the feed chamber so that it is always full. This appears to be a small point but causes considerable problems on a large plant with self-contained power generation because, not only does the plant switch off, but this unloads the power station and requires generator changes, etc.

RO Plant — The reverse osmosis plant being the largest relatively novel section of the plant was, naturally enough, the focus of much attention. It has, in fact, proved remarkably straightforward to operate and maintain once management and operations staff became familiar with handling the equipment and interpreting operating data. Perhaps the single most important operation requirement has been the development of a suitable strategy for responding to upstream process changes, particularly those causing potential out-of-specification conditions in the RO feed water. It is fair to say that initial guidelines on feed water quality resulted in alarm responses that were somewhat conservative, with the effect that in the early stages the plant was shut down for conditions that, while detrimental over long periods, could be tolerated for a short time. Since the feed to all stacks is common, water quality alarms shut off the entire plant, thus requiring a complete startup sequence when the water is back to the appropriate quality. As experience was gained, a more flexible strategy was developed and the plants now operate regularly on a 24-hour/day basis, and shutdowns now are normally planned.

Handling and interpreting the performance data from the RO stacks have developed into a routine that is carried out by the plant operators. Essentially, the data is normalized and plotted, and any trends noted and appropriate action taken. For example, a sudden increase in permeate conductivity from one bank normally indicates a seal leak, and this is then investigated further, because facilities are available if required for sampling each individual vessel. Common changes in flux or rejection might indicate a requirement for cleaning but it is notable to report that *no cleaning of any stacks* at Buwayb has been required. This is undoubtedly a tribute to the pretreatment and element configuration.

The operating experiences at Buwayb have once again demonstrated the essential simplicity and reliability of the reverse osmosis process. In fact, it is probably the part of the plant requiring least attention.

Modular Construction – Buwayb, in common with other RO plants, is constructed in a modular fashion. This has many well published advantages but this type of configuration does require consideration when planning operating procedures, particularly as at Buwayb, when the feed flow has not been constant or at design capacity caused by shortfalls from the well field and where blending is used. Taking off stream or bringing on stream one large capacity module makes a significant change in the total load in the blended water that can significantly affect the blend solids concentration. It has been necessary to develop a suitable strategy to meet varying flow conditions where whole numbers of stacks at full flow do not give correct flow proportioning. This has been done by turning down some stacks to give the correct output; i.e., by a combination of stacks operating at full flow and, perhaps, one other operating at reduced output. The operation is not difficult but the system needs setting up.

SUMMARY

The Buwayb plant has operated for over two years, providing water to supply for the City of Riyadh. It has been demonstrated both at pilot scale and full size that the process design methods for reverse osmosis plants are reliable and suitable for translating confidently to large scale. Further, it has been shown that the process designs can be engineered into a reliable practical system at this scale. The design philosophy, which was to regard the reverse osmosis plant as an important integrated stage in an overall treatment concept with the object of giving economic and trouble-free operation, has proved successful.

A major feature of the Reverse Osmosis section itself is the flexibility of operation that can be achieved. Routine maintenance can be done easily by rotation of equipment, including the reverse osmosis stacks that can be changed without disturbing the permeate output.

The reverse osmosis elements themselves have been shown to perform predictably over a relatively long time period and, in this particular instance, have required virtually no attention. This is undoubtedly in no small measure due to the provision of flexible and adequate pretreatment plant.

Operating procedures have been developed to suit the RO process and, once installed, these have been straightforward to use.

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SAMMANFATTNING

Denna artikel presenterades vid en internationell avsaltningskongress i Honolulu, Hawaii (1982-07-26--29). Vattenverket i Buwayb med omvänd osmos har varit i drift under mer än två år för staden Riyadh's vattenförsörjning.

Det har visats i både försöksskala och i full skala, att processutformningarna för omvänd osmosanläggningar är tillförlitliga och lämpade att med tillförsikt överföras till stor skala. Dessutom har det visats, att processutformningar kan tekniskt arrangeras i tillförlitliga praktiska system i denna skala. Utformningsfilosofin, vilken var ägnad att betrakta omvänd osmosanläggningen som ett betydelsefullt integrerat steg i ett totalt behandlingsbegrepp med syftet att ge ekonomisk och problemfri drift, har visat sig lyckad.

Ett betydelsefullt inslag i själva omvänd osmosdelen är den driftflexibilitet som kan uppnås. Rutinmässigt underhåll kan enkelt utföras genom roterande användning av utrustningen, inkluderande omvänd osmossstackarna, som kan växlas utan störning i permeatflödet.

Själva omvänd osmoselementen har visat sig motsvara förväntningarna över en relativt lång tidsperiod och i detta speciella fall har det praktiskt taget inte erfordrats något underhåll. Detta beror utan tvekan till stor del på den flexibla och väl lämpade förbehandlingsanläggningen.

Driftschema har utvecklats för att lämpa sig för omvänd osmosprocessen och efter införandet har dessa fungerat utan problem.

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