REVERSE OSMOSIS PLANTS: AD DUR, BAHRAIN

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Summary

This article describes the design and some of the operational experiences on the World's largest operational seawater reverse osmosis plant based in the Arabian Gulf, which are recognised as some of the most difficult feedwaters in the World.

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1 INTRODUCTION

The Plant was a gift to the State of Bahrain from H.M. The King of Saudi Arabia, to help in the development of water resources in the Island state, which was sanctioned in 1983. The multi-stage flash process and the reverse osmosis process were considered for the plant, and the choice was finally made for seawater reverse osmosis. The Saline Water Conversion Corporation who were responsible for water resources in Saudi Arabia, were responsible for the project on behalf of the Saudi Government.

Weir Westgarth Ltd in conjunction with Daewoo were awarded the contract to build the plant, after a fiercely competitive tendering process. Weir Westgarth were the consortium leaders, providing the process design and supply of all the main process equipment. Daewoo were responsible for the civil works and plant erection.

Work commenced on the project in earnest in 1987 and was ready for commissioning in 1989.

The Ad Dur installation was the largest seawater reverse osmosis plant in the World at the time it was built and is still the largest operating plant in the Arabian Gulf. The design and operational experience gained by Weir and the membrane supplier has been used on later generations of plant located throughout the World.

The plant is located at Ad Dur 35 km south of Al Manama on the East Coast of Bahrain in the Arabian Gulf.

2 PRE-DESIGN STUDIES – MARINE INVESTIGATION

Before commencing with the detailed design of the plant a detailed marine investigation took place. The data obtained was used to design the intake and filtration systems. These covered a number of areas:

2.1 Tidal Studies

Measurements of tides and currents showed a current influenced strongly by tide with a normal level variation of 0.7m between high and low tides. Storm surges giving a range in excess of 1m could be expected at least once per year. However, detailed discussions with local marine experts suggested that provision for very low tides (1.2m below mean sea level) should be made, as meteorological conditions in the Arabian Gulf and Indian Ocean could give very low tides from time to time (3 or 4 times per 50 years). This information was taken into account in the design of the onshore intake chamber and the vertical location of the sea water supply pumps, within the chamber.

2.2 Mathematical Models

Computer models based upon established mathematical criteria were undertaken to produce local distant currant movements. Actual measurements were used to validate these models. This work had the purpose of examining the possibilities of unusual water movements, which might bring contaminants from the more populated areas to the North. No unusual conditions emerged from this analysis. However, a mathematical study of the maximum shut-down surge affecting the intake chamber, did suggest that provision should be made for a surge spillway to avoid possible damage to the chamber roof.

2.3 Temperature and Salinity Profiles

Vertical temperature and salinity profiles showed a characteristic density stratification for the area. At the intake location, the thickness of the upper homogenous layer varied around 5m. The density difference between the upper and lower layer was 1.5 to 1.9 kg/m3. Figure 1 is typical of these profiles and the data assisted in fixing the depth of the offshore terminal.

2.4 Suspended Solids

Contrary to expectation the suspended solid content was and lay in the range 1.0 to 4.2 mg/l, with a grain size distribution in the range 0.02 to 0.06 mm. Occasional excursions to 15 mg/l suspended solids content were noted during storm conditions. Design of the dual media filter beds allowed for levels up to 25 mg/l.

2.5 Pilot Filtration Plant

Pilot filter pant studies were undertaken with the aim of establishing the chemical treatment conditions necessary to achieve a filtrate quality, which would be acceptable as feed to the membranes. The membrane manufacturer’s requirement was for an SDI of less than 3. The pilot filtration plant was designed to simulate parameters such as filter flux, mixing and retention times. Filtration trials were carried out between September 1985 and August 1987, during which the sea water feed salinity and temperature varied in the ranges, 44,250 to 46,500 ppm and 19.5°C to 38°C, respectively. Some 300 trial runs were carried out.

3 PLANT DESCRIPTION

The plant consists of an offshore seawater intake, supplying water to the onshore seawater supply pumps. These pumps supply gravity dual media filters, the filtrate is collected in a clearwell before being pumped through cartridge filters and the suction of high pressure pumps. There are eight first pass trains, each rated at a capacity of 248m3/hr product water, a portion of which is then a passed through a second stage of reverse osmosis to bring the product water quality to the required standard. Post-treatment comprises carbon dioxide stripping, lime addition and chlorination.

The plant layout is shown in Figure 2, the process diagram in Figure 3, the plant in Figure 4 and the overall design parameters for the plant are shown in Table 1.

3.1 Intake System

The seawater intake point is 1,200m from the seawater intake pump house. Water is taken at 4m below sea level in a conventional ‘pill box’ structure and flows through a 1.2m diameter glass fibre reinforced pipe. The water is chlorinated at the intake structure to ensure maximum contact time.

3.1.2 Intake Pump House

The Intake Pump House, houses the electrochlorination unit, trash racks, band screens, intake pumps and local control room (Figure 5).

The intake pipe is isolated from the intake chamber by a penstock followed by a stop-gate. The chamber is then spit into two 50% streams. Each intake stream has a trash rack (50 mm openings) to prevent floating and semi-submerged debris from entering the system, which are cleaned by a common traversing rake initiated manually.

Following the trash racks are the band screens, which remove much finer debris with a square mesh of 9.5mm. Cleaning is by way of 2 x 100% screen wash pumps, which are initiated by timer or differential pressure across the screens. The debris is flushed via a channel into one of two collection baskets, which can be removed using the buildings overhead crane.

After the band screens each stream can be isolated from the main intake sump by a stop gate. The sump contains the screen wash pumps and the main seawater supply pumps, which feed the dual media filters. Great care was taken in the design of the intake sump, to ensure that surge was catered for. The three 50% duty, seawater supply pumps are of the multi-stage suspended bowl type.

3.2 Pre-filtration Chemical Dosing Equipment

Feed water prior to the multi-media filters is conditioned to produce the optimum conditions for filtration. Provision is made to adjust the pH from its inlet value of 8.1 to approximately 7.6 by dosing sulphuric acid, the optimum pH for dosing the coagulant ferric chloride. A coagulant aid (high molecular weight polymer) can also be dosed.

Each of the dosing systems operate with flow proportional control by means of variable speed drives for the dosing pumps. The sulphuric acid system operates with both flow proportion and pH feedback control, to allow rapid changes to be made in dosing flowrate when changes occur to the feedwater flow to the dual media filters.

The feed water passes through a concrete contact tank, which is part of the dual media filter structure. It has been designed with a series of baffles to provide sufficient mixing energy for the coagulant. The coagulant and coagulant aid are both introduced by means of a horizontal sparge pipes, with the coagulant dosed at the inlet to the contact tank and the coagulant aid at the outlet.

3.2.1 Coagulant Dosing System

The coagulant system includes two complete systems, each of which is capable of dosing the full plant requirements. The ferric chloride is supplied in liquid form and stored in one of two storage tanks (24 hour capacity) constructed from glass reinforced plastic. Each tank has a low speed paddle wheel mixer, with the ferric chloride being diluted to 18% solution strength. These tanks feed two 100% duty dosing pumps, which have a common calibration column and are equipped with discharge pulsation dampers and relief valves on each of their discharges. The ferric chloride is mixed with carrier water, which is injected using a sparge pipe at the inlet to the contact tank

3.2.2 Coagulant Aid Dosing System

To assist in the coagulation process, organic polymer is sometimes dosed. There are two identical 100% duty and standby coagulant aid dosing systems. Each system is complete with solids handling system, mixing tank, ageing tank and dosing tank, sized for 24 hours storage.

The coagulant aid is mixed with carrier water, which is injected using a sparge pipe at the outlet of the contact tank. The dose rate was typically 0.1mg/l of a high molecular cationic polyelectrolyte.

3.2.3 Sulphuric Acid System

The concentrated sulphuric acid system consists of a bulk handling and storage system (2 x 7 days capacity), the acid day tank and transfer system and the chemical injection systems. One system doses before the dual media filters and the other after the filters.

Two 100% rated dosing pump systems are provided with the pipework constructed from carbon steel. The acid is injected into a static mixer before the contact tank. The injection pipe was initially made from hastalloy but it had a relatively short life and rapidly decreased in length, subsequently the material was changed to solid PTFE, which was much more successful.

Another identical set of dosing pumps are used to dose acid between the cartridge filter feed pumps and the HP pump suction, to adjust the feed Stiff and Davis Index to a pH of 6.2 to 6.4, to prevent calcium carbonate scale formation within the membranes. The minimum pH of 6.2 while being below that required for scale control, has the advantage of producing carbon dioxide in the feedwater, which subsequently reacted with the lime used in the plants post-treatment system to produce a non-corrosive product water.

3.3 Dual-media Filters

The filters are of the rapid gravity type and constructed from reinforced concrete. Twelve filters are provided one of which is on standby, at the design flow. See Figure 6.

Each filter is identical in design with the downflow of seawater through anthracite (effective size 0.92 mm) and fine sand (effective size 0.50 mm), which are supported on three gravel support layers. The filter floor contained specially designed filter nozzles.

64 m^2 of surface area is provided per filter, which operate at a design filtration velocity of 8 m/hr. The filters are self-regulating, with an inlet weir controlling the flow to each filter so that they all operate at the same rate. The level in each filter increase as the pressure loss increases until the filter is isolated on high differential pressure or on filter run-time. The automatic air scour and backwash sequence is then initiated.

Two 100% duty air scour blowers, equipped with inlet air filter/silencers and discharge silencers, are provided. The two 100% rated backwash pumps (suspended bowl type) feed the backwash water via a manual flow control valve, which is adjusted to set the optimum backwash flow depending on the seawater temperature.

Each filter is equipped with on-line turbidity measurement, however in practice our experience indicated there was little to be gained relative to the maintenance required for this instrumentation.

Clear water from each of the filters is collected and transported by concrete ducting to the covered clearwell (Figure 7). The clearwell is split into two compartments by a concrete division wall, which has been designed to ensure that backwash water compartment only begins to fill when there is sufficient water within the main compartment, which supplies the main plant. An overflow weir from the clearwell connected by concrete culverts to the north side of the plant facilitated commissioning of the dual media filter system and ensures that the pre-treatment system can continue to operate in the event of an RO system planned shutdown or trip.

Three cartridge filter feed pumps (suspended bowl type), each rated at 2777 m3/hr @ 34 m and 50% duty, supply water to the cartridge filters and the first pass high pressure feed pumps. The pump flow is controlled by a minimum flow re-circulation loop on the common discharge of the pumps.

Both the cartridge filter feed pumps and the backwash pumps, are covered by a sunshade and an overhead crane is provided for maintenance purposes.

3.4 Post-filtration Chemical Dosing Equipment

The chemicals that are dosed after the dual media filters are sulphuric acid and sodium bisulphite. The sulphuric acid is used for the final pH adjustment of the feedwater prior to the first stage of reverse osmosis, which is described in Section 3.3.3. Sodium Bisulphite is dosed to remove all the chlorine in the feedwater, which would otherwise damage the membranes.

3.4.1 Sodium Meta-Bisulphite Dosing System

Two completely independent systems are provided – a primary and a secondary dosing system, to ensure maximum reliability of this critical dosing function.

Sodium Meta-Bisulphite ($Na_2S_2O_5$) is supplied in powder form and is transferred to one of the four stainless steel mixing / dosing tanks – two 24 hour capacity tanks (4m3) for the primary and secondary systems respectively. The sodium meta-bisulphite is mixed with water to form sodium bisulphite, which is facilitated by a motorised mixer.

Each pair of tanks feed two 100% duty dosing pumps. The dosing rate of both systems is proportional to process flow using a control signal from the cartridge filter feed pump flow and a signal from the residual chlorine analyser, located after the cartridge filter pumps.

Both the primary and secondary sodium bisulphite solutions are discharged into a static mixer prior to the cartridge filters. The reason for dosing before the cartridge filters is that when the plant was designed and built, this was a mandatory requirement of the membrane supplier. The apparent philosophy being that any biological fouling will first take place within the cartridge filters and not the membranes and so remedial action could be taken. We disagreed with this philosophy, on the basis that the cartridge filters would become a source of biological contamination of the entire membrane system and our view was that the de-chlorination point should be located after the cartridge filters.

After two years of operation, it was decided to move the de-chlorination point just downstream of the cartridge filters. The entire redox detection system was moved and the sample piping revised because the time available to detect the presence of chlorine and shut the RO streams down before chlorine entered the membranes was considerably reduced. Furthermore the pipework arrangement at the cartridge filters did not allow the inclusion of a static mixer. Following detailed computational fluid dynamics modelling of the pipework and injection systems we satisfied ourselves that the sodium bisulphite would have mixed properly before the redox instrumentation.

This modification was made during the summer of 1992. The effect was to more than double the cartridge filter life to more than 2 months operation and the membrane cleaning frequency, under normal conditions to in excess of 3 months.

3.5 Cartridge Filters

The cartridge filters are designed to remove any particulate matter exceeding a size of ten microns that would affect the performance of the membranes. (Field trials were conducted on smaller sizes but we concluded that ten microns gave the best combination between cartridge filter life and membrane cleaning frequency).

Eight duty and one standby filter are provided, connected by common inlet and outlet headers. These were constructed from glass reinforced plastic and were the largest cartridge filters ever constructed from GRP when they were installed. Each filter contains 219 30 inch polypropylene wound filter elements, which are mounted in removable stainless steel cage.

A spare cage can be charged with filter elements, so that when a filter requires replacement it can be easily carried out. The cartridge filter area is covered by a sunshade and equipped with an overhead crane to help remove the filter covers and install a new cage of filter elements.

The pressure drop across the cartridge filters is monitored on-line, while flow indicators are provided on each of the cartridge filters. This allows the performance of each filter to be monitored and facilitates the planned replacement of the filter elements.

In practice all the cartridge filters were operated at all times. We found that if a filter was left on standby there was the possibility of seawater leaking into the filter, which then caused biological growth within the filter. When the filter was brought on-line biologically active material was forwarded to the membranes, which helped to accelerate membrane fouling.

3.6 First Pass Reverse Osmosis System

The first pass reverse osmosis system consists of eight streams, each producing 247.6 m3/hr at the design conditions and 35.2% conversion. A Standby Bank is provided to supplement the output of a first pass steam when it is being cleaned.

3.6.1 High Pressure Pumps and Energy Recovery Turbines

The high pressure pumps take their suction from a common header running the entire length of the first Pass High Pressure Pump Room (Figure 8), with each one isolated from the header by an actuated isolation valve. The pumps are of the multi-stage horizontal split case type and constructed from a high-grade stainless steel (ASTM A744 GR CG8M). Each stream has one 100% duty pump with no standby, rated at 703.3 m3/hr and 70.7 bar and is driven by a 6.6 kV motor, rated at 2MW.

A shaft extension at the non-drive end of the HP pump is connected to the energy recovery turbine via an automatic clutch. The turbine is a reverse running centrifugal pump, with a similar construction to the HP Pump. The turbine can be completed isolated from the brine stream and a full flow by-pass is provided, which also controls the turbine inlet pressure. The turbine was designed to recover 600kW of energy.

The stream is controlled automatically by feed flow control on the streams HP pump discharge and the product flow (conversion) is controlled by a control valve in the reject, which adjusts the reject pressure to the required value. Downstream of this valve is the energy recovery turbine.

3.6.2 Membrane Configuration

Each stream has four independent banks of membranes fed from a common header running the length of the stream. This arrangement allows a bank to be isolated with the stream operating, so that membrane cleaning or maintenance can be carried out with no loss of water production (assuming the Standby Bank is operating). Each individual bank is further divided into two half banks, each of which can be isolated from the main stream.

Each half bank has three feed, reject and product risers, with the capacity for 22 pressure vessels per riser, making a maximum capacity of membranes per stream of 528. The initial design value was 448 membranes per stream. The membranes were of the hollow fine fibre type, Du Pont Model B10 6840T, each housed in a single fibreglass pressure vessel.

Figure 9 shows one of the first pass streams from the feed / brine side.

An extensive on-line monitoring system is provided for measuring a total of 192 membrane differential pressures, one membrane per riser and each of the half bank product conductivities is also monitored. Provision was made for extensive manual differential pressure measurement to supplement the on-line measurements when required.

3.6.3 Standby Bank

This system is one quarter the capacity of each of the main streams and is equivalent to one bank (4 banks per stream) of the main first pass streams. It's purpose is to operate during the cleaning of one of main streams, which is done on a bank by bank basis, so that the full plant's capacity can be maintained.

The configuration is very similar to the first pass main streams, except that there is no energy recovery turbine, no equivalent second pass system and the product water is fed directly to the drawback tanks.

3.7 Second-Pass Reverse Osmosis System

A second pass stream is provided for each of the eight first pass streams. These systems are designed to treat 38% of the first pass product water, to ensure that the final product quality meets the design requirements. The design product water quality from the first pass is 521mg/l, with a design value of 50mg/l from the second pass, before it is blended with the remaining first pass product water.

The high pressure pumps were of the multi-stage horizontal split case type and constructed from 316L stainless steel. Each second pass stream had one 100% duty pump with no standby, rated at 93m3/hr and 31.7 bar.

The stream is controlled automatically by feed flow control on the streams HP pump discharge, which regulated the flow to the stream from the first pass product. Similarly the product flow (conversion) is controlled by a control valve in the third stage reject, which adjusts the reject pressure to the required value.

3.7.1 Membrane Configuration

The membranes in the second pass are arranged in three brine staged arrays (18:9:4 arrangement), to allow the very high conversion of 90%. The third stage reject is returned to the first pass high pressure pump's suction to reduce the TDS and quantity required of the incoming feedwater. The membranes were also of the hollow fine fibre type, Du Pont Model B9 0040, each housed in a single fibreglass pressure vessel.

The product from each of the three stages is collected and blended to give the overall second pass product. The entire second pass can be isolated, when a reduction in TDS of the first pass stream is not required, thus increasing the total plants output by 4% (ie a total plant output of 47,539 m3/day).

Since these membranes use feedwater, which is RO permeate there will be minimal fouling and the process monitoring requirements are considerably less than the first pass. On-line instrumentation is provided for product and brine conductivities for each stage, product pH, feed and third stage reject pressure and feedwater temperature. Differential pressure indicators are provided on one membrane per stage.

The membranes could be chemically cleaned using the common chemical cleaning system and the on-line chemical injection system. We found that over the course of two years there was no requirement to clean any of the second pass systems, which was to be expected.

3.8 Post-Treatment System

The post treatment, consisted of low TDS / drawback tanks, carbon dioxide removal using a packed bed tower, chlorination using chlorine gas and lime addition.

3.8.1 Low TDS / Drawback Tanks

The entire product water from the reverse osmosis streams, including the standby bank are combined in a header and are piped to the drawback tanks. The tanks provide a reservoir of low TDS, unchlorinated water that can be used for drawback and flushing.

Four identical 80 m3 horizontal elevated tanks, constructed from glass reinforced plastic were provided, which were connected in parallel. The tank capacity was based on the calculated drawback requirements given a total plant trip, with sufficient excess to flush all the first pass streams.

The flow to the tanks was by bottom entry and exits at the top. Recirculation lines within the dome ends were provided to prevent stagnant pockets within the tank. Each tank could be isolated for maintenance and was equipped with vacuum breakers and vent valves.

3.8.2 Decarbonator (Carbon Dioxide Degasser)

The product water contains approximately 66mg/l of carbon dioxide, as a result of the feedwater acidification. To minimise the consumption of lime a decarbonator is employed to treat a portion of the flow, the remainder by-passes the decarbonator into the sump.

The decarbonator is a conventional packed bed tower constructed from GRP, with product water introduced at the top via a distribution system, it then flows down through the pall-ring packing and is collected in the sump. A countercurrent flow of air is used to strip the carbon dioxide, supplied by two, 100% duty air blowers.

A valve at the inlet to the decarbonator controls the residual carbon dioxide, in the sump, by automatic flow proportional control. The pH in the sump is measured and can be controlled manually using a ratio controller operating on the inlet valve at the top of the decarbonator.

3.8.3 Product Water Pumps

Three 50% duty product water pumps were provided to pump the water from the decarbonator sump (operating on level control) to the two 15,000m3 product water storage tanks. The pumps were of the horizontal split casing type, with double entry impellers, due to the low NPSH requirements.

3.8.4 Lime Dosing System

This system uses hydrated lime, which was prepared in one of the two 17m3 dosing tanks, each sized for 24 hours capacity. These tanks fed one of two 100% rated dosing pumps which have a common calibration column and are equipped with discharge pulsation dampers and relief valves on each of their discharges. The dosing lines were equipped with automatic flushing connections when the duty pump was changed over or on shutdown to prevent the lines clogging with lime.

The dose rate was controlled by flow proportional control and the pH of the product water.

A number of modifications were made to the system to improve its reliability, all aimed at reducing the possibility of clogging the dosing lines:

a. Addition of a pump to continuous recirculate the lime from the conical bottom section of the dosing tank to the top.

b. Redesign of the pipework to facilitate ‘roding’ of any blocked lines.

3.8.5 Chlorine Dosing

A conventional vacuum liquid chlorine system was provided, with one 100% rated chlorinator. The chlorine was injected at the suction of the product water forwarding pumps, with a provision for chlorinating the degasser sump when required. The dose rate was controlled by flow proportional and feedback control, via a chlorine analyser.

3.9 Membrane Chemical Cleaning and Related Systems

The plant was equipped with a variety of systems to facilitate membrane cleaning and chemical treatment.

3.9.1 Chemical Cleaning System

This system consists of a chemical mixing system (tank, mixing / transfer pumps and cartridge filter) used to facilitate the preparation of the various chemicals. These prepared chemicals are then forwarded to the chemical storage tank.

Two 100% rated chemical cleaning pumps are fed from the chemical storage tank and discharge via a cartridge filter and seawater cooled heat exchanger. The cleaning chemicals can either be recirculated to the tank or forwarded to a common header running the length of the building. Return headers were provided from both the product and reject during cleaning operations.

Initially flexible hoses were used to connect from the headers to the bank that was being cleaned. This was subsequently replaced by a completely piped system to facilitate the ease of cleaning the membranes.

3.9.2 On-line Chemical Injection System

Two 100% rated pumps chemical injection pumps, fed from the chemical storage tank, are provided for on-line injection of various chemicals at the first pass HP pump suction. These allow the on-line injection of chemicals to improve the salt rejection of the membranes (polyvinyl methyl ether and tannic acid), biocides and cleaning chemicals.

In practice we found that it was far more effective to take a first pass bank off-line and then treat it using the main chemical cleaning system.

3.9.3 Low TDS Flush System

This system was designed to flush the first pass RO streams with low TDS unchlorinated water taken directly from the drawback tanks. The flushing system consisted of 2 x 100% duty flushing pumps, connected to a common discharge. Connections were provide on each of the inlet suction lines to the HP pumps, which were equipped with automatic isolation valves so that the entire stream could be flushed with low TDS water. The flush was initiated automatically after a train shutdown took place or on operator command from the control system.

A separate pump system is used to provide the HP pump seal cooling water system.

3.10 Control System

This system is a distributed control system, capable of total operator control and monitoring from a central control room, located in the sub-station building and/or satellite positions. (See Figure 10).

The central control room is provided with two operator stations (COPSV) plus one operator console (COPCV). All three are provided with keyboards and colour monitors for plant control. Each COPSV is capable of independent operation and each has access to hard and soft disc backup to retain historical data and the ability to interface between the distributed system and the graphic monitors and keyboards. The operator console (COPCV) is only supplied with a monitor and keyboard, and acts as a slave to the COPSV unit.

All analogue and digital control algorithms are held in the distributed control system located as appropriate in the following four areas:

a) Main Substation
b) Seawater Intake
c) Pre-treatment
d) Reverse Osmosis

Areas (b), (c) and (d) have a single colour graphic operator station (COPSV). Each part of the distributed control system incorporates full redundancy of communication cards, power regulators and multi-loop (analogue) controller cards to give a high level of reliability of operation.

As appropriate, each local area has a further back-up of PID control algorithms by the inclusion of certain dedicated single loop controllers.

In addition, the system incorporates a 1st pass membrane performance monitoring computer, VDU and printer to enable the performance monitoring to take place independently of the control system. For this, 192 differential pressure signals, 32 conductivity signals and other relevant information are taken from the data highway connecting local areas to the central control room via a computer interface.

Communications between the central control room and the elements of the distributed control system are by fully redundant high speed data highways.

3.11 Electrical Distribution System

Electrical power to the plant is supplied by twin 66 kV cables, each connected to a 25 MVA 66/6.6 kV transformer located in the sub-station building. Each incomer is capable of supplying the entire plant's power requirements.

From the transformer the 6.6kV supply is distributed to the HP Pump MCC and various 6.6/0.4 kV transformers which serve the 400V motor control centres (MCCs) at different locations. Two 6.6/0.4kV transformers are provided at each location, each of which is capable of operating alone. Similarly each MCC has two incoming feed supplies, in case one should fail.

In order to protect the computer control and monitoring system, four independent uninterrupted power supply (UPS) systems are located in the following areas; Sub-Station Building, Sea Water Intake, Pre-Treatment Building and RO Building. Each UPS is fed by two independent 400V AC supplies to achieve a high degree of availability.

A standby generator system is provided to supply critical loads in case of failure of the two main incoming supplies. The emergency power is provided by a diesel engine driven generator (820 kV, 3 phase 400/230 V, 4 wire) in the generator room, which is located in the Machine Shop and Warehouse Building. This system is capable of providing power to essential equipment such as air conditioning plant, fire water pumps, fire detection system and building lighting.

4 OPERATIONAL EXPERIENCE

The Arabian Gulf is generally accepted as being one of the most arduous seawaters in the World and accurate process monitoring of such a large plant was absolutely essential. Especially when one considers there were 33 banks of membranes including the standby bank to be monitored. A number of the more important aspects associated with process monitoring are now discussed.

4.1 Algae Blooms

One of the characteristics of the water in the Arabian Gulf are periodic algae blooms, once or twice a year. Under these conditions, the potential for biological fouling of the membranes is significantly increased and if this situation is not recognised at an early time then RO streams may need to be shut down. Primarily due to the inability of a single centralised cleaning facility not being able to clean all the banks fast enough as the plant fouls-up.

As well as the detailed performance monitoring of the RO stream and pre-treatment system, daily readings were taken of biological activity within the pre-treatment, RO feeds and brines. We used the serial plate dilution technique and the more complicated and labour intensive process of the AO and INT microscopic techniques.

Figure 11, shows the rapid average increase in differential pressure on one of the first pass streams during an algae bloom. It can be see how effective the sodium bisulphite flushes were in controlling the fouling on the membranes – a technique developed at Ad Dur. The biological activity corresponding to this period is also shown in Figure 12.

4.2 Feedwater Total Dissolved Solids Measurements

One of the more difficult measurements is the seawater TDS, which plays a crucial role in assessing the performance of a plant, all the other measurements, temperature, feed pressure, feed flow etc are easily determined. The usual method for determining the TDS on a daily basis is to measure the conductivity and apply a conversion factor to obtain the TDS, backed up with actual seawater analyses and evaporations. Typically a factor of 0.7 is used for Gulf seawaters, however we found at Ad Dur the value was higher. Figure 13 shows the results of over 200 evaporations to determine the relationship between conductivity and TDS for the feedwater at Ad Dur. At an evaporation temperature of 105°C the linear factor was 0.745 and at 180°C, 0.711. Figure 13 shows the results of the evaporations relative to the measured conductivity. The merits and demerits of the different techniques are not discussed in this article.

The importance of determining the relationship between conductivity and TDS is very important, especially now with the extended warranties Clients require on plant performance. However in the day to day monitoring of the plant, provided the TDS – Conductivity relationship is consistent, then the plant performance trends can be accurately monitored.

4.3 Membrane Performance Monitoring

An extensive suite of software was developed to assist in the process management of the plant and in particular the First Pass RO Streams. The accepted practice for monitoring RO streams is to use the ‘Normalisation’ Technique [ASTM D 4516-85], which compares the streams performance relative to its design performance. This is useful in trending but it does not allow the absolute performance of the stream relative to the as-new membrane performance, which allows the calculation of the degree of fouling and therefore the maximum output of the plant at any given time.

Software was written to calculate and trend the performance of the first pass membranes. This allowed effective early action to be taken in the event of a performance downturn and a comparison with the membrane suppliers predicted irreversible membrane compaction, which is associated with membranes of the hollow fine fibre type. The first 7,000 hours operation of one of the first pass streams is shown in Figure 14 and the importance of measuring the conductivity is illustrated in Figure 15, which shows the variability of the seawater TDS at the Ad Dur site.

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Table 1: Plant Process Summary

Parameter	Units	Value
Total Plant Net Output	MIGD (m3/hr)	10 (1,894)
Product Final Total Dissolved Solids (TDS)	mg/l	500 (max)
Product Final Chloride Concentration	mg/l	200 (max)
Power Consumption (actual) per cubic meter	KWh/m3	6.537 (net)
Feed Flow / Train	m3/hr	694.0
Feed Temperature Range	°C	18 – 36
Total Feed to Trains	m3/hr	5,553.0
1st Pass Feed / Train	m3/hr	703.0
2nd Pass Feed / Train	m3/hr	93.0
Media Filter Total Flow	m3/hr	5,673.0 – 6,000
Media Filter Flow per Filter	m3/hr	515.06
Media Filter Velocity	m/hr	8.06
Media Filter Backwash Flow / Filter	m3/hr	1,440 – 1,600
Media Filter Air Scour Flow / Filter	m3/hr	1,498
Hypochlorite Dosing Rate (max)	mg/l as Cl_2	6.0
Acid Dose Rate (Filter Inlet)	mg/l	71.1
Acid Dose Rate (Filter Outlet)	mg/l	0
Coagulant Dose Rate (max)	mg/l as $FeCl_3$	8.5
Coagulant Aid Dose Rate (max)	mg/l	0.5
Sodium Meta Bisulphite Dose Rate (Primary)	mg/l	5.7
Sodium Meta Bisulphite Dose Rate (Secondary)	mg/l	5.7

1st Pass Permeate Flow	m3/hr	248.0
Parameter	Units	Value
1st Pass Product TDS	mg/l	530
1st Pass Membrane Manufacturer		Du Pont Permasep Products
1st Pass Membrane Model and No Off		B10 6840T - 448 off
2nd Pass Permeate Flow	m3/hr	83.7
2nd Pass Product TDS	mg/l	50
2nd Pass Membrane Manufacturer		Du Pont Permasep Products
2nd Pass Membrane Model and No Off		B9 0040 - 31 off
Decarbonator Inlet Flow	m3/hr	953
Decarbonator Inlet CO2	mg/l	66.3
Decarbonator Sump Outlet Flow	m3/hr	1,906
Decarbonator Sump CO2 Content	mg/l	35.7
Chlorine Dose Rate (Product)	mg/l as Cl_2	1.0
Lime Dose Rate	mg/l	50

ACKNOWLEDGEMENTS

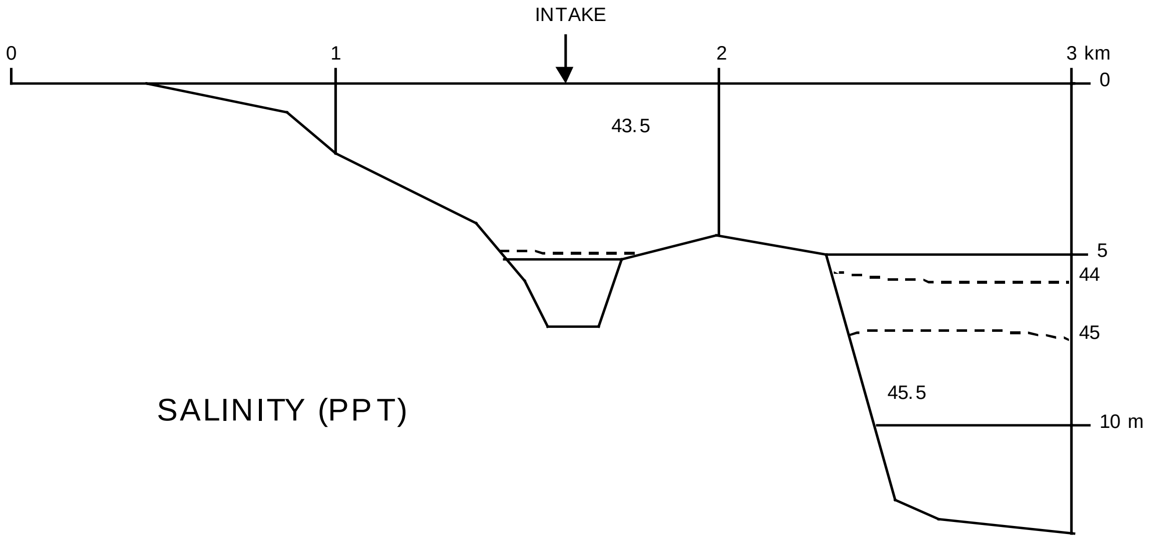
Bibliography and Guide for Further Study

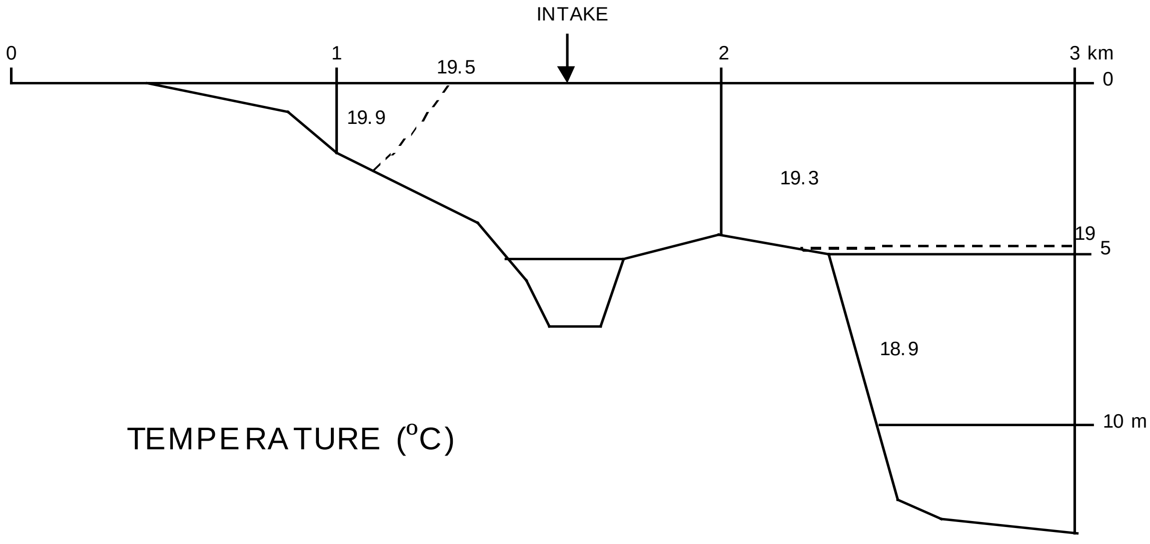
ASTM D 4516-85 *Standard Practice for Standardizing Reverse Osmosis Performance Data*

Nicoll P G et al. (1995) *Large Seawater Reverse Osmosis Installations in Gulf Waters and a Process Comparison with Multi Stage Flash Distillation*. IDA World Congress on "Desalination and Water Sciences" (Proceedings, Abu Dhabi, November 18 – 24, 1995), Vol. V pp. 27 – 41. Abu Dhabi: Abu Dhabi Printing & Publishing Co.

List of Figures

Figure 1 Typical Temperature and Salinity Profile





Note: Sections are vertical, along the intake axis (in direction due east), and are measured from the centerline of the site co-ordinate system.

Figure 2: Plant Layout

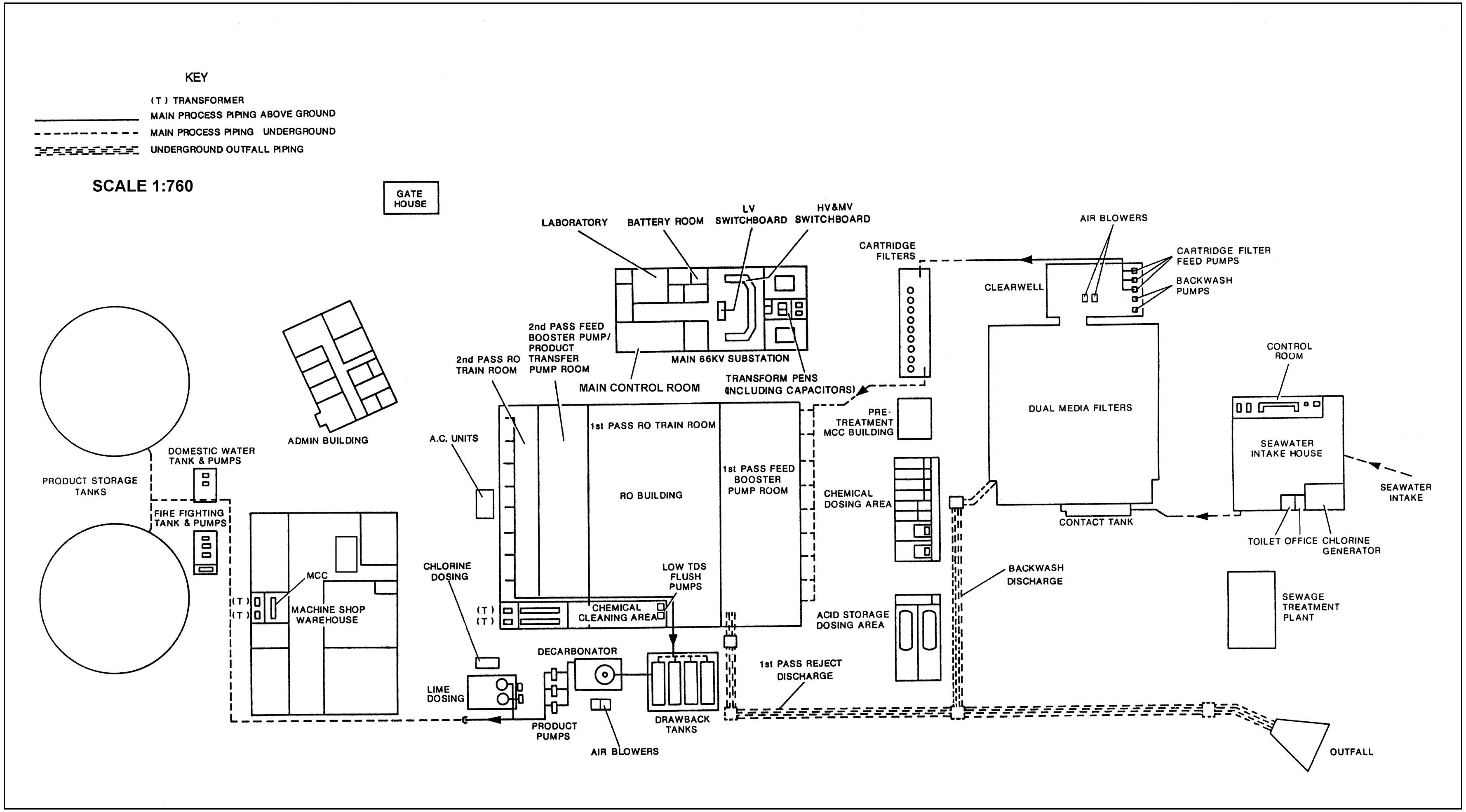
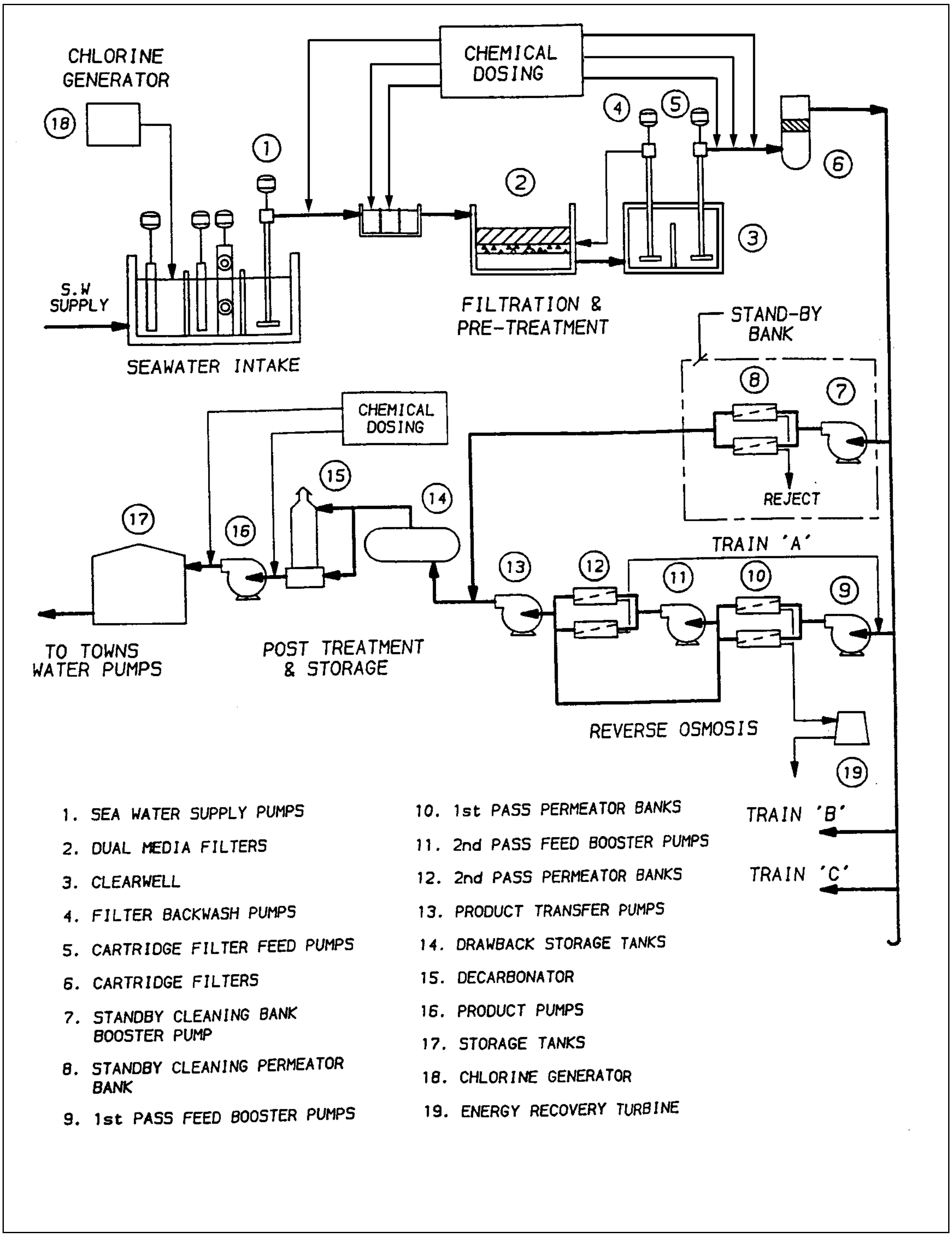


Figure 3: Process Diagram



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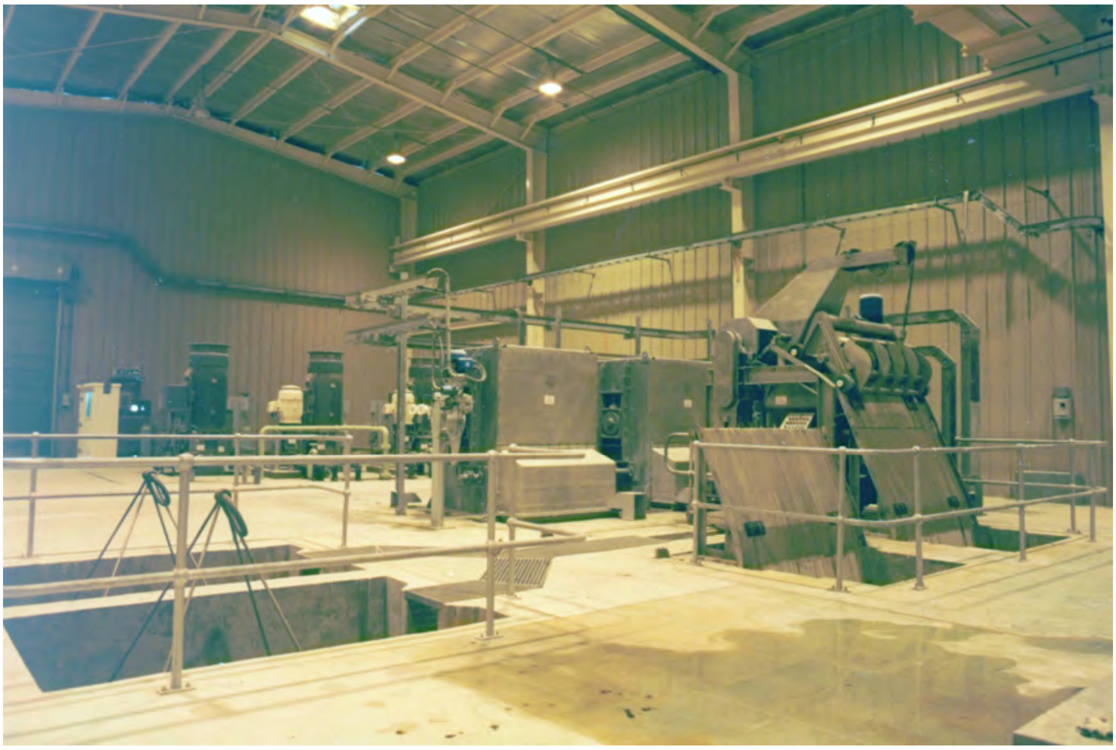

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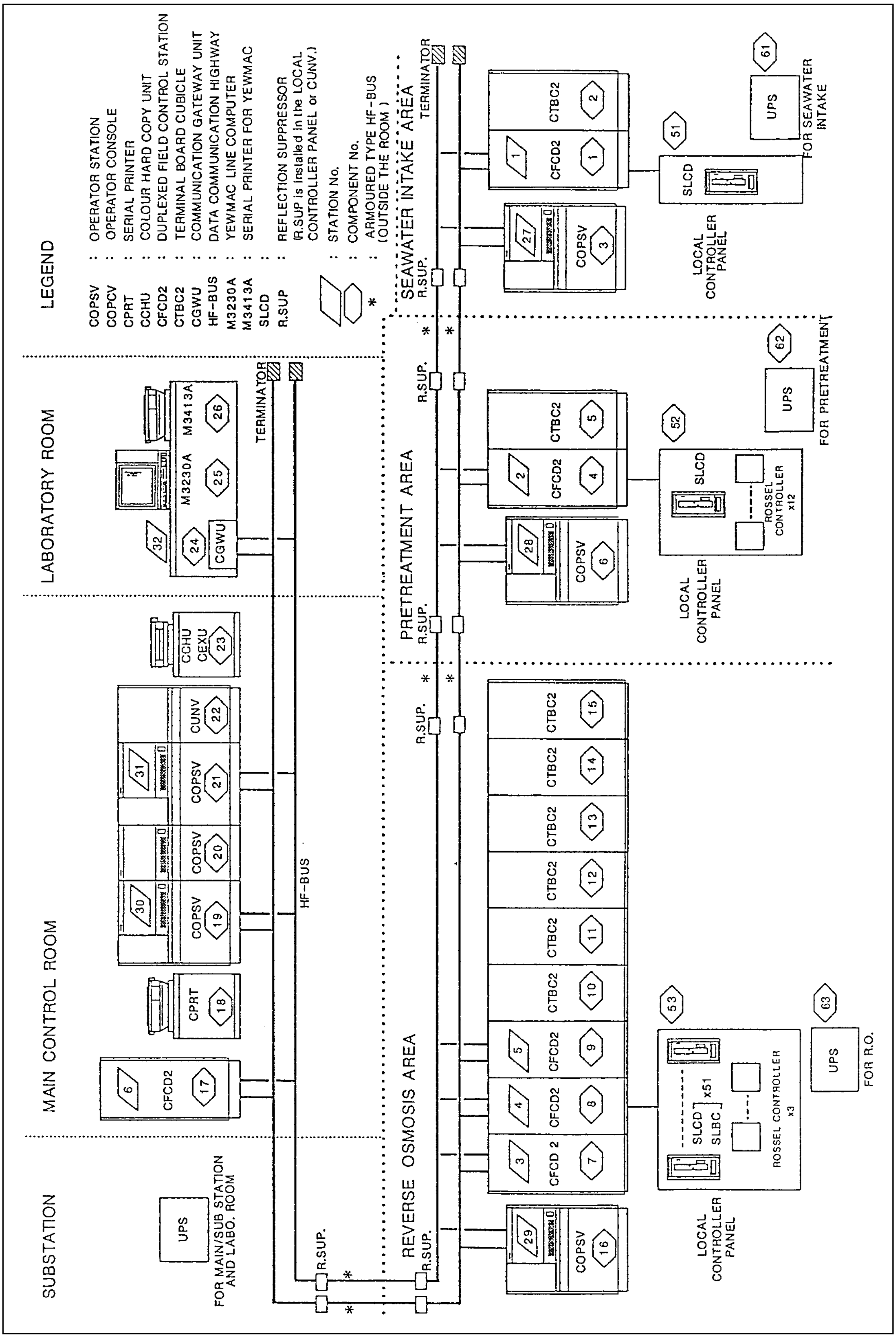

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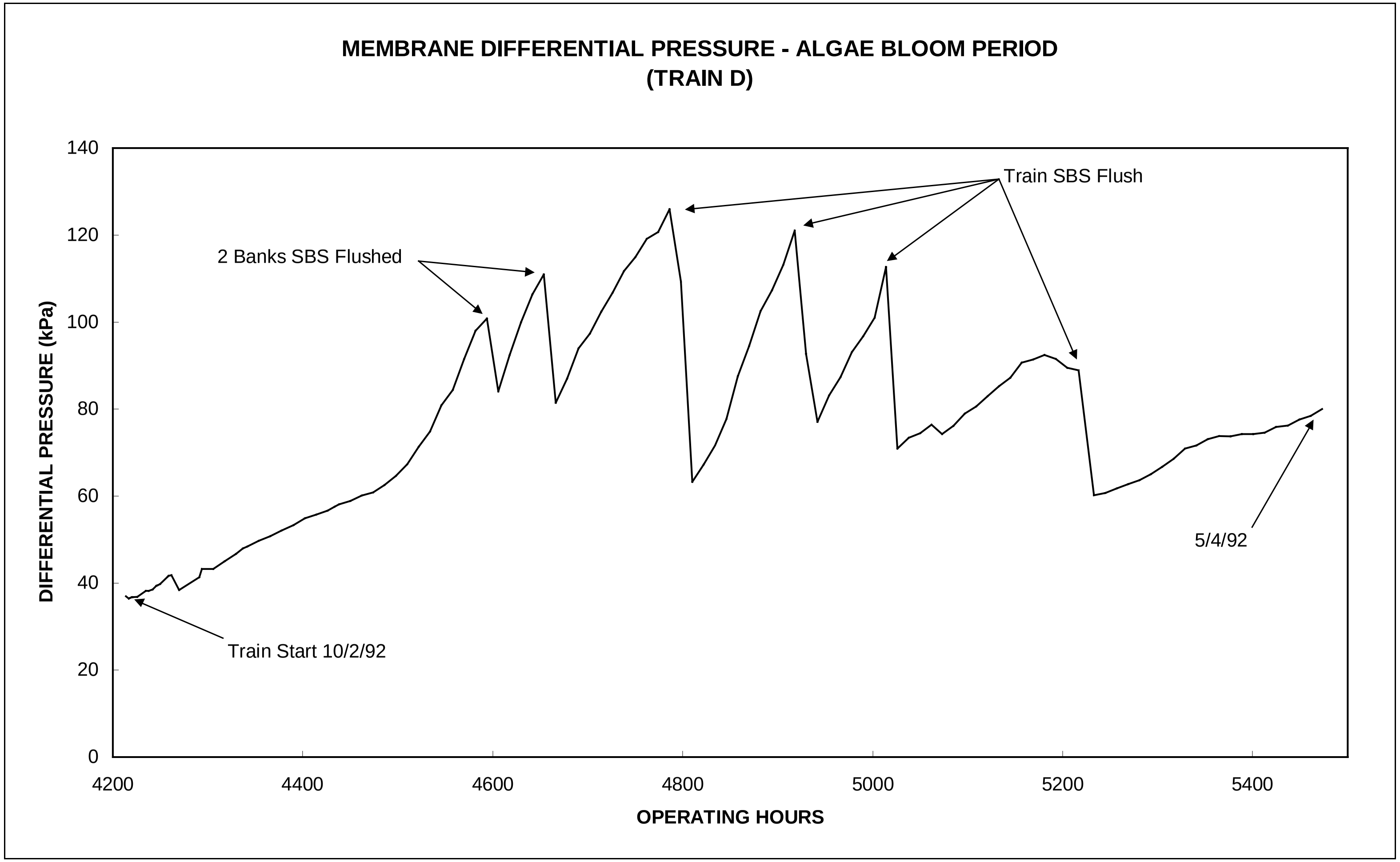


Figure 12: Biological Activity During Algae Bloom Period

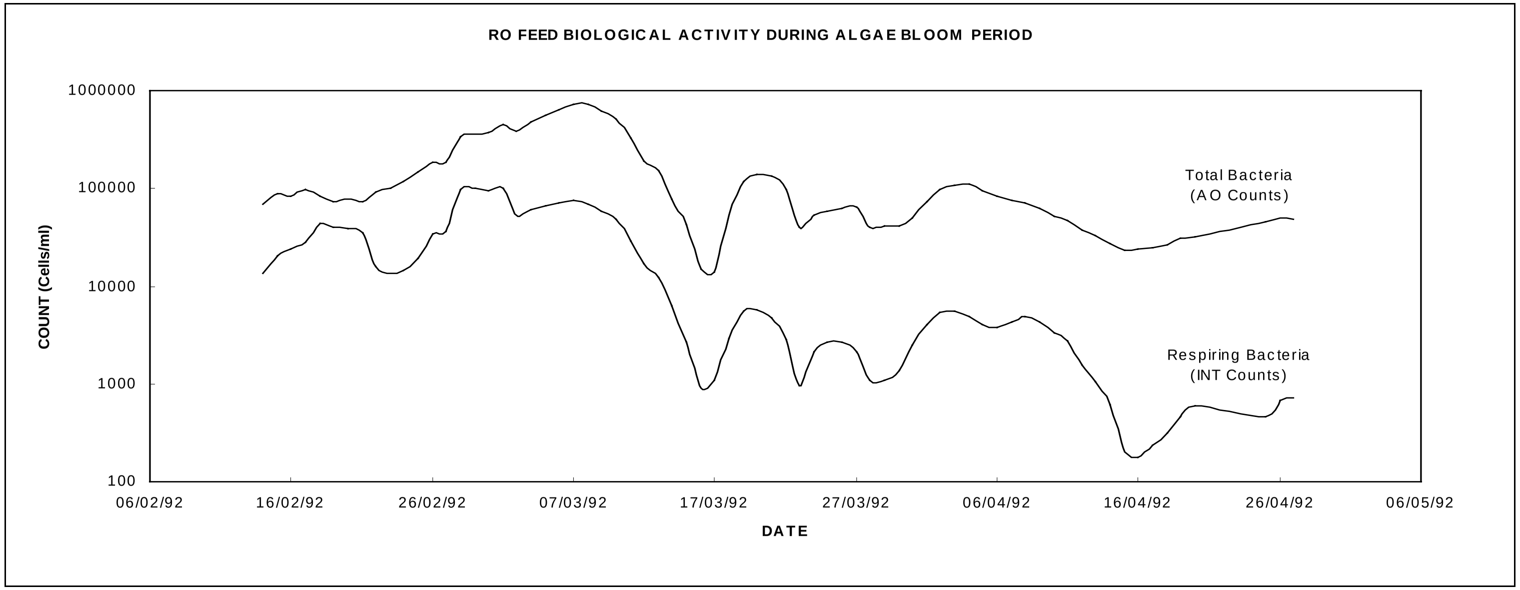


Figure 13: Feed TDS Versus Conductivity

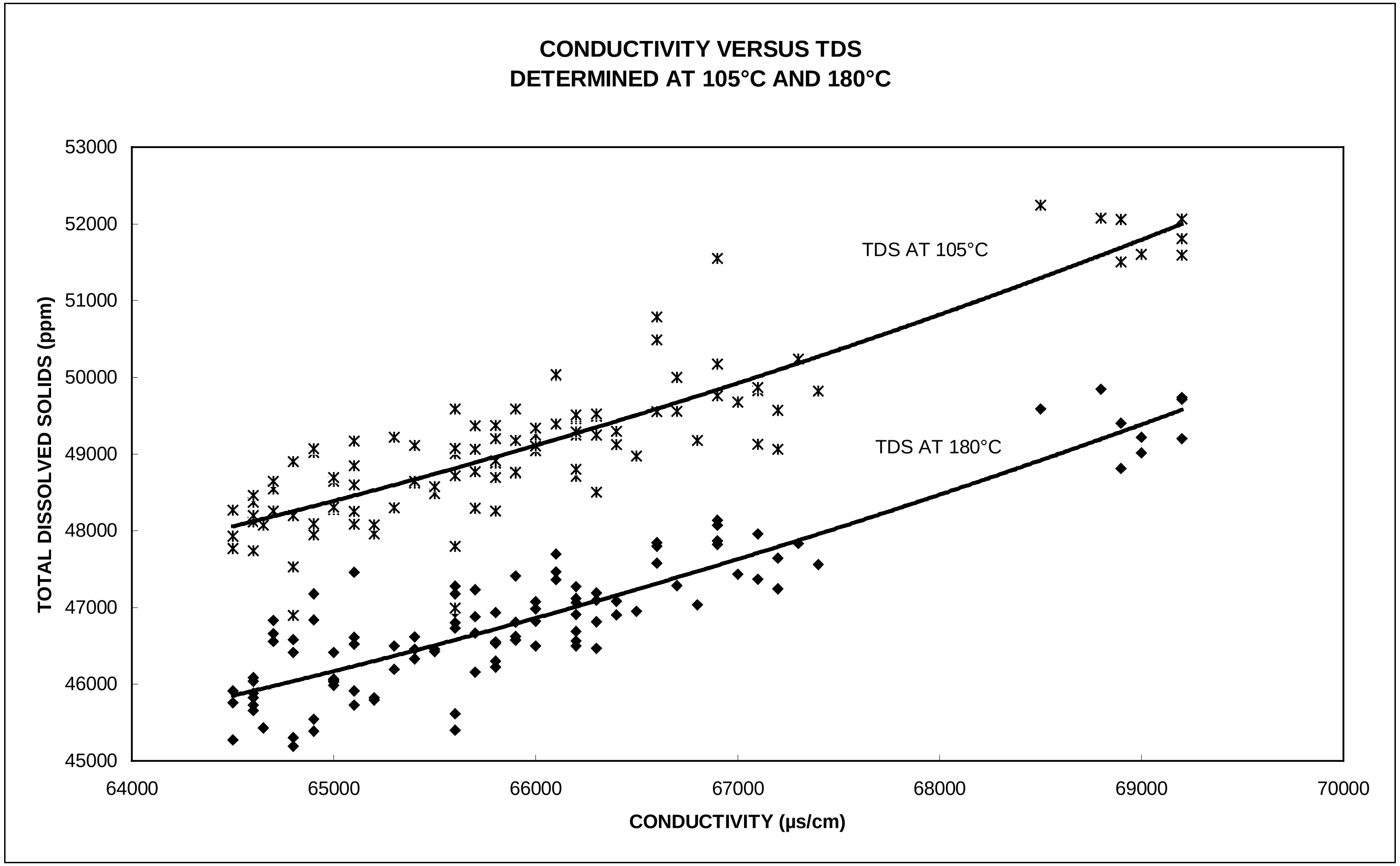


Figure 14: Typical First Pass Performance

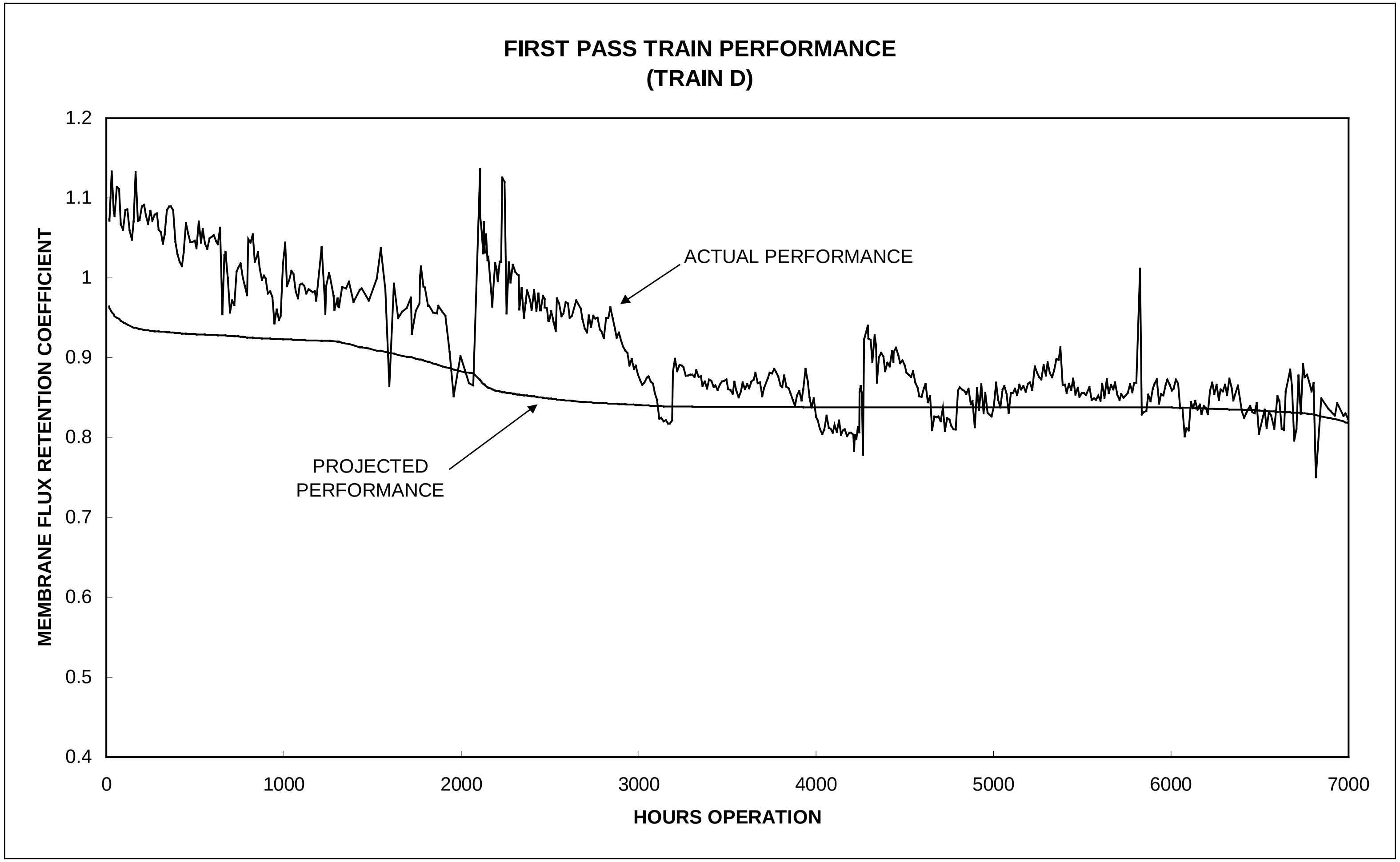
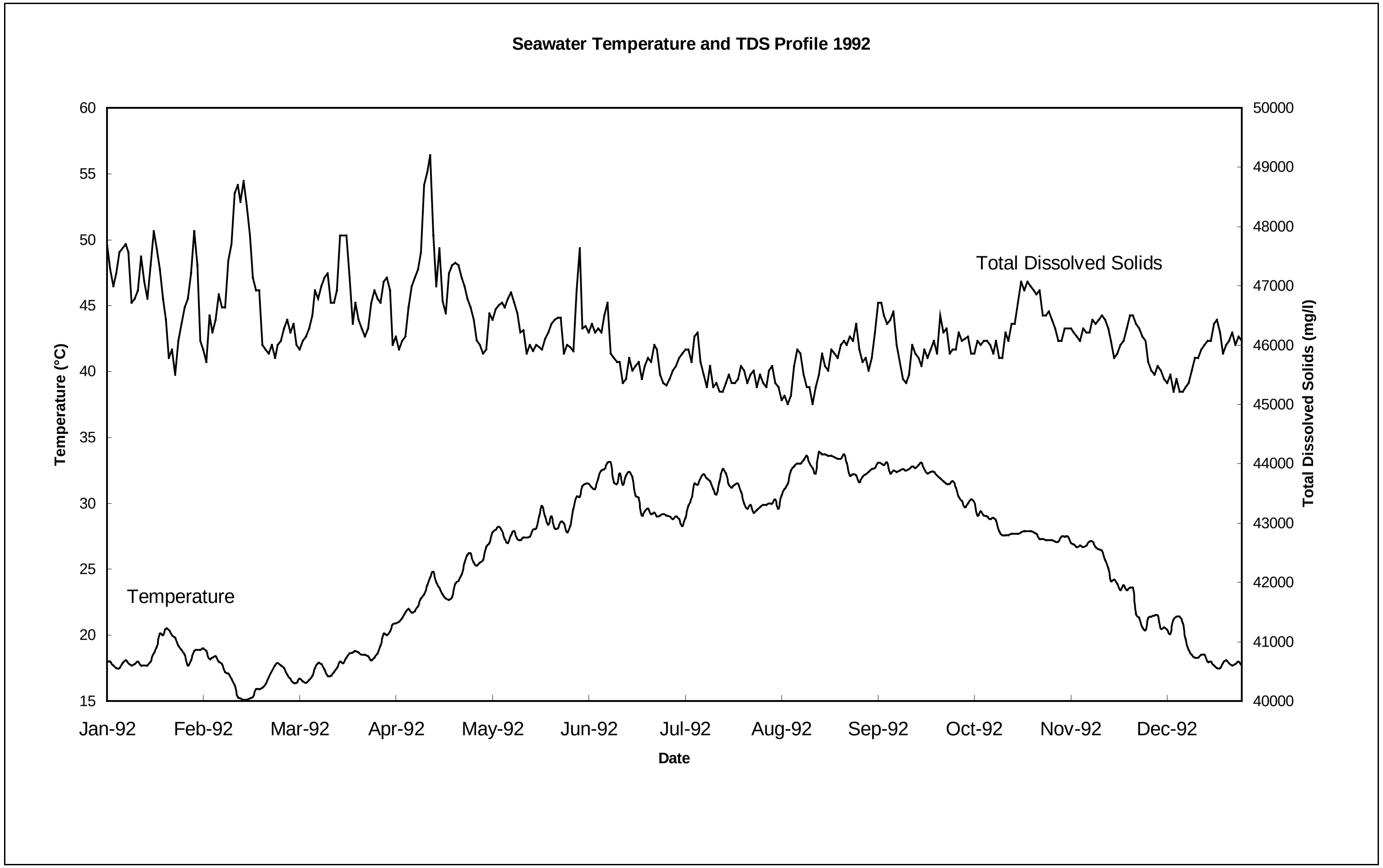


Figure 15: Seawater Temperature and Total Dissolved Solids Profiles – 1992



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Biography:

Peter Nicoll graduated from Glasgow University in 1985 with an honours degree in Mechanical Engineering and is a Chartered Mechanical Engineer. The early part of his career was spent with Weir Pumps as a Design Engineer. In 1989 he joined Weir Westgarth and since then has been involved in the design, commissioning and operation of large desalination plants in the Arabian Gulf, the Indian Subcontinent and the Far East. These have been of both the reverse osmosis and multi stage flash types, including the associated remineralisation plants. Mr Nicoll has held the positions of Design Manager, Project Manager and is currently the Sales Manager.