WSTA Sixth Gulf WATER Conference
In concurrence with
Second Symposium on Water Use Conservation
in the Kingdom of Saudi Arabia

The Ministry of Water
Kingdom of Saudi Arabia

Water Science and Technology
Association (WSTA)

Secretariat
General - GCC

CONFERENCE PROCEEDINGS
VOL . I I

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Under the Patronage of

H.R.H Prince ABDULAH BIN ABDULAZIZ AL SAUD

Crown Prince, Deputy Prime Minister and Head of the National Guard

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"Water in the GCC...Towards Sustainable Development"

8-12 March, 2003

Riyadh, Kingdom of Saudi Arabia

CONFERENCE PROCEEDINGS
Vol. II

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  - The Water Science and Technology Association (WSTA)
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In concurrence with

Second Symposium on Water Use Rationalization in the Kingdom

" Water in The GCC… Towards Sustainable Development"

8-12 March, Riyadh, Kingdom of Saudi Arabia

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TABLE OF CONTENTS
VOL.II

DESALINATED WATER

Desalinated Water

WSTA Sixth Gulf WATER Conference
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The First Successful Operation of a Single Stage Seawater RO Plant Exceeding 50% Recovery in the Middle East

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The First Successful Operation of a Single Stage Seawater RO Plant Exceeding 50% Recovery In The Middle East

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Abstract:

Development in membrane technology and competition among membrane manufacturers accelerated the modern Reverse Osmosis (RO) technology to reach higher recoveries. Higher recovery using single stage RO membrane has immense financial and technical benefits resulting in lower total water cost.

Seawater RO plants in the Middle East, were typically designed for a recovery of 35%-40% due to the high seawater salinity and high operating temperatures. This consequently impacted the economics, making total water cost in this arid, desalination dependent region high.

In line with several contributions to the desalination industry made through experience based applied research projects, Bushnak Water Group joined hands with Toyobo together to test single stage seawater desalination, at recovery exceeding 50%. This was made possible due to the graceful permission of Kindasa Water Services Company, pioneers in BOT/BOO concepts in Kingdom of Saudi Arabia, who permitted the installation of this pilot plant at their SWRO desalination Plant facility.

During the 10 months of continuous trial operation, the RO system maintained high performance, stable production and a remarkably low permeate conductivity at 50% recovery with seawater TDS of around 41,000 ppm. The differential pressure rise across the RO modules had been stable (less than 0.6 bars). To push this technology even further, recovery ratio was increased to 52%, and finally to 55% in the last one month of operation.

This successful demonstration of high product water recovery operation using SWRO technology will substantially reduce the total water production cost by about 20%. The membranes excellent performance entails lower energy consumption and smaller pre-treatment capacity requirement which assume greater significance in large scale RO plants.

1. **Introduction:**

Seawater Reverse Osmosis (SWRO) desalination process has many advantages from the viewpoints of saving energy, lower capital cost, short start-up & shutdown time, short construction period, less installation space and less total water cost . The RO has become a key technology of obtaining fresh water from the sea, especially in the Middle East. However, several membrane manufacturers are trying to develop membranes with higher water recovery, lesser energy and installation cost, in order to enable the RO process being recognized as the most popular method for supplying fresh water around the world. Toyobo developed a new type RO module for high water recovery in order to reduce the cost of RO desalination.

In a SWRO process, seawater is subjected to disinfection, coagulation-filtration and acidification process in the pretreatment section and forwarded as feed water to RO section. When the recovery ratio, which is the ratio of product flow rate to feed flow rate, is high the feed water requirement for a desired production is low and hence the pretreatment system chemicals cost, equipment sizing and the energy cost consequently goes down[1,2].

This paper describes the high recovery RO seawater desalination process and pilot plant performance data on the first successful operation of a single-stage RO test plant at recovery ratio exceeding 50% in the Middle East, between the period August 2001 and June 2002.

2. **General description of high recovery seawater RO desalination:**

In areas such as the Middle East where seawater has high salinity, commercial seawater RO desalination plants, due to high osmotic pressure of the seawater, were normally designed to operate at approximately 35% recovery ratio, since most of commercially available RO membrane, in the past did not allow high pressure operation above 7.0 MPa. Osmotic pressure of seawater in the Red Sea Coast is approximately 3.2MPa. In the case of operation with recovery ratio of 35%, the osmotic pressure of brine is around 4.8MPa in RO module, If the recovery ratio is raised to 50%, the osmotic pressure of brine increases to around 6.1MPa. Therefore, a higher feed pressure is required for high recovery operation in comparison with a conventional low recovery operation .In order to enable the high-recovery operation, the RO module shall be designed and manufactured to withstand high pressure.

3. **Features of the TOYOBO's HB series module used in pilot plant:**

TOYOBO's hollow fiber RO modules, HM type are widely used around the world in several RO desalination plants. Based on the operating experience and research efforts , TOYOBO developed a new high-pressure high-flux "HB-series" modules which are an improved version of their conventional HM type of module, made using the same materials [3-5]. The hollow fiber membrane in the "HB-series" module is wound in a cross arrangement, designed to minimize pressure loss and allow the uniform flow in the module. This cross-arrangement module is designed to provide a better tolerance to fouling matter in the feed water, because of this unique construction as shown in Fig.1. The fine hollow fiber of this HB series has high pressure resistance owing to design of hollow fiber dimension and optimization of manufacturing conditions.

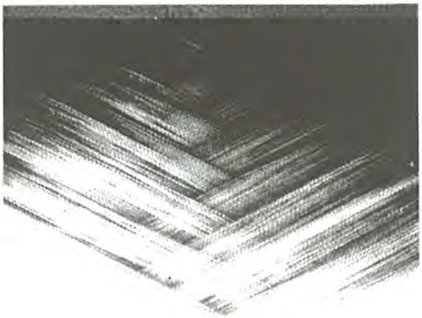

Figure 1. Cross arrangement of hollow fiber

4. High recovery process description:

4.1 High-pressure single-pass method for high recovery:

This high-pressure, single-pass desalination process with high recovery ratio was being applied to the SWRO test plant at Red Sea Coast in the Middle East for the first time, a detailed review of the process to be used for the test was carried out.

The "HB series" modules allow for high pressure operation, which enabled design of a RO system that could operate at high recovery. As shown in Fig.2, high recovery ratio operation can reduce the feed seawater flow rate around 30% compared with conventional system. Therefore, it makes possible to reduce construction and running cost of pretreatment process. In addition, energy can be recovered efficiently from high pressure brine by energy recovery turbine, therefore, energy consumption per cubic meter of water produced is also expected to be less compared to conventional process.

Single pass 1:1 brine staging system developed by Toyobo for high recovery, maintaining a suitable velocity on membrane surfaces within the module, was selected to be used for the pilot plant. In the 1:1 brine staging arrangement, the feed is admitted into the first module and the brine from the first module is admitted into the second module without further boosting the pressure. The permeate is produced in both the modules. Thus more percentage of feed water is converted into permeate. The system recovery is controlled by adjusting the brine control valve.

The described 1:1 brine staging system was adopted for the pilot test as there is no heavy fouling reported on the surface of the membrane in the module even when the high-pressure single-pass method is used at a high recovery ratio [6]. This was confirmed by simulation calculations by analyzing module performance[7,8]

As the osmotic pressure of the brine with recovery exceeding 50% is more than 6.1 MPa, a suitable reciprocating feed pump was selected to provide adequate feed pressure.

4.2 Intermittent Chlorine Injection Method:

RO plants with Toyobo membranes, operating in the Red Sea Coast, have successfully adopted intermittent chlorine injection (ICI) in the feed to the membranes, due their chlorine tolerance and successfully eliminated the bio-fouling in membranes [9]. There are two types of ICI being practiced. In first method, chlorine is continuously injected at the intake with de-chlorination is done for 23 hours and no de-chlorination for one hour thereby allowing chlorine to admit in to the membranes an hour once in a day. In the second method only chlorine is injected in to the feed water for an hour once in a day. The second ICI method not only reduces the chemical consumption, compared to continuous chlorination process, but also makes the process more environmental friendly as no disinfectant by-products are generated and discharged out of process continuously. Hence, it was decided to use the second ICI method for the pilot plant. In this test, the interval of injection time was proposed to be one hour in a day and was envisaged to be checked and adjusted during commissioning the pilot plant. The ICI dosing normally ranges from 0.3 to 0.4 ppm depending on chlorine demand, which is measured by checking the residual chlorine in the brine during chlorine dosing.

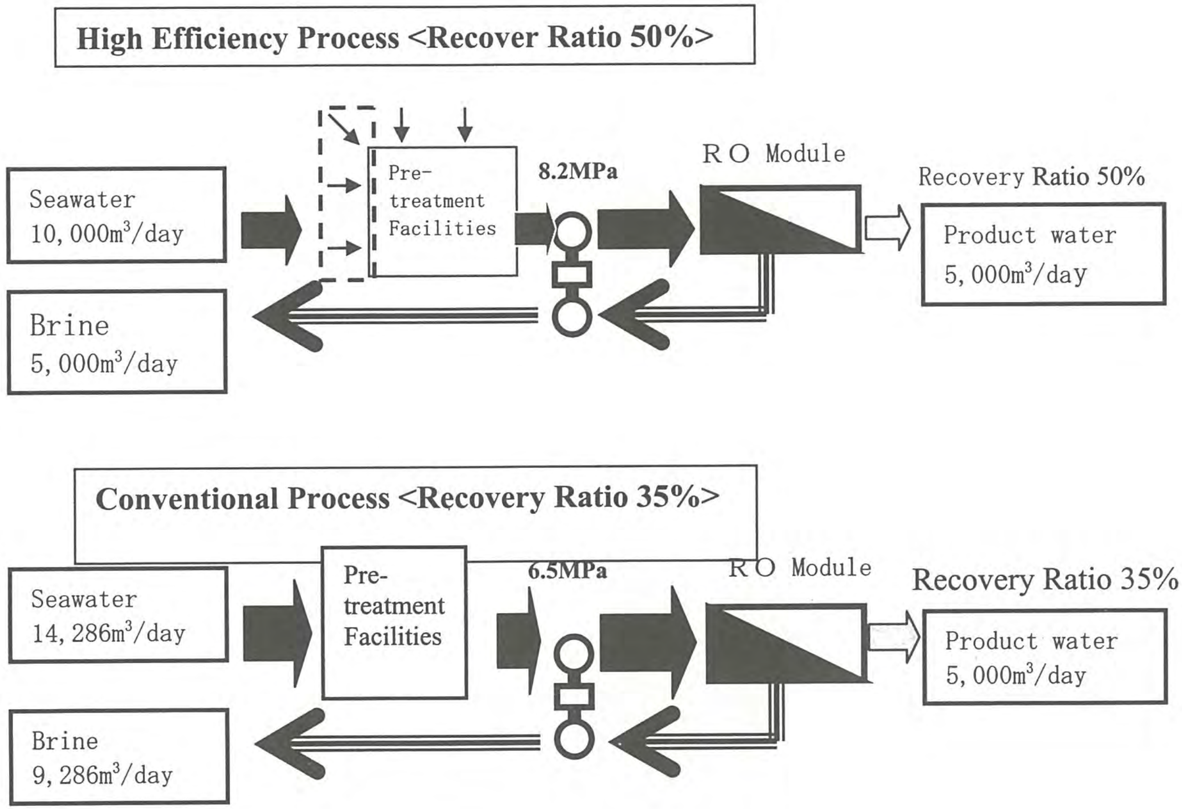

Figure 2. High efficient RO process/ 1 stage high recovery system

5. Pilot Test Unit set up at Kindasa Water Services (KWS):

The high recovery single-pass desalination test was conducted by using Toyobo's test unit DS-50RH. The specification and the flow diagram of the test unit DS-50RH are furnished in Table1 and Fig.3. The test unit was installed near KWS phase-A (14,000m^3/day) plant at Jeddah Islamic Port (JIP) in Saudi Arabia. The filtered seawater was supplied to feed seawater tank of the test unit from KWS Phase-A plant feed system. After pH adjustment by dosing sulfuric acid and chlorination by intermittent chlorine injection ,the filtered feed water was passed through a 5 micron cartridge filter before admitted into to RO modules. Four RO modules were used in this test unit. The modules were arranged in 1:1 brine staged array, as shown in Fig.3. TOYOBO's "HB9155FI" modules were used in the pilot test plant. The general specification of "HB9155FI" is furnished in Table 2.

Table 1 Specifications of TOYOBO HOLLOSEP RO DESALINATION UNIT,DS-50R

Production flow rate	35-40 m^3/day
Feed flow rate	75 m^3/day
Operation pressure	Max 8.3 MPa
Recovery ratio	48-55 %
Chemical dosing unit	Acid(H_2SO_4) & Chlorine($Ca(ClO)_2$)
RO membrane	4 modules (HB9155FI)
	(1:1reject series) x 2 lines

Table 2 General Specifications of TOYOBO HOLLOSEP HB9155FI Membrane

Material of membrane		Cellulose triacetate
Number of elements/vessel		1
Element size	Diameter	216mm
	Length	1025mm
Production flow rate	Minimum	22.5m^3/day
Salt rejection	Minimum	99.3%
Test conditions	Feed water(NaCl solution)	35,000mg/L
	Pressure	6.9MPa
	Temperature	25deg.C
	Recovery Ratio	35%
Operation conditions	Max. Pressure	8.2MPa
	Temperature	5-40deg.C
Feed water qualities	Fouling Index(SDI_{15})	less than 4
	pH	3-8
	Residual Chlorine	0-1.0 mg/L

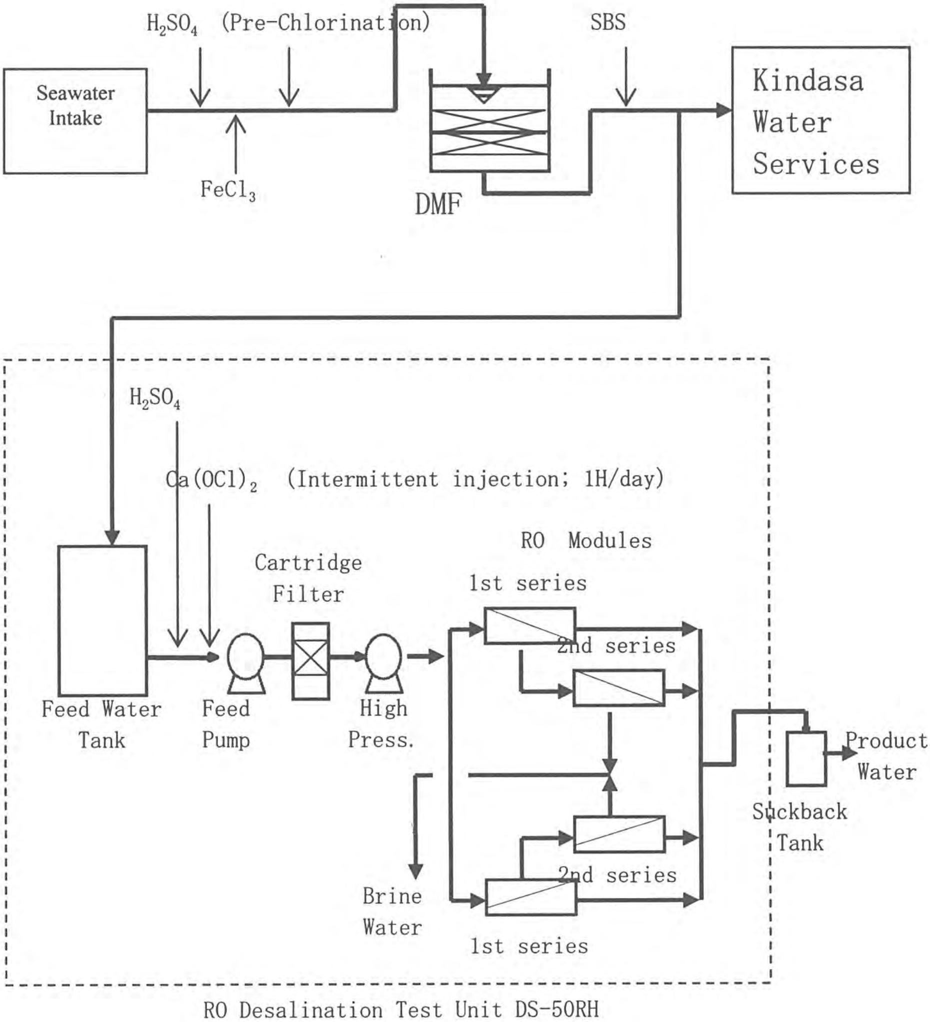

Figure 3 Flow diagram RO test unit DS-50RH

6. Operation Conditions and Test Results:

6.1 Operation conditions:

The test consisted of 4 phases operations as shown in Table 3. The first phase operational period was from August 8,2001 to November 8,2001, with a recovery ratio of 48% as trial test before 50% recovery test. The second phase was between November 9,2001 and March 18,2002 with 50% recovery. After 50% recovery operation, the two challenging tests with 52% and 55% recovery ratios were carried out. All the tests were carried out with the intermittent chlorine injection (ICI); 1hour injection in 24hour operation.

The characteristics of feed seawater, during the test period, is shown in Table 4. SDI_{15} ranged from 2.3 to 4.6. Residual chlorine level indicated in this table shows the value during the chlorine (ICI) injection period.

Fig.4 to 7 show the change in feed conductivity, SDI_{15}, pH and temperature of feed seawater during the test period. The feed conductivity could not be recorded from September 13,2001 to October 14,2001 due to conductivity probe damage.

Feed SDI_{15} value was sometimes more than 4.4, especially during January to February, after around 5 months operation, and in May after 9 months operation. The pH had been controlled within 6.2 to 6.6 after sulfuric acid injection started in the middle of August,2001 ,in order to prevent hydrolysis of cellulose triacetate membrane. Feed seawater temperature ranged from 24.8deg.C to 35.3deg.C,during the test period, and had been more than 28deg.C except in January and February,2002.

Table 3 Test Period and Recovery Ratio in Operation

Phase	1	2	3	4
Test Period	8.Aug.2001 to 8.Nov.2001	9.Nov.2001 to 18.Mar.2002	19.Mar.2002 to 31.Apr.2002	1.May.2002 to 1.Jun.2002
Operating time (hours)	2206	3072	1028	606
<Cumulative Time>	<2206>	<5278>	<6306>	<6912>
Recovery ratio (%)	48	50	53	55
Product Flow Rate (m^3/day)	35	38	40	41

Table 4 The Characteristic of Feed Seawater

	Phase	**Average**	Max.	Min.
Electric Conductivity	(μS/cm)	56,858	60,200	52,190
Temperature	(deg.C)	30.9	35.3	24.8
SDI_{15}	(-)	3.65	4.63	2.32
PH	(-)	6.5	7.2	6.2
Residual Chlorine*	(mg/L)	0.34	0.89	0.02

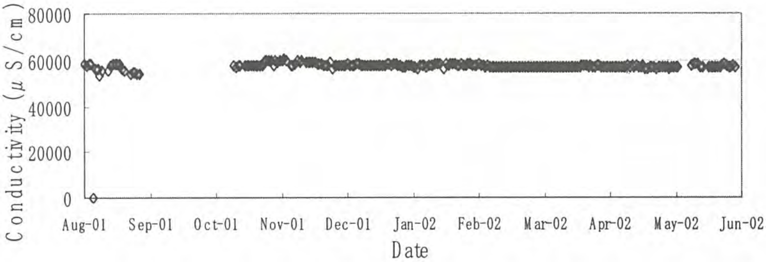

Figure 4 Conductivity of feed water

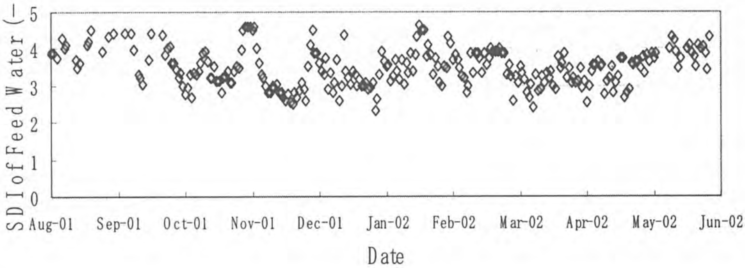

Figure 5 SDI of feed water

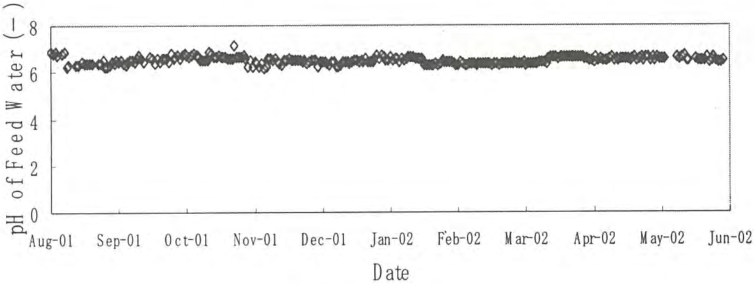

Figure 6 pH of feed water

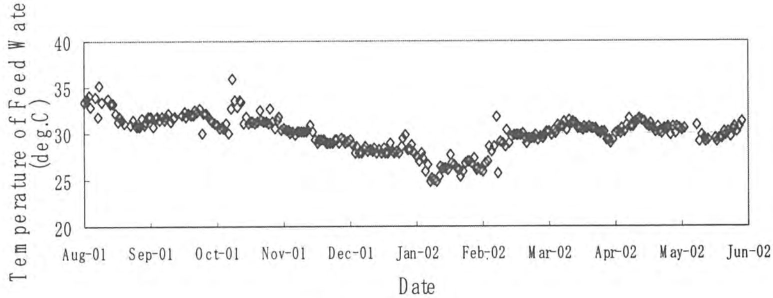

Figure 7 Temperature of feed water

6.2 Operation results of test plant:

Fig.8 and 9 show the change in feed pressure and recovery ratio respectively during the test period. Feed pressure had been stable ,however, increased moderately with increase in the recovery ratio from 48% to 55%.The change in chlorine concentration in the feed water to modules and change in differential pressure in the modules are shown in Fig.10 and 11 respectively. The chlorine concentration indicated in this figure corresponds to the values during the chlorine injection time ,which is during one hour ICI in a day. The chlorine concentration had been stable around 0.3-0.4 mg/L except few discontinuous values over 0.6mg/L . The differential pressure which was 0.032 MPa during initial commissioning had also been stable and remained below 0.06 MPa during the entire operation period. After about 6 months operation, however, the differential pressure increased rapidly to 0.055 MPa due to high SDI, which remained above 4 continuously. Chemical cleaning by citric acid solution was conducted in February,2002 in order to reduce the differential pressure across the hollow fiber membranes. After chemical cleaning, the differential pressure dropped from 0.055 MPa to 0.045 MPa and had remained almost stable. and was less than 0.06MPa during ten months operation. Inference from the results confirmed that cross arrangement of hollow fiber was effective in providing fouling tolerance to the membrane and the ICI method is also effective in preventing from bio-fouling.

Fig.12 and 13 show the variation in product flow rate and product conductivity recorded during the test period . The product flow rate had remained stable and increased with rise in recovery ratio. The product conductivity decreased due to natural compaction of the membrane at the beginning of operation. After one month operation, the product conductivity became stable and remained less than 300 micro S/cm, until it increased with rise in recovery ratio and temperature.

Normalized product flow rate and normalized product conductivity are shown in Fig.14 and 15. As shown in these figures, both normalized values of product flow and product conductivity had been stable. Test results proved that Toyobo RO module, HOLLOSEP “HB series” can be operated stably by single stage, at high recovery, more than 50% , in Red Sea Coast.

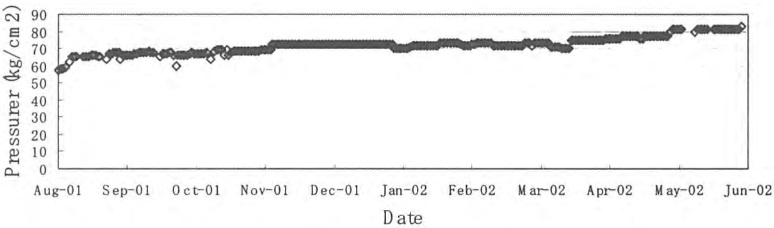

Figure 8 Change of feed pressure

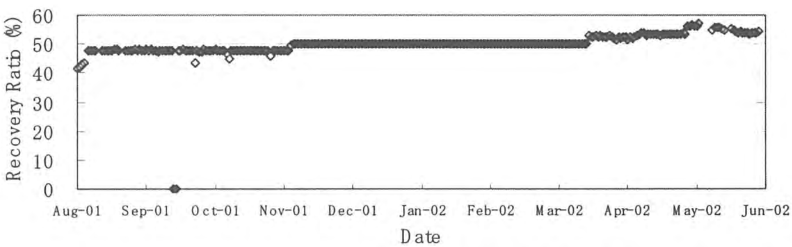

Figure 9 Change of recovery ratio

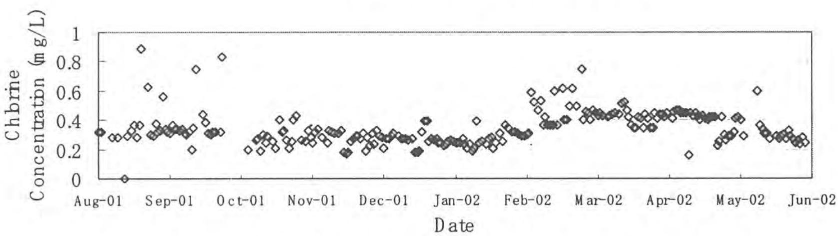

Figure 10 Change of residual chlorine concentration

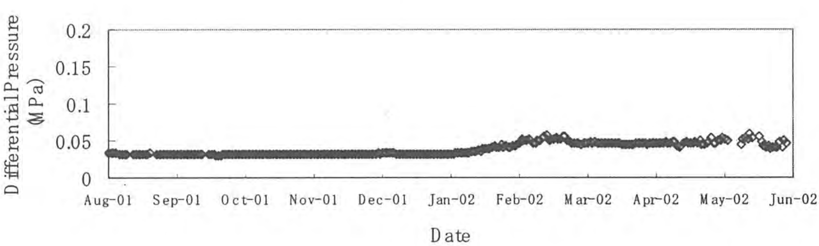

Figure 11 Change of differential pressure

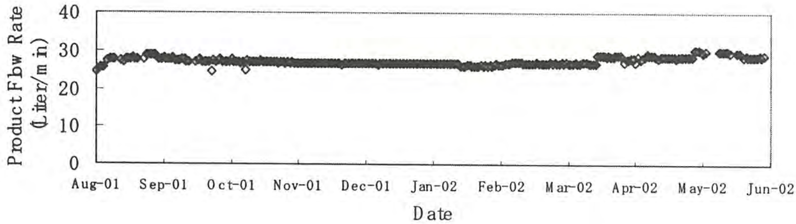

Figure 12 Change of product flow rate

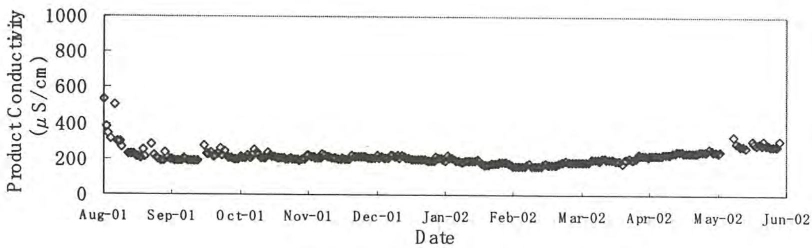

Figure 13 Change of product conductivity

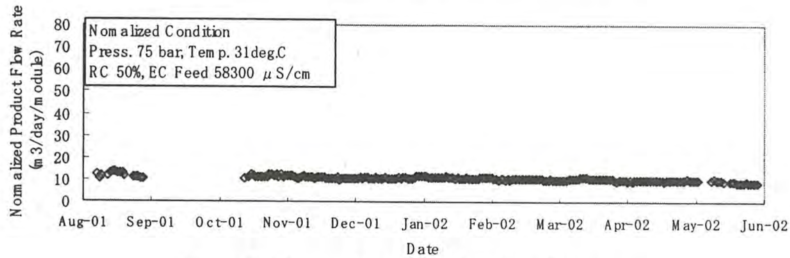

Figure 14 Change of normalized product flow rate

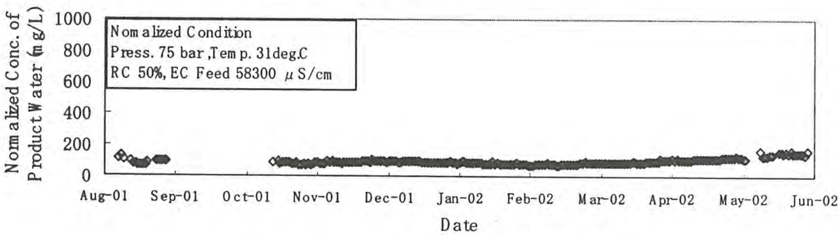

Figure 15 Change of normalized conc. of product water

7. Conclusions:

- Bushnak Water Group and Toyobo have succeeded in operating RO seawater desalination test plant at recovery exceeding 50%, in single stage, to desalinate high salinity and high temperature Red Seawater. TOYOBO's HOLLOSEP "HB series" membrane had proved successful operation at more than 50% recovery ratio in the Middle East.
- It was confirmed that both product flow rate and product conductivity were stable during the 10 months operating period, even at high recovery ratio of 52 and 55%.
- From the stable differential pressure operation and requirement of chemical cleaning only once during the 10 months operation, it is proved that cross arrangement of hollow fibre was effective in high fouling tolerance and the ICI method is effective in preventing bio-fouling.

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Operational Performance of 2 x 5000 m3/dayMSF Sidi Krir Desalination Plant- Part 1- Enhancement of Chemical Cleaning & B.H. Condensate Process

Dr. Hassan El-Banna Fath and Mohamed A. Ismail (Egypt)

Operational Performance of 2 x 5000 m3/day MSF Sidi Krir Desalination plant Part I

Enhancement of Chemical Cleaning & Brine Heater Condensate Process

By

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ABSTRACT

This paper discusses effect of the abnormal seawater carbonates concentration at the 2 x 5000 m3/day Multi Stage Flash (MSF) Sidi Krir desalination unit's site and the variation in scale grade in both (i) Brine Heater and (ii) Evaporator Condensers (water boxes). The negative side effects of combining the two heat transfer components in one acid cleaning circuit are discussed and the approach for separating the cleaning circuits of these two heat transfer components is presented. On the other hand, an indirect Brine Heater heating system; using a separate re-boiler, is proposed. The technical and economical advantages of these proposals are highlighted.

Key Words; Desalination, MSF, Performance, Scale, Chemical / Acid Cleaning.

INTRODUCTION

Sidi Krir power plant (2 x 325 MWe), located at the Mediterranean Sea (West coast of Alexandria, Egypt) has a 2 x 5000 m3/day MSF distillation units of brine re-circulation type. Each unit consists of 17 heat recovery stages and 3 heat rejection stages. Heating steam is delivered from the power plant's auxiliary boiler of a reduced pressure of 7-8 bars. More plant design specifications are given in Table (1). Being at the south coast of Mediterranean Sea, Sidi Krir MSF desalination units face a relatively higher sea water salinity and abnormal sea water concentration of carbonates. Such special concentration is mainly due to the geological structure of this coast, which is distinctive with high lime sediments, in addition to the minor effect of tidal and civil activities. Similar water analysis could be expected along the south Mediterranean Sea and in plants sites as Al Arish (Egypt) and Zilton and Derna (Libya). Table (2) shows the differences in concentrations between standard sea water and measured values at Sidi Krir site. As it known, such water concentration will be a main cause of scale deposits that significantly influences the unit operational performance. The intake system of these plants can not be improved (by conventional pre-treatment processes) and operation staff have to face and deal with this phenomenon and its side effect. This abnormal seawater concentration shows, therefore, its negative impact on the unit performance, specially the rate of acid cleaning required. The first part of this paper discusses effect of such abnormal seawater carbonates concentration on the plant operation The negative side effects of combining the two heat transfer components in one acid cleaning circuit are discussed and the approach for separating the cleaning circuits of these two heat transfer components is presented.

On the other hand, in Sidi Krir (as most of desalination plants), Brine Heater is supplied with high quality auxiliary steam from the main power plant circuit. A conductivity analyzer is installed in the condensate line to guarantee the high quality condensate return. There is always a possibility of condensate contamination (tubes leaks) with the malfunction of the analyzer. The operation staff may prefer to dump the condensate to sea (through a discharge line) in case of any doubts or irregular performance of the analyzer in order to avoid any disturbances in the power plant condenser if such condensate in returned back to the main plant condenser. The second part of this paper proposes, therefore, an indirect Brine Heater heating system; using a separate re-boiler, is proposed. The technical and economical advantages of these proposals are highlighted.

I- SCALE DEPOSITS & ACID CLEANING

A- Factor Affecting Scale Deposits

Scale deposits on the heating surfaces represents one of the major problems facing the operational performance in MSF distillation units . Dissolved salts such as Calcium Carbonate, Magnesium Chloride, Sodium Chloride and Calcium Sulfate are common seawater salts of different solubility. Presence of other salts often exerts a strong influence on the solubility. Different factors are considered as a prerequisites for scale deposit; i) presence of nucleation sites, ii) dissolved solids reaches its super saturation condition, and iii) reasonable retention time of solution inside the unit. Scale formation is also influenced by solution temperature, pH and fluid velocity (flow turbulence). Smooth heat transfer surface minimizes the presence of nucleation sites for scale deposits and crystallization. Higher flow velocity and enough turbulence (and less presence of stagnant pockets) also reduces scale deposition.

As saline water temperature increase, the solubility of some salts is lowered; hence super saturation is reached and is immediately followed by salt deposits. Solubility – temperature relationship is considered a prim controlling factor for creating super saturation and scale deposit conditions. It has been explained by the inverted solubility curve of the common dissolved solids in the saline water. Generally speaking, scale formation occurs more quickly in the tube sections of the high temperature such as Brine Heater and high temperature stages of the evaporator. Decreasing the system Top Brine Temperature (TBT) could improve the scale deposit situation, however, low TBT negatively influence the system performance and productivity (reduction in the flashing range). Designers have to strike the correct TBT that can technically and economically balance scale deposits, operational performance, capital and running costs.

The formation of alkaline scale (calcium carbonate and magnesium hydroxide) is considered to be a natural phenomenon in sea water distillation plants. High alkalinity (carbonate, bicarbonate and hydroxides) was recorded with such abnormal concentration along the Sidi Krir site coast, as indicated in Table (2). Six kg per cubic meter of hardness (expressed as calcium carbonate) require softening chemicals of almost the same order. For a 2x 5000 m3/day Sidi Krir (and large capacity) plant(s) this would consume several tons of softening chemicals per day and the cost of pre treatment chemicals and softening will be quite considerable and can not be economically justified. In addition, the pretreatment using Nano filtration has not, yet, proved technically and economically to be the alternative solution.

Another factor influencing the scale deposit, which is the solution pH. The solubility of calcium carbonate is determined by the solubility product of calcium and carbonate ions; i.e. c Ca x c CO3. Increasing the solution temperature deposits Calcium Carbonate (CaCO3) from its saturated solution). This situation occurs even if no carbon dioxide is lost and no evaporation takes place. In practice, however, the heating of saline water leads to loss of carbon dioxide from the water which in addition to the progressive increase in concentration (due to evaporation) enhances calcium carbonate deposits.

Scale formation indications are usually observed and monitored by ; (i) An increase in brine heater pressure and temperature, (ii) drop in TBT (increase in Brine Heater terminal temperature difference), (iii) Loss of distillate production (the rated distillate output can no longer be maintained under the same steam consumption), (iv) reduction in performance ratio (PR). Different techniques are implemented for scale prevention (or minimization) of Sidi Krir and most of desalination plants including; i) Design the unit temperatures and brine concentrations with minimum opportunity to form salts super-saturation solution before it leaves the unit, ii) partial removal of salts causing scale-formation from saline feed water (intake system) using softening (Ultra and/or Nano Filtration), specially for small units iii) Chemical additives (e.g. acids) which causes a decrease in pH, iv) Anti scalent additives that retards (or delays) scale deposition on heating surface (2.g. polyphosphate, Belgard EV-2000, ...etc), v) Mechanical cleaning (e.g. spongy balls, ...etc) and Chemical (Acid) cleaning to remove precipitated scale during operation., and finally, vi) Scheduled acid cleaning

B- Acid Cleaning

Scheduled acid cleaning process is used to remove accumulated alkaline scale of calcium carbonate (Ca CO3), and magnesium hydroxide (Mg (OH)2) during a specified period of operation. This process is accomplished by circulating a diluted acid solution through the loop to be cleaned. A good monitoring and operation of the scheduled acid cleaning is necessary to maintain a good plant performance and at the same time protect the heat transfer tubes from corrosion. As indicated before, scale formation would be more apparent in the brine heater (and the nearer stages of the evaporator condenser tubes) due to the higher saline water temperature, leading to reaching super saturation conditions. In addition, the danger of hard scale deposit may also be possible in such high temperature zones that increase the hardship of scale removal (In fact, inspection staff usually notice the presence of such high grade –hard- scale inside the brine heater tubes). In addition, some brine heater tubes blocking is observed, while the low temperature condenser tubes (and water boxes) are clean). These factors should be taken into consideration when acid cleaning process is applied.

A usual plant practice is to test a selective sample in the plant laboratory, in order to detect the minimum active acid concentration that can dissolve the scale (in an acceptable cleaning time) with tube corrosion protection. Table (3) shows a typical acid cleaning test results. The table indicates that the acceptable acide concentration Table (4) summarizes the acid cleaning process specification, while Table (5) summarizes the plant typical acid cleaning process specifications and procedure.

C- Enhancing Acid Cleaning Process

In most of desalination plants, design of acid cleaning circuits combine both (i) brine heater and (ii) evaporator condensers tubes in one integrated circuit. Figure (1) shows the conventional acid cleaning circuit, which incorporates both brine heater and condensers tubes.

Inserting the two heat transfer components in one acid cleaning circuit (same acid dilution and cleaning period) may lead to the deterioration of condenser tubes material which are usually made of lower grade alloy than Brine Heater tubes. Exposing the lower grades (and relatively clean condensers tubes) to the same cleaning process and rates as the (higher grade alloys and highly scaled) brine heater tubes, cause a higher chemical stress on condensers tubes, where a considerable copper ions (Cu^{++}) was recorder (> 5 ppm) although inhibitor is normally added.

A modification in acid cleaning circuit is therefore needed to prevent such chemical stress and maintain high unit performance (performance ratio - PR) and short unit outage (availability factor - AF). The proposed new approach separates the cleaning circuits of the brine heater and evaporator components as shown in Figure (2). The modification of the original system (compare Figures (1) & (2)) consists only of adding a Tee connection at the ball cleaning line. A few meters (2 m -10 m) 3.0 inches pipe line connects the Tee to the acid cleaning tank with an isolation valve. A blind flange will be installed at the line connecting the B. H. to the evaporator to isolate the B. H. from the evaporator. In this case we can have two circuits operates separately. In case B.H. is only needed to be cleaned, acid flow out from the B.H. will be forced to flow through the Tee to the acid cleaning tang (the blind flange will block the acid flow to the evaporator), as shown in Figure (2). In case both B. H. and evaporator are to be cleaned, the isolation valve is closed the and flow is forced to go as normal to the evaporator as shown in Figure (1).

The effect of the proposed approach in enhancing the acid cleaning process, as well as its technical and economical advantages could be obtained from Table (6). The advantages includes; (i) Low chemical consumption, (ii) Shorter outage time, which increases the unit availability and, therefore, production, (iii) protection of water boxes and condensers tubes against chemical stresses, and (iv) improving the performance of ball cleaning system. All these factors leads ultimately to lower water production cost.

II- HEATING STEAM TO BRINE HEATER

As previously indicated, the operation staff may prefer to dump the condensate to sea (through a discharge line) in case of any doubts or irregular performance of the analyzer in order to avoid any disturbances in the condenser if such condensate in returned back to the main plant condenser. In the last year, condensate dumping took place in about 70 % of the plant-operating time. Loss of Brine Heater condensate (600 m3/day) represents about (3000 $ of water + 1000 $ of heat = 4000 $) per day; i.e. 1.0 $ million per year.

In order to prevent or reduce such water and heat cost loss, an indirect Brine Heater heating steam system; using a separate re-boiler, is proposed. The proposed system would provide the B.H. with the required steam where its condensate is contained in a closed loop, separate from the main power plant steam. As conventional re-boilers used in the plant, auxiliary steam from the power plant will be used as a source of heat for the re-boiler. Figure (3) illustrates typical re-boilers used in Sidi Krir plant to provide 5.0 bars, 160 C saturated steam for different processes as (i) Mazout storage and transfer heaters, (ii) burners fuel heaters, and (iii) heat tracing piping steam.

Figure (4) illustrates the proposed re-boiler circuit for B. H. steam supply. For new plants, this circuit could be replaced by the proposed separate re-boilers system, as shown in Figure (5) or integrated with the re-boilers for other plant processes. Due to the location limitation in Sidi Krir, the circuit would be built separately and as near to the desalination units as possible. Similar to the other re-boilers circuits, the system will be designed to provide the B. H. with the required saturated steam at 7.0 bars, 205 C and 600 m3/day. Condensate from B. H. would be collected in the re-boiler condensate collection tank and (or directly) forwarded to the re-boiler feed tank by the re-boiler condensate transfer pump(s) (In the conventional re-boiler system, the unit condensate transfer pumps supply any shortfall in condensate tank requirements, in order to maintain the condensate level, through a level control system). Condensate is then pumped back to the re-boiler. The same auxiliary steam at 15 bar(g) and 275 C is supplied with the required flow rate to the new re-boiler as its heat source. The steam is then de-superheated to 213 C by a desuper heating system before it enters the tube side of the re-boiler. The auxiliary steam is condensed and the condensate is collected in the drain tank, Figure (10), then transferred to the main circuit by pressurizing the drain tank with the auxiliary steam (from the auxiliary steam header).

Table (6) summarizes the expected capital cost of the re-boiler system, while Table (7) summarizes the running cost and the pay back period of the newly proposed system. From these tables, it seems that the proposed system is economically feasible and its pay back period is only 7-8 months. This adds to the technical advantages of the proposed B. H. heating system of either (i) protecting the main power plant water quality or (ii) water and energy loss of dumping B.H condensate to the sea..

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Table (1) Technical Specifications of Sidi Krir 2 x 5000 m3/day MSF Desalination Plant

Parameter	Valur (Remark)
No. of Units	2
Unit Capacity	5000 m3/day
No. of Stages	20 (17 + 3)
Designed PR	8 kg (PW) / kg (steam)
TBT	110 C
Seawater Temp.	27 C
Heating Steam Temp.	117 C
Cooling Water Flow Rate	1570 m3/hr
Brine Recirculation Flow Rate	1850 m3/hr
Seawater Concentration	43900 ppm
Brine Concentration	63000 ppm
PW Quality	25 ppm
Method of Scale Control	High Temp. Additives (Belgard EV 2000)
Tube Sheet Material (BH + Condensers)	90 / 10 Cooper Nickel
Condensers Tubes	90 / 10 Cooper Nickel
Brine Heater Tubes	70 / 30 Cooper Nickel
Water Box (BH + Condensers)	90 / 10 Cooper Nickel

Table (2) Sidi Krir Site Sea Water Concentration

Item	Site	Standard	Difference (%)
Na Cl	23000	23476	- 476 (- 2 %)
Mg Cl	5800	4981	819 (16.4 %)
$Na_2 SO_4$	4420	3917	503 (12.8 %)
$Ca Cl_2$	1260	1102	158 (14.3 %)
K Cl	800	664	136 (20.5 %)
Alkalinity ($Ca CO_3$)	290	192	98 (51 %)
TDS	43,900	34,480	9,420 (27.3 %)

Table (3) Acid Cleaning Laboratory Test Results

Sample Weight (gm)	2.5	2.5	2.5	2.5	2.5
Acid Solution Volume (mL)	100	100	100	100	100
Acid Solution %	0.5	1.0	1.5	2.0	2.5
Duration Time (Hr)	12	12	12	12	12
PH (Strat)	1.1	0.85	0.3	0.15	<0.1
PH (Final)	1.8	1.4	0.85	0.4	0.15
Solubility (%)	10	10	100	100	100

Table (4) Specification & Procedure of Acid Cleaning Process

Specifications Circuit Volume = 67 m3 Concentration of Acid Cleaning Solution = 1.5 % Concentration of Inhibitor Circuit = 0.2 % Recirculation Max. Duration Time = 24 hours
Procedure - Unit shut down and cool down - Investigate of scale formation in condensers and take samples and photos - Prepare acid concentration required and the acid cleaning circuit - Recirculate the acid solution through the cleaning circuit for the specified period - Monitor the circuit main parameters (pH, HCl, T.H., Cu+, …) during the cleaning process till a constant values are obtained (at the end of the cleaning process, pH should be less than 1.0 to indicate active acid can react with more scale) - Neutralization and drain the circuit - Perform post cleaning inspection

Table (5) Comparison Between Present and Modified Acid Cleaning Circuits

Item	Present	Modified
Circuit Volume (m3)	67	8
Acid Consumption (Liters) (37 % Concentration)	3 000	400
Inhibitor Consumption (Liter)	150	20
Neutralization Caustic Soda (Lit) (50 % Concentration)	1500	200
Outage Time (Days)	3	1
Chemicals Cost (USD), (1)	1,250	220
Cost of PW Loss During Cleaning (USD), (2)	18,000	6000
Total Cost (1) + (2)	**19,250**	**6220**

Table (6) Estimating Capital Cost of Sidi Krir Reboiler System

Item	Cost ($)
Aux. Reboiler Heater (A,B) Feed + Condensate Pumps (A,B) Drain + Feed Tanks Furnishing Pipes + Insulation Furnishing Equipment	365,859 35,220 123,562 20,000 61,000
Total	**605,641**
Pay Back Period = Total Cost / Annual saving = 605,641 / 1000,000	**7 – 8 months**

Table(7) Reboiler System Running Cost

Item	Cost ($)
Pumps Power (Feed =24 kW, Condensate=10 kW) = (24+10) kW x24 hrs/ day x 365 day/year x 0.02 $./kWhrs)	 5,957
Capital Installment (Annuity) = 605,641 [$(1+.06)^{25}$] / 25	77,695
Total	**83,652**

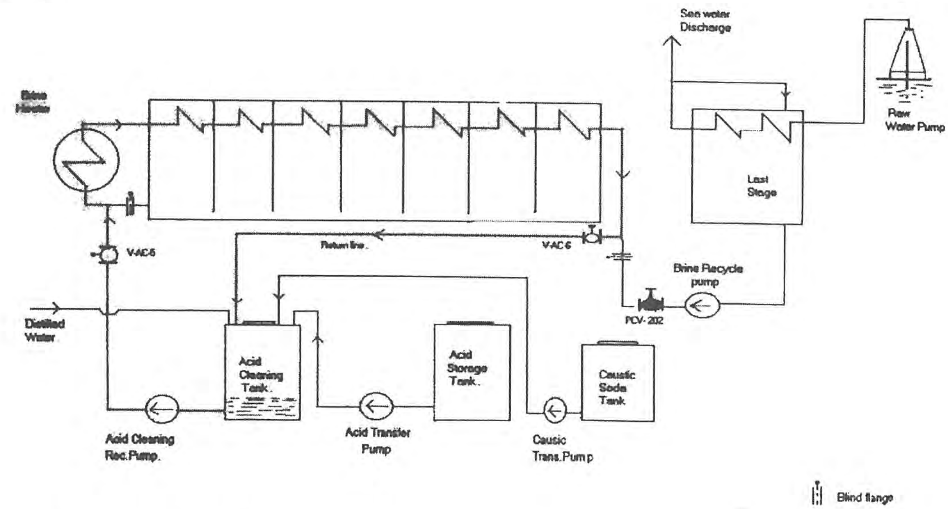


Figure (1) Conventional Complete Circuit (Brine Heater+Condensers)

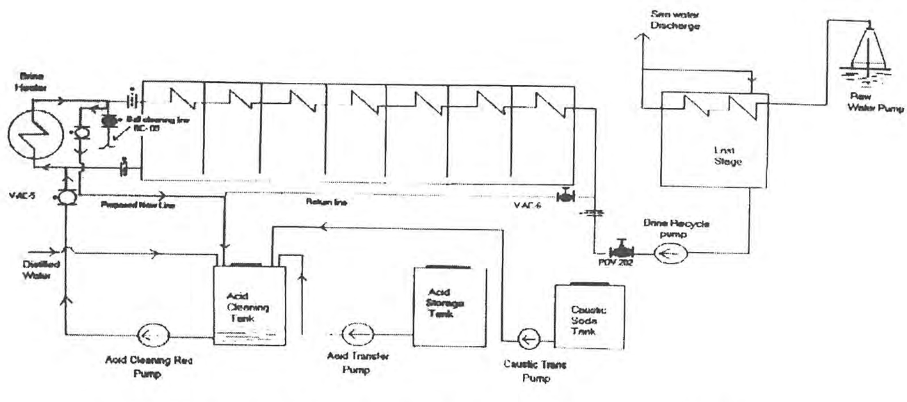
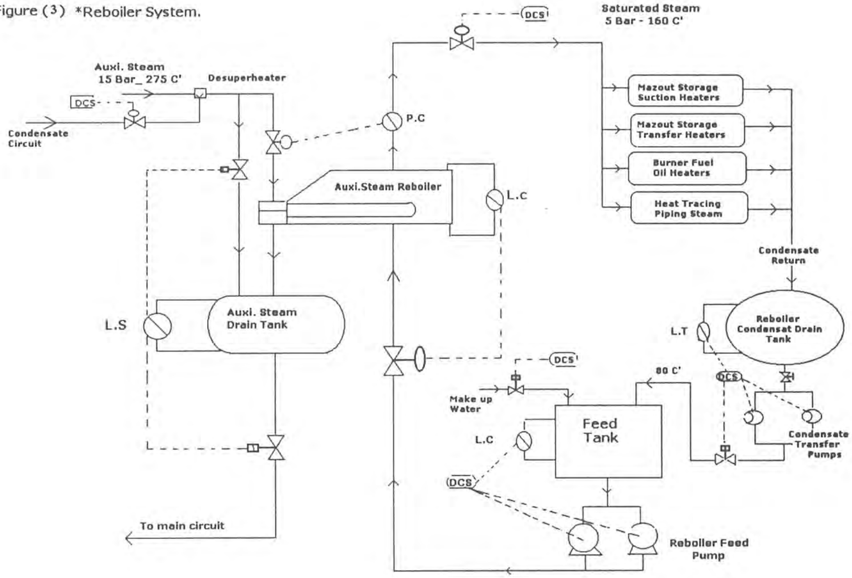


Figure (2) The proposed Modified Acid Cleaning Circuit

Figure (3) *Reboiler System.



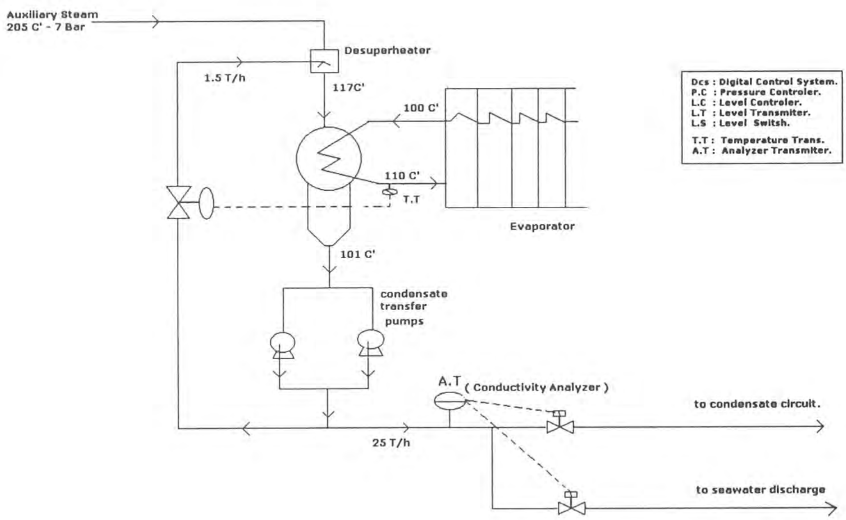
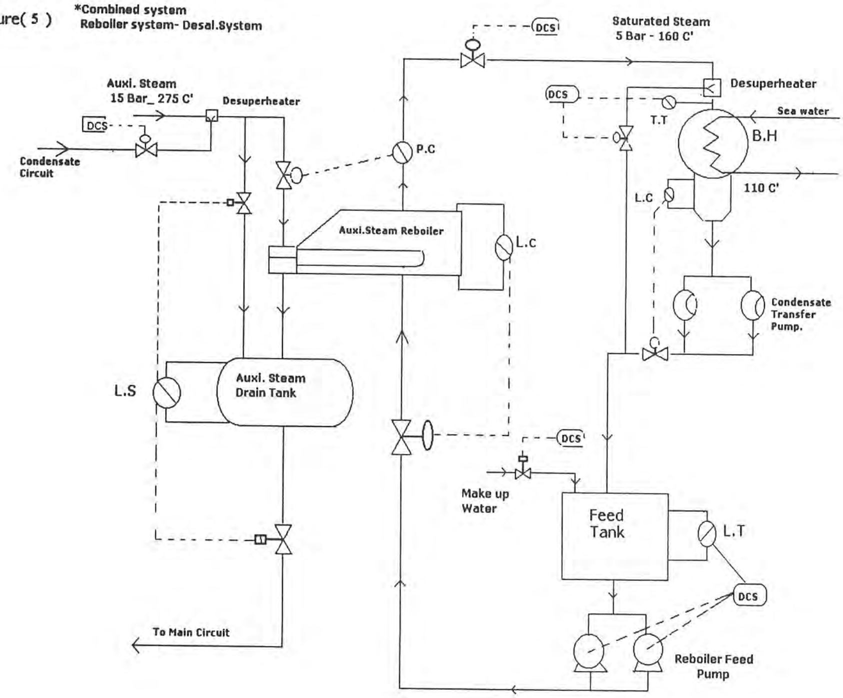


Figure (4) *Brine Heater And Its Condensate System

Figure(5) *Combined system
Reboiler system- Desal.System



Investigation of the Re-circulation of Effluent Discharge at Umm Al Nar Power and Desalination Plant

Dr. Khaled A. Mohamed and Mohamed El-Dahshan (U.A.E.)

Investigation of the Recirculation of Effluent Discharges At Umm Al Nar Power and Desalination Plant

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ABSTRACT

Umm Al Nar Power and Desalination Plant is one of the main plants, which produce power and electricity in Abu Dhabi Emirate. The plant has been built in Umm Al Nar Island, which is a small island located inside the inner water North of Abu Dhabi Island. It was decided by Abu Dhabi Water and Electricity Authority (ADWEA) to extend the capacity of the plant. A hydrodynamic study was carried out to investigate the feasibility of increasing the plant capacity. The study comprised field measurements and the application of a two dimension horizontal hydrodynamic numerical flow model. The model was calibrated and verified with the prototype data and covers the tidal waters around Abu Dhabi Island, adjacent lagoons on both sides and adjacent part of the Arabian Gulf. The intake and outfall of the plant was simulated in the model. Since the recirculation of salinity and temperature is the main factor affects the plant efficiency, a comprehensive recirculation study has been carried out to investigate the excess temperature and salinity, which may occur at the intake due to the plant extension. The paper describes the tidal system around Abu Dhabi Island where the plant is located. It also describes the plant and the proposed extension and presents the hydrodynamic model used in the study. The paper presents and discusses the computational results on the recirculation study.

Keywords: Tides, Hydrodynamic models, Effluent discharge, Recirculation, Residual flow

1. INTRODUCTION

Umm al Nar Power and desalination Plant was built in the mid-eighties. It is located inside a lagoon east of Abu Dhabi Island. Figure 1 shows the location of Umm Al Nar plant within the extensive system of interconnected lagoons along the Arabian Gulf of Abu Dhabi. The latitude of the area is 24.75 degrees. A brief description of the tidal system around Abu Dhabi Island is presented in Section 2.

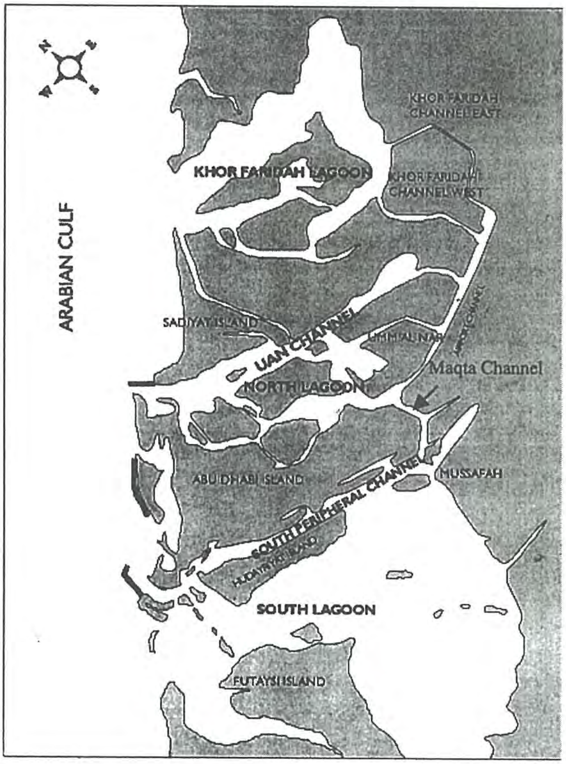

Figure 1: Location of Umm Al Nar Island within the Abu Dhabi Lagoon System

A calibrated and verified two dimension horizontal hydrodynamic model simulates the tidal motion around Abu Dhabi Island was developed. The model is used to determine the recirculation of salinity and temperature from the plant outfall to the intake. Model computations were carried out for the existing situation and after the proposed plant extension. The effect of the plant extension on the recirculation processes was obtained by comparing the model results for the situations before and after the proposed capacity extension.

The tidal system around Abu Dhabi Island is described in Section 2 and Umm Al Nar Plant in Section 3. The hydrodynamic model is presented in Section 4 and model calibration and verification in Section 5. Model computations are presented in Section 6 and model results in Section 7. Conclusions are presented in Section 8.

2. DESCRIPTION OF THE TIDAL SYSTEM

Abu Dhabi Island is surrounded by complex and unique tidal system. The inner waters around Abu Dhabi Island are fed from the Arabian Gulf through two main deep channels, which are UAN channel in the North Lagoon passing Mina Zayed and South Peripheral Channel (see Figure 1). They are interconnected through Maqta channel. This system is further interconnected to Khor Faridah Lagoon in the north east and to South Lagoon in the south west (see Figure 1). Umm Al Nar Power and Desalination Plant is built on Umm Al Nar Island, which is located within the complex tidal system.

The tide in this part of the Arabian Gulf is of mixed, predominately semi-diurnal but with a significant diurnal component. The tidal wave approaches the coast obliquely, with a direction of propagation along the coast from south to north. It first enters into Khor Faridah lagoon, a few minutes later into North Lagoon (the channel at Mina Zayed) and another few minutes into South Peripheral Channel and South Lagoon, respectively [1].

The tidal wave deforms when propagates inside the lagoons. The rate of deformation depends to large extent on the geometry of the channels and lagoon system (i.e. cross sections, tidal flats and bed roughness).

The meeting point of the tow tidal waves, approaching through UAN Channel and South Peripheral Channel is located nearby Maqta Channel and Umm Al Nar. The location of this meeting point, the deformation of the tidal wave in both systems and the interaction with the Khor Faridah and South Lagoon systems are the factors governing the generation of residual flow and hence long-term water circulation and dissipation patterns within the lagoons and to/from the sea. Any significant change in the geometry of a channel of the Northern or Southern Lagoon systems will effect the propagation of the tidal wave and hence the mutual effect of interconnecting lagoons, location of meeting point(s) and long-term residual flow.

3. UMM AL NAR POWER AND DESALINATION PLANT

Umm Al Nar Power and Desalination Plant is located inside the North Lagoon east of Abu Dhabi Island. The location of the plant and its intakes and outfalls are shown in Figure 2. To minimize the direct recirculation of heat and salt, a long path is created by building the plant's intakes and outfalls on opposite sites of Umm Al Nar Island. The plant capacity is 1000 Mega Watt (MW) power and 98 Million Gallon per day (MGID) of distillate water. The plant extracts the water needed for desalination and power production from the North Lagoon through the intakes and discharges the effluents back to the lagoon through the outfalls. The effluent discharge has a higher concentration of heat and salt due to the desalination and power production processes. A recirculation with higher salinity and temperature may occur from the plant outfalls to its intakes leading to less plant efficiency. The plant vicinity is relatively shallow and healthy mangroves are located nearby the plant. In the existing situation the intakes and outfalls discharges are 109 and 104 m^3/s, respectively. The admissible excess temperature and salinity above ambient water at the plant outfalls are 5.7C and 2.5 ppt, respectively.

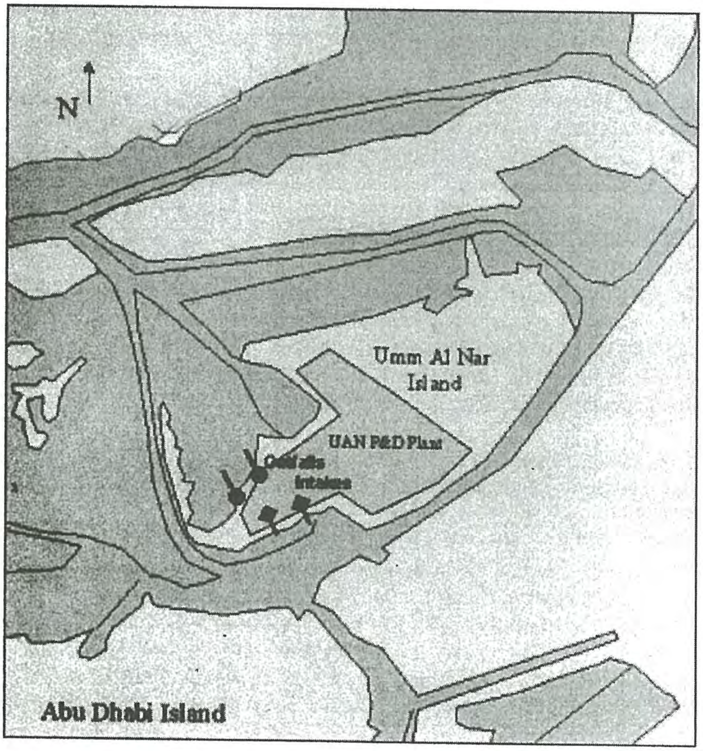

Figure 2: Location of the Intakes and outfalls of Umm Al Nar Plant

4. THE HYDRODYNAMIC MODEL

In the presence of large deep channels and gullies, with relatively high flow velocities and effective mixing, no or hardly stratification can be expected within the lagoon system around Abu Dhabi Island. The field observations, which were carried out in April 2000 have confirmed this [2,3], showing more or less uniform vertical distribution of salinity and temperature all over the area, except in the vicinity of the plant outfall. It was therefore concluded that it is accurate enough to apply the two dimension model in studying the transport and dispersion of heat and salinity loads produced by the plant and discharged through its outfalls.

A 2-dimension horizontal hydrodynamic flow model, which was developed by Delft 3D software package of Delft Hydraulics, is available in the Hydraulic lab of ADWEA Research Center. Figure 3 shows the computational grid of the model.

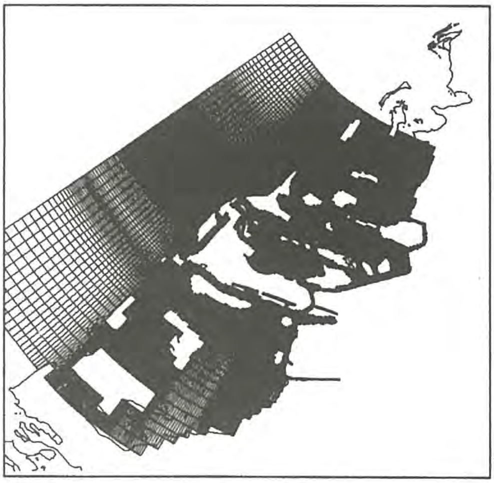

Figure 3: The hydrodynamic model grid

The model covers Abu Dhabi Island, adjacent lagoons on both sides and a part of the Arabian Gulf. The model uses curvi-linear coordinates, which enables a refinement of the grid cells in the area of interest. The grid size varies from about 1500 m at open boundaries to about 70 m in the narrow channels and inner waters around Abu Dhabi Island. The total number of grid cells is 173 x 228, with approximately 20000 active cells. As it can be seen from Figure 3, the highest grid resolution is in the inner waters around Abu Dhabi Island and in the deep channels, which feed the lagoon system (see Figure 1). Highest resolution in this area enables an accurate prediction of the hydrodynamic forcing and recirculation process of effluent discharges from the Umm Al Nar Power and Desalination Plant, which is located inside the North Lagoon, where the highest grid resolution was made. The orthogonality and smoothness of the computational grid were considered and satisfied the numerical requirements.

5. MODEL CALIBRATION AND VERIFICATION

The model was updated and recalibrated based on the comparison of the model results with the pre-processed measurement data. The calibration of the tidal motion was carried out in the frequency domain by comparing the computed and observed tidal constants of water level at several monitoring stations covering the model area. This procedure requires a model simulation of at least one month period to allow for a tidal analysis of the model results to determine the sets of tidal constants of the simulation [2,3]. These constants were compared with the sets of tidal constants of the monitoring stations in the model area. The correct representation of the amplitudes and phases of the tidal wave implies that the tidal character as a whole is well represented independent of springs and neaps. Table 1 summarizes the hydrodynamic calibration results for water level stations for the main 4 astronomical tidal constituents M2, S2, K1 and O1. The absolute mean tidal amplitude differences of the four constituents are 0.03m or less, and the absolute mean phase differences are lower than 5^o, which is considered as a very good results

Table 1 Model performance at 10 water level stations

Hc = computed amplitude Ho = observed amplitude Gc= computed phase Go= observed phase	O1	K1	M2	S2
Mean Hc-Ho	-0.003	-0.017	-0.017	0.000
Abs. Mean |Hc-Ho|	0.011	0.017	0.026	0.010
RMS err. Hc-Ho	0.016	0.021	0.034	0.013
Mean Hc/Ho	0.988	1.062	1.048	1.003
Mean Gc-Go	-0.7	-3.4	-0.6	-2.7
Abs. Mean |Gc-Go|	4.5	4.5	2.6	3.0
RMS err. Gc-Go	6.1	5.3	3.8	4.3

Computed and observed current velocities and discharges were compared with each others for locations South Peripheral channels, in Maqta Channel and at Mina Zayed. Good results are obtained at all locations, as it can be seen in Figure 4.

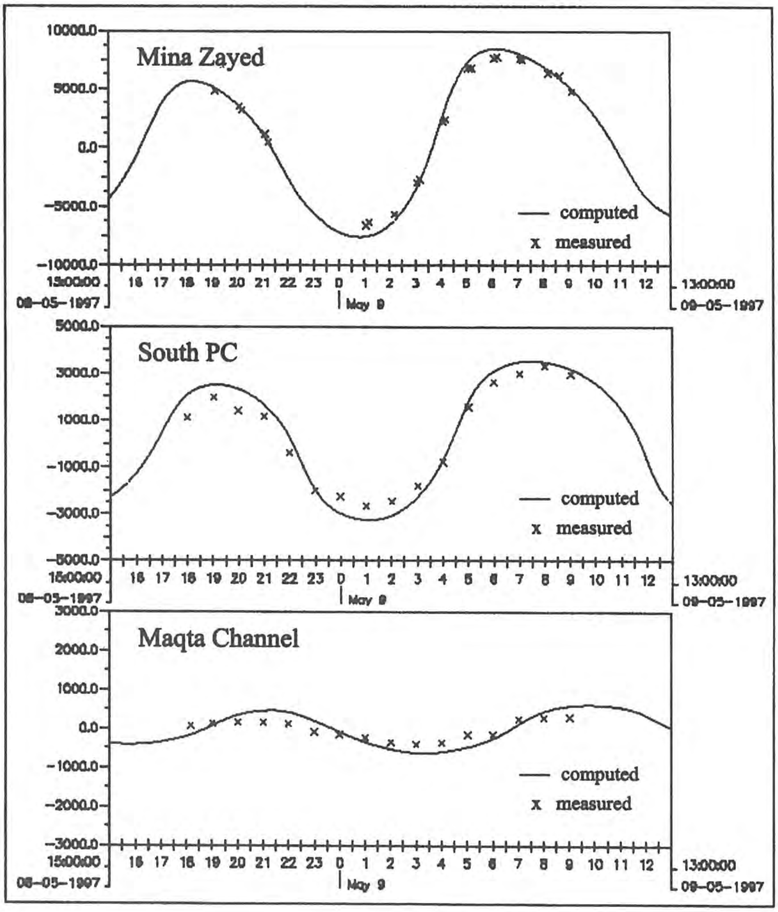

Figure 4: Computed versus measured discharges for Mina Zayed, South Pc and Maqta

6. MODEL COMPUTATIONS

Model computations were carried out to determine the effect of increasing the plant capacity on the increased recirculation of heat and salt from the plant outfalls to the intakes. Computations were done for situations before the proposed capacity extension (X1 = 98 MGID and 1000 MW) and after the extension (Y2 = 62.5 MGID capacity extension) with three wind conditions obtained from the wind rose of the modeled area. The wind rose can be seen in Figure 5.

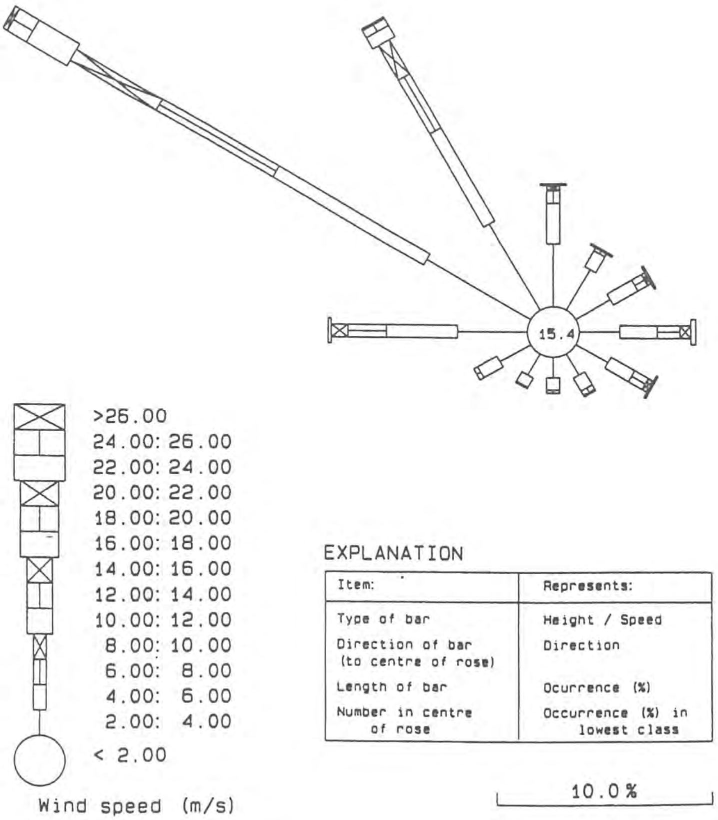

Figure 5: the wind rose for the study area

These wind conditions are:

1. Daily wind: characterized by land boundary North wind with speed up to 5 m/s during the day and in the opposite direction with speed up to 5 m/s during the night. It occurs 71 % of the time.
2. Favorable wind (WNW with a speed of 10 m/s), which occurs 19% of the time.
3. Unfavorable wind (E wind with a speed of 6 m/s), which occurs 11% of the time.

The favorable wind condition generates a residual currents anti-clock wise which reduce the circulation of effluents from the plant outfall to the intake. The unfavorable wind generates residual current clock-wise, which increase the recirculation at the intake.

Table 2 presents the applied design conditions of the model scenarios, which presents the situations before and after the proposed capacity extension under the three wind conditions. In the table ΔT_o and ΔS_o are the admissible excess temperature and salinity at the outfalls of the plant, respectively. In the computations the ambient water conditions at sea are taken as Ta = 32 C and Sa = 45 ppt (summer conditions).

Table 2: the applied design conditions for the model scenarios

	Scenario notation	Wind condition	Intake discharge (m3/s)	outfall discharge (m3/s)	ΔT_o	ΔS_o
Existing situation	X1a	Daily wind	109	104	5.7	2.5
	X1b	WNW wind				
	X1d	E wind				
with proposed extension	Y2a	Daily wind	145	137	6.2	3.2
	Y2b	WNW wind				
	Y2d	E wind				

An initial computation of the 2D model has been carried out with a simulation period of 1 month. This time period is required to obtain an initial equilibrium of the hydrodynamic flow conditions and the temperature/salinity distribution in the model according to the (tidal) forcing on the boundaries, the wind and the discharges. The one-month simulation period includes, of course, the daily tidal cycles and also the two weeks spring-tide/neap tide cycles.

The hydrodynamic situation around Umm Al Nar plant is exceptional due to its location inside a lagoon. The plant has caused a permanent accumulation of heat and salinity in the inner area around Umm Al Nar Island. It can be said that the plant has created a pool around its location with a higher level of salinity and temperature. The plant subtracts its cooling water from this pool on the one side and discharges its hot brine to it on the other side. Based on this unique phenomenon around Umm Al Nar Island, the computational procedures proceeded further in an iterative way. Taking the (average) water temperature and salinity at the intakes site at the end of this initial equilibrium, new values of discharge water temperature and salinity at the outfalls are calculated by adding the appropriate ΔT and ΔS values, and the computation run is continued until a new equilibrium is reached (this usually took some 3 weeks simulation time). From the resulting (average) water temperature and salinity at the intakes site at the end of this new equilibrium, new values of discharge water temperature and salinity at the outfalls are calculated, and the computation run is further continued until another new equilibrium is reached. The procedure is repeated until there would be no need to increase the discharge water temperature and salinity.

When the final equilibrium is reached, the results during the last two weeks of the computational period are further analyzed. These two weeks period represents the full spring-neap-tide cycle, and is thus representative for the most important variations to the seasonal long-term average condition, and are valid for the considered extension scenario and considered wind conditions. To represent annual conditions, a weighed average and weighed standard deviation are calculated by taking the frequency distribution of wind conditions into account.

7. MODEL RESULTS

The computed water levels, temperature and salinity at the intakes for situation X1 (existing situation) at a fixed background values of respectively Ta = 32C and Sa = 45 ppt are presented in Figures 6a, 6b and 6c.

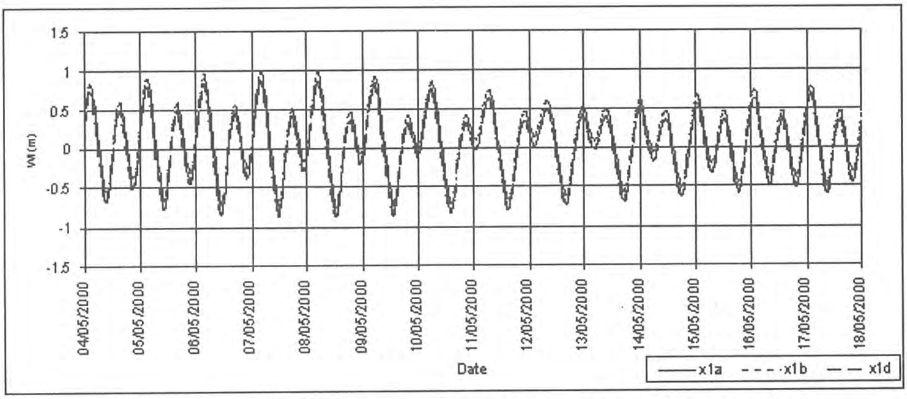

Figure 6a: Computed water levels at the intakes for X1 scenarios (existing situation)

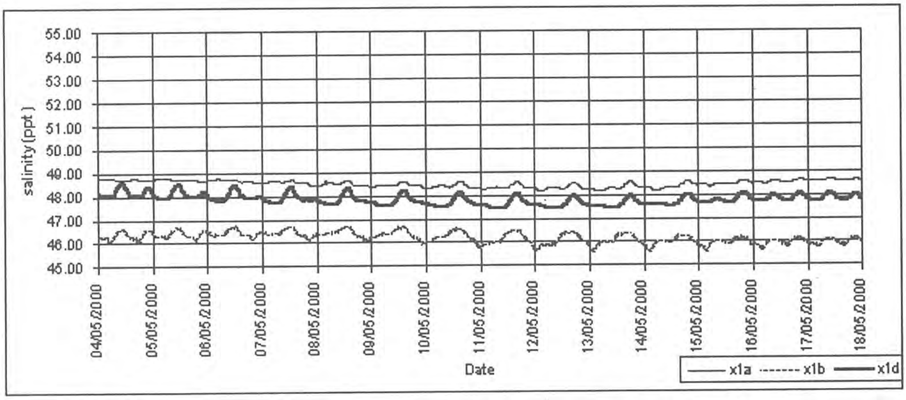

Figure 6b: Computed salinity at the intakes for X1 scenarios (existing situation)

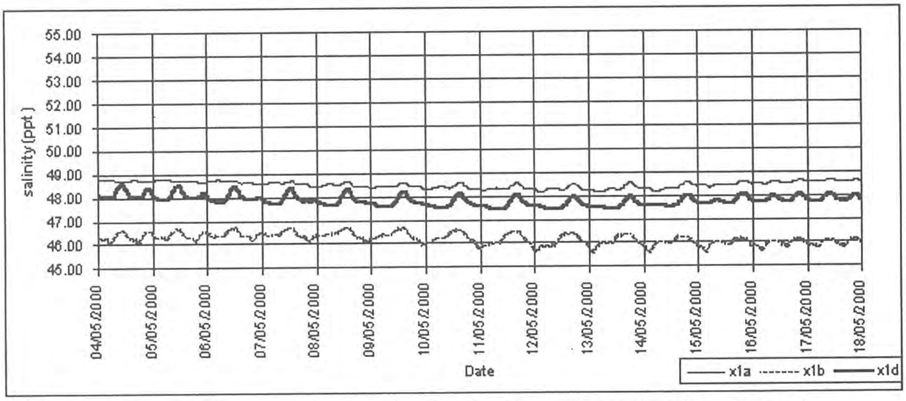

Figure 6c: Computed temperature at the intakes for X1 scenarios (existing situation)

Figures 6a, 6b and 6c show the effect of the wind direction on the level of salinity and temperature at the intakes. The figure shows that lowest recirculation of temperature and salinity at the intakes occurs due to the WNW wind. The maximum recirculation occurs due to the daily and eastern winds, respectively.

Figures 7a and 7b show the computed temperature and salinity for Y2 situation at the intakes. Y2 scenarios represent the existing situation in addition to the proposed capacity extension of the plant. Comparing Figures 6a and b representing the Y2 situation with the alternating Figures 5b and 5c representing the situation X1, the effect of the increased capacity on salinity and temperature at the intakes can be investigated. From the comparison it is clear that increasing the plant capacity by 62.5 MGID will cause a little increase in the recirculation of salinity and temperature from the outfall to the intake.

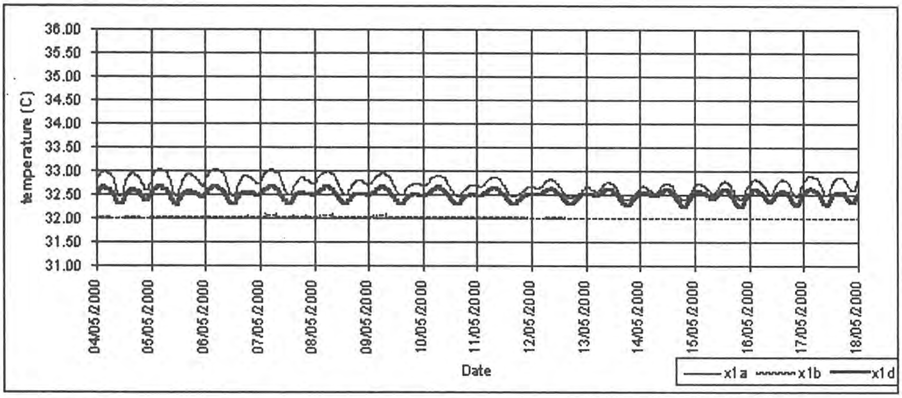

Figure 7a: Computed salinity at the intakes for Y2 scenarios (proposed extension)

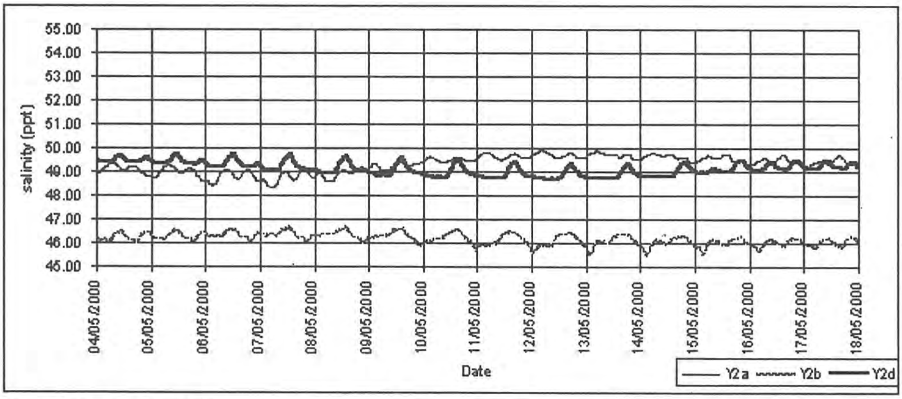

Figure 7b: Computed temperature at the intakes for Y2 scenarios (proposed extension)

Table 3 presents the increased seawater temperature and salinity at the plant intakes due to the recirculation for each wind condition separately and the weighed mean values for all wind conditions.

Table 3: Excess temperature and salinity at Umm Al Nar intakes

Scenario notation	Excess temperature (C)		Excess salinity (ppt)	
	Average	Standard deviation	Average	Standard deviation
X1a	32.7	0.2	48.5	0.2
X1b	32.0	0	46.2	0.3
X1d	32.5	0.1	47.8	0.2
X1(all wind)	**32.6**	**0.1**	**48.0**	**0.2**
Y2a	32.9	0.2	49.5	0.2
Y2b	32.0	0	46.2	0.2
Y2d	32.6	0.1	49.1	0.3
Y2(all wind)	**32.7**	**0.2**	**48.9**	**0.2**

The table shows that the capacity extension of the plant will increase the recirculation of temperature and salinity at the intakes (on average for all wind conditions) by about 0.1 C and 0.9 ppt, respectively. This minor increase in temperature and salinity at the intakes was accepted by Abu Dhabi Water & Electricity Authority.

These results are based on 2 weeks simulation period consists of spring/neap tidal cycles, which represents the most tidal seasonal variations. The annual frequency distribution for the scenarios can be obtained by assuming that the excess temperature and salinity can be represented by a normal distribution, characterized by its average and standard deviation values. The probability of non-exceedence of seawater temperature and salinity at Umm Al Nar intake can be determined by combining the computed excess temperature and salinity with the year-long measured temperature at sea and measured salinities at Umm Al Nar intake.

8. CONCLUSIONS

It is proposed to increase the capacity of Umm Al Nar Power and Desalination Plant by 62.5 MGID. Hydrodynamic study was carried out to investigate the increased recirculation at Umm Al Nar Plant intakes due to the proposed capacity extension. The study comprises extensive field measurements and hydrodynamic modeling. The hydrodynamic model was calibrated and verified by the prototype data. Model computations were carried out for situations before and after the proposed capacity extension for the three dominant wind conditions. The computations showed that increased plant capacity will increase the recirculation of temperature and salinity at the intakes (averaged over the all wind conditions) of about 0.1 C and 0.9 ppt, respectively. These values indicate a small increase in the recirculation of hot brine due to the proposed plant extension, which was accepted by the client.

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Corrosion Prevention of Steel Structure with Sodium Silicate, Dr. Anees U. Malik, Nausha Asrar

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CORROSION PREVENTION OF STEEL STRUCTURE WITH SODIUM SILICATE

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ABSTRACT

Corrosion of steel structures is a common problem in everyday life. Use of carbon steel or mild steel as a construction material is taken as an onus despite its poor corrosion resistance properties at ambient temperature. This is because of its abundance, easy availability, low cost, good formability and workability and remarkable strength. The corrosion in steel structures is generally controlled by 3 methods, viz, cathodic protection, coating or use of an inhibitor. For pipelines, storage tanks or similar structures, silicate or silicate based materials appeared to be potent inhibitors providing protection to iron and steel by prohibiting its anodic dissolution.

Tests have been performed to study the corrosion prevention properties of sodium silicate chemicals with special reference to its application to steel pipes used in product water transport system. Under laboratory testings, coupons of steel were immersed in flowing (dynamic) and stagnant (static) water containing different amounts of silicate inhibitor ranging from 3-200 ppm at ambient temperature. Studies were also carried out in a corrosion test loop in order to simulate operating conditions existing in water transmission lines. Corrosion rates were determined by weight loss method. Open circuit potential (OCP) measurements were also carried out under conditions similar to immersion tests. The results of OCP provide information regarding the nature of protective scales formed on silicate addition.

The results of studies indicate the positive effect of sodium silicate addition in controlling the corrosion of carbon steel immersed in potable water. Loop tests show that 5 ppm concentration of silicate is sufficient to suppress the corrosion of carbon steel by 62% in tap water having a dissolved oxygen level of 5.5 ppm and a flow rate of 2.5 m/s. Electrochemical studies indicate that silicate concentration in the range of 3-5 ppm provides remarkable inhibition to flowing water.

Key words : Corrosion, silicate, protection, pipeline, inhibitor, potable water

1. INTRODUCTION

1.1 Sodium Silicate as a Corrosion Inhibitor

Sodium silicates are the most commonly used commercially available alkali silicates. These materials are usually manufactured as glasses if dissolved in water form viscous alkaline solutions. The soluble silicates, called water glass, have been used in cements, coatings, water treatment and ore beneficiation. These applications are based on the ability of silicates to form gels or to react with multiscalant metal ions in solutions or oxide surface [1]. Sodium silicate has been used for the inhibition of the corrosion of steel for more than 70 years, the general principle lies in feeding dissolved silicate to the metal water pipe where a protective film is formed on the inner surface of the pipe. Sodium silicate has been used for prevention of corrosion in water heating pipelines, centralized heat supply system, steam boilers, industrial plant, circulated municipal water system and water transmission steel pipelines [2-4].

Silicates inhibit corrosion by forming a thin silicate film on the surfaces of metal water pipes as the silicate is fed through them. The films are almost invisible and do not increase in thickness with time. Once the film is formed, the protection is maintained as long as silicate treatment is continued; if stopped, the protection is gradually lost, if damaged, the film is self-healing, as long as the silicate feed is continued.

1.2 Theory of Silicate Inhibition

The silicates are considered anodic inhibitors, initially forming a film on anodic areas. Lehrman and Shuldener [5] investigated the mechanism of the process and concluded that the deposition of the film depends on the presence of small amounts of corrosion products on the metal surfaces.

The negatively charged siliceous species can react with the metallic cations to form the protective films. However, with continuous feeding of the silicates, the films extend to cathodic areas [6]. This is important, because as Scheider and Stumm [7] point out, the reduction in the free surface for anodic action, without a corresponding reduction in the surface available for cathodic action, will lead to an increase in current density at any unprotected anodic sites and result in accelerated corrosion and pitting at these sites. For this reason, it is important to use a maintenance dosage that is high enough to preserve the film throughout the entire system. Maintenance dosages as low as 4 ppm and lower dosages should be tried gradually.

1.3 Mechanism of Inhibition

According to Robinson, et al. [8] the basic mechanism of rust control by silicate is not explainable by silica iron complex as envisaged by earlier investigators [9]. A colloidal solution formation is more consistent with the facts. The influence of pH on the corrosion inhibition of iron and mild steel by sodium silicate is studied and it has been found that dissolution of sodium silicate in water generally increases the pH and the latter appears to play a pivotal role in the inhibition of corrosion [10]. A positive effect due to soluble silicate species resulting from pH change could be distinguished. Armstrong [11] reported that in unbuffered solution, sodium silicate is effective as a corrosion inhibitor for iron by inhibiting the anodic dissolution of the metal. However, the reduction of the corrosion rate in the pH range 9.6-11.6 can be accounted for, entirely by the change in pH caused by the addition of sodium silicate. Shams El-Din et al. [12] showed that the corrosion of rusted steel in conditioned potable water was decreased by a maximum of 47% in the presence of 16 ppm Na_2SiO_3. However, once protection has been achieved, 4 ppm was the minimum amount to sustain a state of permanent inhibition.

Keeping in view, the great versatility of sodium silicate in preventing corrosion of iron and steels and its promising application in carbon steel and galvanized steel pipelines, a study was initiated to carry out testing of this chemical in corroded or rusted steel water pipelines. This paper presents the results of immersion and electrochemical studies carried out on steels in tap water with and without sodium silicate under static (stagnant) and dynamic (flow) conditions.

2. EXPERIMENTAL

2.1 Immersion Tests

The corrosion tests on carbon steel have been carried out in tap water under static and dynamic conditions. The composition of the potable water used during the experiments is given in Table 1.

2.2 Coupon Preparation

Commercial grade carbon steel containing 0.3% carbon was used for the tests. Carbon steel coupons of 100 x 40 x 4 mm size with a hole of 6 mm φ near the edge were cut from the sheet. Coupons were abraded and finished at 600 grit silicon carbide paper. After taking the initial weight and dimension, coupons were hanged in the silicate solutions of different concentrations. In order to avoid galvanic and crevice corrosion, coupons were loosely tightened in the holes using Teflon nuts and bolts..

2.3 Soluble Silicates Solution Preparation

Sodium silicate solutions supplied by the manufacturer have the chemical composition: Na_2O - 9.8%, SiO_2 - 31.2% and the specific gravity of 1.44 at 20°C. The normality of silicate solution is calculated to be 7.47 which is equivalent to 448838 ppm silicate in 1 liter of silicate solution.

2.4 Calculation of Corrosion Rate and % Inhibition

Corrosion rates (in mils per year, mpy) were calculated according to the following equation [13]:

$$\text{Corrosion Rate} = \frac{534 \times W}{D \times A \times T}$$

Where;
W = Weight loss (mg), D = Density of coupon material (g/cm^3), A = Area ($inch^2$),
T = Time of exposure (hr.)

In order to evaluate the effect of inhibitor, percentage inhibition was calculated according to the following equation:

$$\%\ Inhibition = \frac{(C.R.)_{TR} - (C.R.)_{UTR}}{(C.R.)_{UTR}} \times 100$$

Where
$(C.R.)_{UTR}$ = Corrosion rate in untreated tap water
$(C.R.)_{TR}$ = Corrosion rate in treated water

3. RESULTS

3.1 Immersion in Static Water – Laboratory Tests

Polished coupons were immersed in tap water containing 0, 5, 10, 15, 25, 35, 45, 100, 150 and 200 ppm of sodium silicate. Glass beakers of 1000 cc were used to immerse the coupons for the period of 14, 28 and 42 days. Silicate solutions were daily replenished by fresh ones. In order to avoid the experimental errors, two coupons were immersed in each solution. After the completion of immersion period, the coupons were taken out, their condition was observed visually and photographed. Subsequently, the coupons were chemically cleaned for removal of corrosion products adopting ASTM procedure GI-90, Designation – C.3.4. The cleaned samples were then weighed to determine the weight loss and corrosion rate.

3.2 Immersion in Dynamic Water – Laboratory Tests

Coupons were immersed in silicate solutions of above mentioned concentrations stirred with magnetic stirrer with 1300 rpm (velocity = 2m/sec). Duration of the test and weight loss measurement procedures were same as in the case of static water.

While studying the effect of 5, 10, and 15 ppm of silicate, coupons were exposed for 14, 28 and 42 days. During these tests it was observed that the corrosion behavior of carbon steel showed similar trend during all the three durations. Similar observations were made during the use of 25, 35 and 45 ppm of silicate when the tests were carried out for 14 and 28 days. In view of this during other tests experiments were carried out for 14 days.

3.3 Corrosion Loop Test

In order to study the inhibitive effect of silicate in flowing tap water, tests were carried out in a dynamic corrosion test loop. The test loop assembly is comprised of a plastic tank of 200 liter capacity, stainless steel pump, temperature, pressure, flow rate and dissolved oxygen measuring system. All the pipes and fittings of the loop were of PVC. At one end of the pipeline of the loop, two polished and initially weighed carbon steel coupons of known dimension (100 × 40 × 4 mm) were fixed on retractable coupon holder. In order to measure the dissolved oxygen and temperature of the recirculating water, the probe of Dissolved Oxygen Monitor was connected with the water flowing in the pipeline and on-line monitoring of dissolved oxygen was done. Coupons were allowed to oxidize for 24 hours in the loop. After 24 hours, the required amount of silicate was added to the 200 liters of the tap water recirculating in the loop. Tests were carried out at 35 °C in 0, 3, 5, 10 and 15 ppm of silicate solutions for 160 hours. The flow rate was maintained at 80 GPM (2.5 m/ Sec). After 160 hours of exposure, coupons were taken out, cleaned in ultrasonic bath, dried and finally weighed to know the weight loss/ area. The corrosion rate is calculated, from the obtained weight loss, time of exposure and original exposed surface area of the material, by the aforementioned formula.

3.4 Open Circuit Potential (OCP) Measurement

While carrying out the loop test, OCP measurement was also carried out under the same condition and concentration of silicate. OCP measurement was carried out to study the change in potential of the carbon steel immersed in flowing water with time and concentration of silicate. The OCP curve pattern gives an idea about the protective behavior of the oxide scales formed on the metal surface.

For this study, polished probe electrodes (for Petrolite Corrosion Meter) of 1018 MS material and 44 × 6 mm dimension were inserted into the pipe line of the loop with the help of a tightly fitted rubber cork and connected to the plotter for on-line measurement of change in potential against saturated calomel electrode (SCE). OCP of the carbon steel electrodes were plotted for 160 hours at a chart speed of 2 cm/ hr.

4. DISCUSSION

4.1 Immersion Tests Under Static and Dynamic Conditions

The corrosion data of the steel in water under static and dynamic conditions indicate that the trend of the corrosion inhibition by different concentrations of silicate did not change with time (Fig 1). On the basis of the study of the corrosion rate of carbon steel immersed in the tap water containing 5 - 200 ppm of sodium silicate, following generalizations can be made:

- In static tap water containing up to 100 ppm silicate, corrosion of carbon steel was always less than that in the dynamic water.
- Under dynamic conditions, the tap water containing more than 100 ppm silicate shows protection.

The present results show that under static immersion conditions, silicate fails to suppress the corrosion rates even at concentrations as high as 200 ppm. Under dynamic immersion conditions, corrosion rates appear to decrease at silicate dosing higher than 100 ppm. There is lowering down of corrosion rates by 17.8 and 71.0 % at silicate concentrations of 150 and 200 ppm, respectively.

High concentration of dissolved oxygen (8.5 ppm) and velocity of water (~ 2 m/ Sec.) appear to be the cause of higher corrosion rate observed during the dynamic immersion test carried out at 25 °C. The analysis of the corrosion product shows that the rust formed during the static and dynamic immersion tests carried out in the beakers was hydrated loose γ-Fe_2O_3 and Fe_3O_4 which give comparatively less protection to the steel from corrosion [14]. No remarkable effect of the inhibitor addition during static and dynamic immersion tests can be attributed to the formation of the above mentioned loose hydrated oxides which may be due to result of the comparatively high concentration of dissolved oxygen.

It is to be emphasized that the dynamic tests carried out in beaker are far from the real situation of water flowing in a pipe line. In view of this, tests were also carried out in a close circuit loop where the experimental conditions were quite close to those prevail in actual pipeline.

4.2 Loop Test

In the loop test corrosion rate was determined at a flow rate of 2.5 m/ sec. and a dissolved oxygen level of 5.5 ppm. Changes in pH during the loop test were also monitored. The pH of the fresh potable water was found in the range of 7.2 - 7.5, but after exposing the carbon steel coupons for five days, the pH of the water was shifting towards more basic range, showing a value of 8.2. The alkalinity of the tap water could be due to the presence of rust (FeOOH) in the water. The pH pattern of silicate treated tap water shows an upward trend with increasing silicate concentrations (3 ppm silicate: pH=8, 15 ppm silicate: pH=8.5). The alkalinity does not show any considerable rise with time.

The results of corrosion test loop showed in general, relatively high corrosion as compared to that observed during dynamic and static immersion tests. But in spite of very high corrosion rates, during loop tests, silicate was found very effective in inhibiting the corrosion of carbon steel. The plots of corrosion rates against the silicate concentration show that the addition of silicate in the range of 3 - 15 ppm inhibits the corrosion by >45% (Fig.2). However, out of the above mentioned concentrations, 5 ppm appeared to be the most effective amount which can inhibit the corrosion by more than 62% (Fig. 3). It is also evident from Figure 2 that an increase in the concentration of silicate above 5 ppm does not increase the corrosion protection.

The remarkable suppression in the corrosion rate of carbon steel in around 5 ppm of Na_2SiO_3 solution observed during loop test is an interesting and important aspect of this study. It has been discussed by many authors that the nature of the oxide scales formed on the steel surface plays an important role in determining the inhibitive effect of Na_2SiO_3 in water. Chen et al [14], postulated that a layered structure of Fe_2O_3/FeO/Fe is responsible for the lowering of the corrosion rate of iron in contact with both aerated and deaerated Silicate solutions. Presence of FeO in the rust formed on the steel coupons exposed in the loop was confirmed by X-ray diffraction analysis. Formation of FeO along with Υ-Fe_2O_3 is expected due to low dissolved oxygen (5.5 ppm) as compared to the dynamic test (8.5 ppm) or also due to higher flow rate.

Comparing the corrosion behavior of carbon steels in sodium silicate treated tap water tested under three different conditions e.g., static immersion, dynamic immersion and dynamic loop, the results of loop test appear to be of far reaching importance. In loop tests, corrosion rates are although more due to high flow velocity, silicate is far more effective in inhibiting the corrosion than other two types of tests.

It is also very important to determine the optimum concentration of the Na_2SiO_3 which should be fed continuously. This is because of the fact that after covering the anodic site, the film of the inhibitor may extend to the cathodic areas. As Schneider and Stumm reported [7], any reduction in free surface for anodic action without a corresponding reduction in the surface available for cathodic action, will lead to an increase in current density at any unprotected anodic sites and result in accelerated corrosion and pitting at these sites.

These results indicate that it is very important to use a maintained dosage of Silicate which could be most suitable to preserve the protective film throughout the system. Also, excess aeration of the flowing water should be avoided to enhance the inhibitive effect of Na_2SiO_3.

4.3 Open Circuit Potential (OCP) Test

The open circuit potentials of clean and rusted C-steel coupons were followed as a function of time in the untreated and silicate treated tap water until a constant value was attained. At the moment of immersion in water, the clean coupons registered potentials ranging between -450 to -480 mV vs SCE. These potentials slowly drifted towards more negative values and attained constancy in the range of -570 mV to -632 mV, after around 15 - 20 hours of immersion. The negative shift in potential is indicative of the destruction of the air-formed pre-immersion oxide film, and the attack on the metal. Shifting of the potential towards the original OCP is an indication of passivation of the metal surface. It is evident from the Figure 4 that an addition of 3 - 5 ppm of Sodium Silicate to tap water provides a maximum passivation to the C-steel coupons as the OCP shifts from ~ -630 mV to ~ -560 mV, while a higher concentration of 10 and 15 ppm of silicate could not shift the OCP below -609 mV. These results are in consistence with the findings of the Loop Test and confirm the remarkable corrosion inhibition when 3 - 5 ppm of silicate is added to the flowing potable water.

5. CONCLUSIONS

On the basis of Static and Dynamic Immersion, Loop and Electrochemical Tests, the following conclusions can be made:

(a) Optimum concentration of silicate depends upon the dissolved oxygen and the rate of flow of the water.

(b) Although the corrosion rates of the steel in dynamic condition are invariably higher than those under static condition but silicate acts more effectively as an inhibitor when the water is in dynamic condition.

(c) From the loop test it is evident that at ambient temperature, 5 ppm concentration of silicate is sufficient to suppress the corrosion of carbon steel by 62% in tap water having a dissolved oxygen level of 5.5 ppm and a flow rate of 2.5 m/Sec.

(d) Electrochemical tests indicate that silicate concentration in the range of 3-5 ppm provides remarkable inhibition to the flowing potable water.

6. RECOMMENDATIONS

In order to protect carbon steel pipes, it is recommended to maintain a continuous dosing of 5 ppm of silicate in potable water because it is effective in controlling the corrosion of C-steels as shown by the results of loop tests.

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Table 1. Composition of Al-Jubail Housing Tap Water

Analytical Parameters		Values
Conductivity	(μS/cm)	426
pH		7.76
m-Alkalinity as $CaCO_3$	(ppm)	40
Total Hardness as $CaCO_3$	(ppm)	120
Ca Hardness as $CaCO_3$	(ppm)	80
Chlorides	(ppm)	83
TDS	(ppm)	275
Residual Chlorine	(ppm)	0.35
Turbidity		0.15

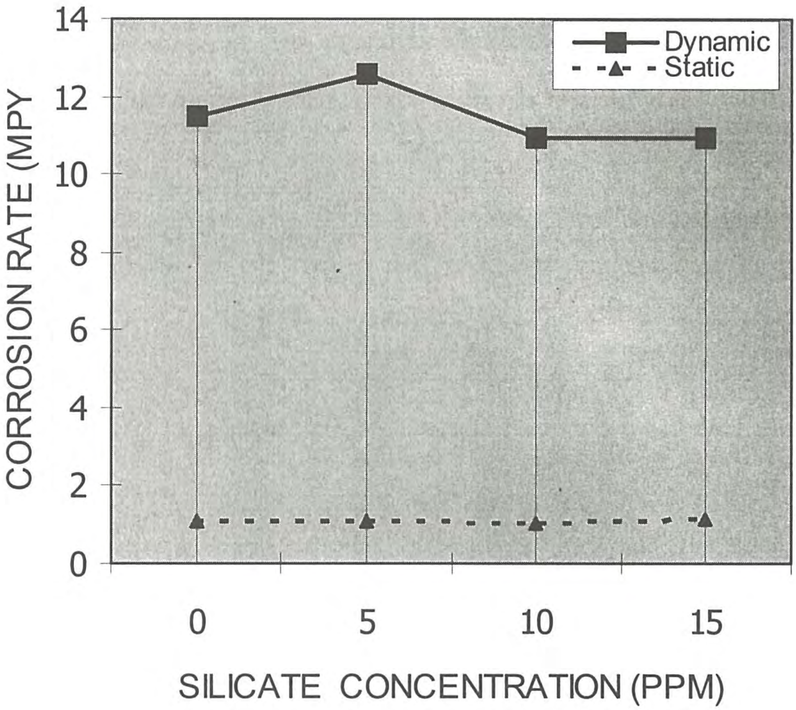

Figure 1. Corrosion of carbon steel in sodium silicate containing tap water (A 14 Day Test Result)

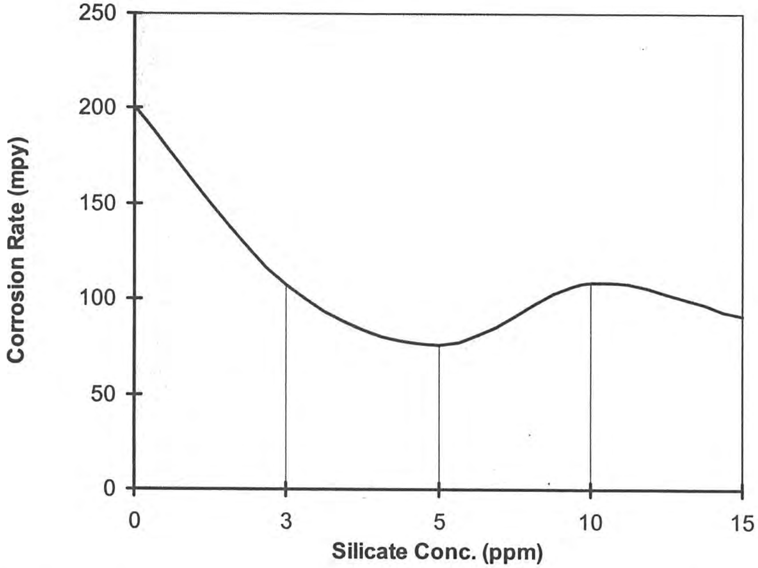

Figure 2. **Corrosion behavior of carbon steel in silicate treated tap water during loop test.**

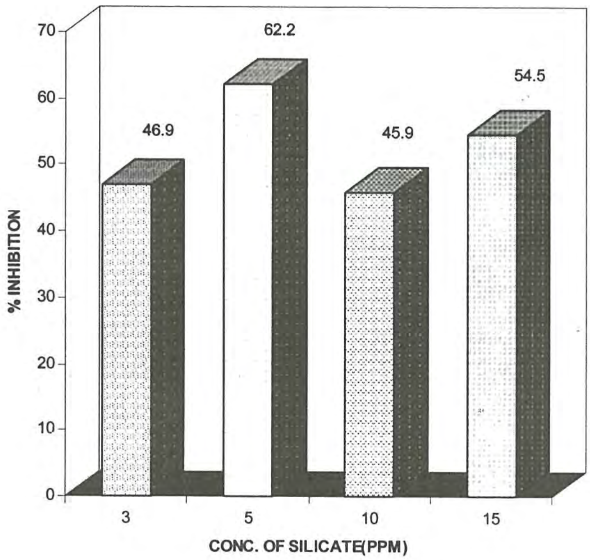

Figure 3. **Corrosion inhibition of carbon steel by sodium silicate treatment in loop test**

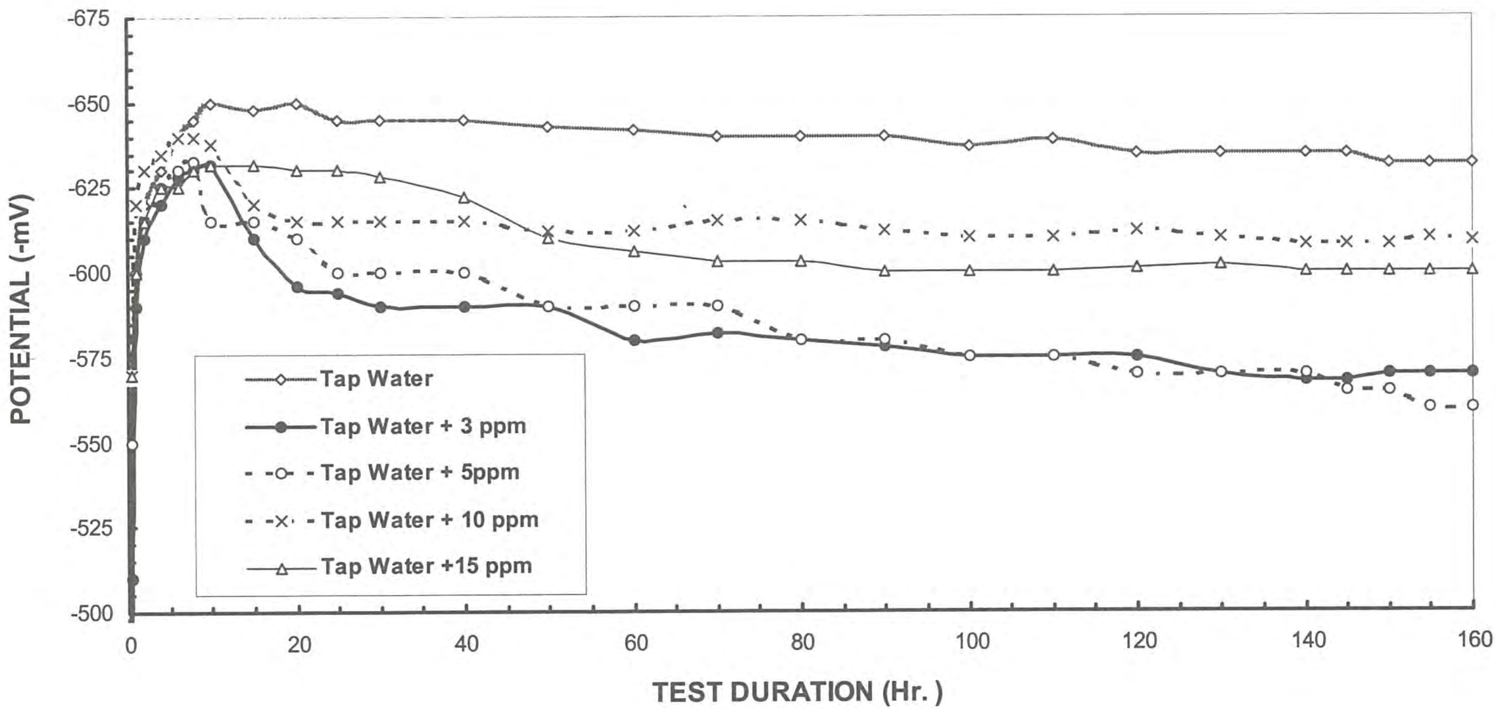

Figure 4. Change in open circuit potential of carbon steel in sodium silicate treated tap water during loop test.

Refurbishment with a Difference GPIC'S MSF Desalination Units Refurbishment Experience, Engr. Bader Mansouri

A. Kareem Moh'd and Joshua Mathew (Bahrain)

REFURBISHMENT WITH A DIFFERENCE GPIC'S MSF DESAL UNITS REFURBISHMENT EXPERIENCE

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ABSTRACT

The Gulf Petrochemical Industries Company's (GPIC) entire complex fresh water requirements are met by the two cross flow MSF desalination units which were commissioned in 1984/85. After two years of operation, during the annual shutdown inspection it was noticed that there was severe corrosion/flaking resulting in thinning down of the upper section of the inter-stage walls and the roof due to the build up of non-condensable gases in the vapor space. The major reason for the above was due to the fact the material used for the upper-wall, baffle plates and roof was carbon steel, where as the lower wall was made of stainless steel. A detailed study on the above subject was made and it was decided that all the carbon steel plates, be replaced with S.S.GR 316 or better material and the roof to be cladded with the same material.

The ultrasonic wall thickness surveys of 1994 revealed that there was significant deterioration of the carbon steel walls in the hot stages. Distiller # 2, first stage had lost more than 58% of its wall thickness. Eddy current tests for the condenser tubes of the heat recovery/reject sections did not show any considerable deterioration and the average life of the Cu-Ni/Titanium condenser tubes was around 25 years.

It was decided to go ahead with the earlier proposal to replace the carbon steel plates with Avesta steel and clad the roof with the same material and at the same time reusing the existing condenser tubes. This paper shows how in GPIC it was possible to reuse most of the existing tubes, which made a huge saving on the overall cost. The tubes were pulled out after cutting it at one end using internal cutters and the novel method of overcoming the shortened length. Only the baffle plates were fabricated outside of the company, all other jobs including the re-design were done in-house. This was carried out successfully on both the desals in 1999/2000. The units are at present running normal.

Key words: Refurbishment, Corrosion/flaking, Inter-stage walls, Baffles, Avesta steel, Tube sheet box.

INTRODUCTION

The desalination plant forms an integral part of GPIC's Utilities Plant. It caters to the entire complex's desalinated water requirements. The desalination plant consists of two identical cross-flow MSF units, each with a distillate production capacity of 150 T/Hr (0.8 million imperial gallons per day). These units consisting of 15 stages of heat recovery and 3 stages of heat reject operates at a maximum TBT of 110 ^{0} C using Belgard EV as the Anti-scale and Sodium Sulfite as the oxygen scavenger where commissioned in 1984/85.

DESIGN TECHNICAL DATA

Evaporator E-4101/3		
Evaporator Manufacturer Distiller type No. of stages of Recovery Section No. of stages of Reject Section No. of Tube passes per stage	Snamprogetti MSF 15 3 2	
Design Parameter		
Unit Capacity Distillate TDS Sea water TDS Top Brine temperature (TBT) Gained output ratio	150 T/Hr 12 ppm 48800 ppm 110 deg. C 8	
Stages material of Construction		
Shell side Interstage Division Bottom Top Brine Orifices and Gates	C.S. cladded with AISI 316 upto demisters AISI 316 upto demisters C.S cladded AISI 316 C.S. AISI 316	
Tubes Specification		
	Recovery section	Reject section
No. of Tubes /Pass	836	563
No. of tubes /Bundle	1672	1126
Heat Exchanger length	4500	4500
Outside diameter (mm)	19.05	19.05
Thickness (mm)	1	0.64
Heat Exchange Surface / Stage(m^2)	450.3	324.8
Material of Construction	Cu-Ni 90/10	Titanium
Support Plates (Baffles)	C.S.	C.S.
Tube Plates	Cu-Ni 90/10	Cu-Ni 90/10
Distillate Tray	AISI 316	AISI 316

CORROSION HISTORY AND INSPECTION REPORT

Desalination Unit No.2 was commissioned in December 1984. The first general inspection was carried out after two months of service in Feb/March 1985 and was reported to be normal. Due to abnormal and unstable operating conditions, an inspection was carried out in September 1986. Stages 1,2,3,9 and 15 of the heat recovery and stage 18 of the heat reject section were opened to investigate the problem. That inspection revealed that there was an active corrosion on the carbon steel walls and roof above the demisters. Copper oxide deposits and hard salt contamination were evident up-to normal brine level covering all the surfaces in varying thickness of the Heat Recovery stages. In the 18th stage Heat Reject section pitting corrosion was evident on the stainless steel floor cladding at the interface of the deaerator rubber lining and the walls were badly stained with ferrous oxide deposits indicating corrosion occurrence of the upper carbon steel walls and roof of the vapor space.

During the next inspection of Evaporator E-4103 in October 1987 it was observed that the internal surfaces of the distillation channel/tray (SS 316) beneath the condensers were heavily fouled with red ferrous oxide corrosion product and various localized pits (pitting corrosion) which had penetrated the full wall thickness (3mm)

To identify the corrosion phenomena, a stainless steel specimen from the distillate channel located below the condenser tubes of stage #2 was examined and the results of the chemical analysis of the scale were reported as percentage of the total amount.

Cations: Iron 79.3 Anions: Sulfates 4.3
Chromium 3.8
Chlorides 6.5
Nickel 1.1
Copper 2.6
Calcium 2.1

Failure of stainless steel distillate channel "floor" plates mechanism is considered as the corrosion product from stages vapor spaces walls, ie C.S. wall and roof above the demisters has been carried over and deposited on the trays which then created oxidation cells beneath the deposits. Thus breaking down the oxide layer. This made that section anodic to the surrounding area.

In March 1989 during the internal inspection it was reported thick scale/layers of iron flakes (1-2mm) mainly oxidation products as ferrous oxide on side walls, roof and on baffles of tube bundles. These observations proved that the progression of the corrosion phenomena in the vapor space area above the demisters and a corrosion rate of 0.65 mm/year were recorded on the side-walls.

The most alarming point was that the five ultrasonic wall thickness surveys which were carried out on Desal Unit #2 from 1986 to 1994 revealed significant deterioration of the carbon steel north wall and the vapour space roof. The June 1991 survey result showed significant material loss on the north wall of stages 1, 6, 7 and 15 with a wall reduction of 3.4 mm, 2.8 mm, 2.9 mm and 2.8 mm respectively against a nominal wall thickness of 12mm. The C.S. condenser tube plates (baffles) also showed various degrees of thinning. The survey of August 1994 revealed that the north wall of stage #1 had lost a massive 58.3% of its wall thickness (from 12 mm it had thinned down to a meager 5.0 mm). Also the survey of Feb/March 1995 on Desal Unit #1 revealed that the north wall of Stage # 2 had lost 46.6 % of its wall thickness.

It was evident that the corrosion problem on Desal #1/2 vapor space was caused by the formation of non-condensable gas, the main component being carbon-dioxide which was evolved by thermal decomposition of bicarbonates ions in sea-water and the higher the TBT the higher is the break-down of the bi-carbonates

$$2HCO_3^- \quad <----------> \quad CO_2 + CO_3^{-2} + H_20$$

Also the ingress of oxygen into the hot stages could lead to corrosion, however this is mostly overcome by the use of sodium sulfite as an oxygen scavenger. This is an universal phenomena, but the main reason for the excessive deterioration was that the material used for the top portion of the inter-stage walls, vapor space roof and tube support-plates was plain carbon steel and it was neither cladded or SS 316 as is the usual case (ref #1) especially on units operating at temperatures above 85 deg. C.

The severe deterioration/corrosion of the carbon steel plates of the distiller was a major factor influencing the remaining service life of the unit. It had been in service only for just over ten years. The average life for the Cu-Ni and Titanium condenser tubes is 25 years (ref #2). Hence it was decided to carry out a comprehensive refurbishment of the distiller stages vapor space in order to improve the performance and establish the long term reliability. The main objective was to overcome the severe corrosion problem by utilizing a product with a higher resistance to corrosion phenomena property. This was to be done by replacing the carbon steel inter-stage walls and the baffle plates with Avesta 254 SMO and cladding of the carbon steel roof with Avesta 254 SMO plates .

The high levels of molybdenum in particular and also the chromium enriched Avesta 254 SMO with good a resistance to pitting and crevice corrosion especially in a sea-water environment even at increased temperature was the ideal material for the job as can be seen from the chemical composition of Avesta 254 SMO in percentage as given below.

AVESTA 254 SMO	Cr	Ni	Mo	N	C (max)
	20	18	6.1	0.2	0.02

REFURBISHMENT

TUBES

1) The tubes were cut at the inside end of the east tube-sheet (approx. 35 mm from the tube sheet face) using an internal cutter. The tubes were then pulled out from the west tube-sheet using tube-pullers

2) The removed tubes were inspected and most of the tubes were observed to be have a length of 4535 to 4545 mm as against an original length of 4570 mm and a maximum elongation of 10 mm due to the pulling. No appreciable change in diameter was observed. These tubes were then inspected and cut to a length of 4490/4500 mm.
3) Tubes with external pitting, bending or were twisted due to pulling, were rejected and new tubes fitted

BAFFLES

1) The baffles were visually inspected after removal of the tubes and severe corrosion was observed on the lower half portion of the baffles and the baffle ligaments were observed to have cracked/broken at a few location. Also severe loose scale, deposits were observed for the entire distillate tray floor.
2) The old baffles (3 nos. in each stage) were cut and removed and new baffles manufactured from 12mm thick Avesta 254 SMO plates were made available. 6 mm thick AVESTA 254 SMO angles were welded on the roof and baffles were welded to the angle.
3) Dye penetrant Examination of the welding was carried out and the same was observed to be satisfactory.

VAPOUR SPACE

1) Inspection of the carbon steel shell above the demister pads, condenser tubes revealed heavy oxide scaling. Carbon Steel shell scaling was removed by shot blasting & chipping.
2) A thickness survey of the roof and side wall walls after shot blasting was carried out and in general the thickness was observed to be 12 to 12.5 mm with a minimum thickness of 9 mm observed at some locations on the roof against the original thickness of 13mm
3) The entire vapor space carbon steel section of the roof and both the side walls were lined with 3 mm thick Avesta SMO 254 plate. Pneumatic leak test at 2.5 PSI was carried out on the lining and the results were observed to be satisfactory and the holes provided on the plates for pressurizing were seal welded and dye penetrant examination was done.

INTER STAGE WALLS

1) The carbon steel inter-stage walls revealed heavy oxide scaling. Holes were observed on the walls and also corrosion was observed on the wall stiffening channels. The corrosion was predominant on the condenser tube side-wall(South wall of each stage).
2) The inter stage wall was cut and removed from the roof down to the Stainless Steel section of the lower wall. The south wall of stages 2 to 5 was renewed with 5mm thick AVESTA SMO 254 plate and stage 6 to 18 was renewed with 4 mm thick Avesta SMO 254 plate. 4mm thick channels were welded as stiffeners on condenser side of the walls.
3) The roof to wall weld root pass was welded using E-0309 electrode and consecutive welding was carried out using Avesta P12 electrode/filler wire. North wall of stage 18 and south wall of stage 1 was shot blasted and lined with 3mm thick Avesta SMO 254 plate.
4) Pneumatic leak test at 2.5 PSI was carried out on the lining and the results were observed to be satisfactory and the holes provided on the plates for pressurizing were seal welded and dye

penetrant examination was done. Also 4mm thick channels were welded as stiffeners on the North wall of stage 18.

TUBE SHEET

1) The west side tube sheets were cut and removed and the tube sheet neck was lined in the work shop with 3mm thick Avesta 254 SMO plate.
2) The tube sheet was then welded to the shell after shortening the east tube sheet to west tube sheet distance by 80 mm (this was to accommodate the shortened length of the condenser tubes). The west tube sheet to shell welding was carried out from inside using E-6010 electrode for root pass and E-7018 electrode for fill up.
3) The internal tube sheet neck surface was lined with 3mm thick Avesta 254 SMO plate. Pneumatic leak test at 2.5 PSI was carried out on the lining and the results were observed to be satisfactory and the holes provided on the plates for pressurizing were seal welded and dye penetrant examination was done. One of the tube holes on stage 5 and 17 were plug welded due to damaged expansion grooves.
4) Severe corrosion/erosion was observed on the 16th, 17th and 18th stages east and west tube sheet face. The corroded area was built up GTAW process using MONEL filler Metal 67.

DISTILLATE TRAY

1) The general condition of the distillate tray was observed to be satisfactory. However severe loose scale, deposits from the carbon steel roof, walls and baffles was observed on the tray floor.
2) The Avesta 254 SMO distillate tray bottom plates which was modified in 1988 was observed to be in satisfactory condition. A doubler plate of SS 316L (3mm thickness) was welded on the outer surface of the distillate tray where the internal division plate stitch weld had been carried out. The doubler plate weld was inspected by Dye Penetrant Examination.
3) The distillate tray was filled with water after complete refurbishment and 40 leaky spots were observed on the distillate tray and north wall. Those leaky spots were repaired by welding.

RE-TUBING

1) New tubes were provided for the bottom 3 rows of stages 1 to 18. For the other rows the existing refurbished tubes were re-used.
2) The distillate tray was filled with water and the tubes & tube sheet expansion joints were leak tested by pressurizing the distiller shell to 0.2 bar g and leak testing was done by applying soap solution. The leaking tubes were re-expanded and the leaks arrested.
3) Approx. 60 of the leaking titanium tubes in stages 16, 17 & 18 were observed to be cracked at the location of expansion due to age hardening of the tube hole bore. All the those tubes were renewed. Also the complete vapor space was filled with water and leak tested.

PERFORMANCE TEST

A performance test was carried out on Desal #2 on 11th January 2000. The unit was started up on 5th January very slowly to avoid any thermal stress on the newly installed material inside the evaporator. The load was gradually increased up to the design TBT of 110 ^{0}C. and the maximum production attained was 142 T/hr and the distillate conductivity was 4.5 micro-siemens.

CONCLUSION AND RECOMMENDATION

1) The refurbishment of Desal #2 was considered a complete success and was confirmed by the results/inspection report during the 2001 and 2002 shut-downs.
2) Similar refurbishment was carried out on Desal #1 January 2000 to March 2000.
3) By being able to re-use the majority of the condenser tubes GPIC was able to have a considerable over-all cost saving and also to run both Desal units for at-least another ten years.
4) Carbon steel alone not to be used for inter-stage walls, baffles or vapor space roof for distillers operating above 85 deg. C. If used it should be cladded with stainless steel or better material.

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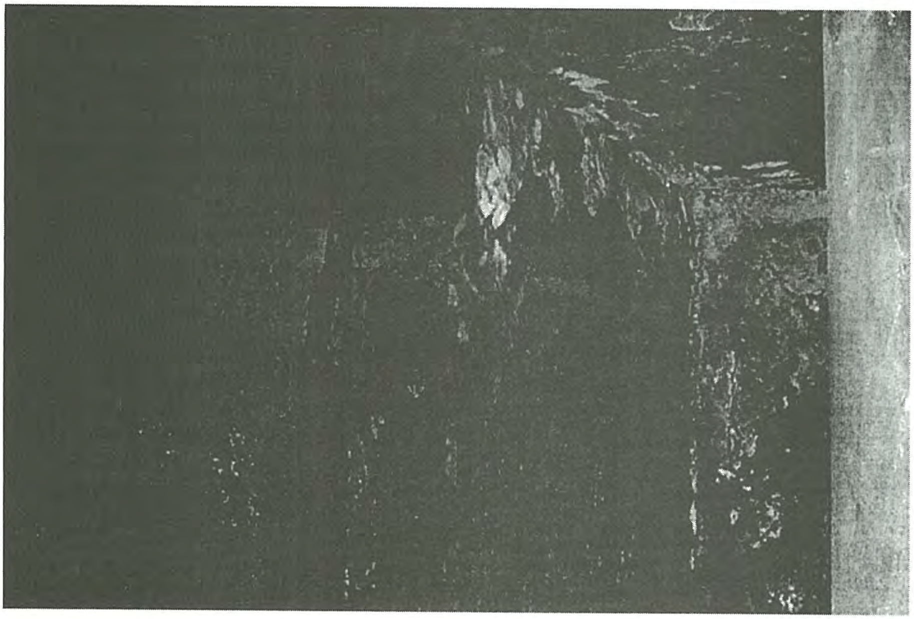

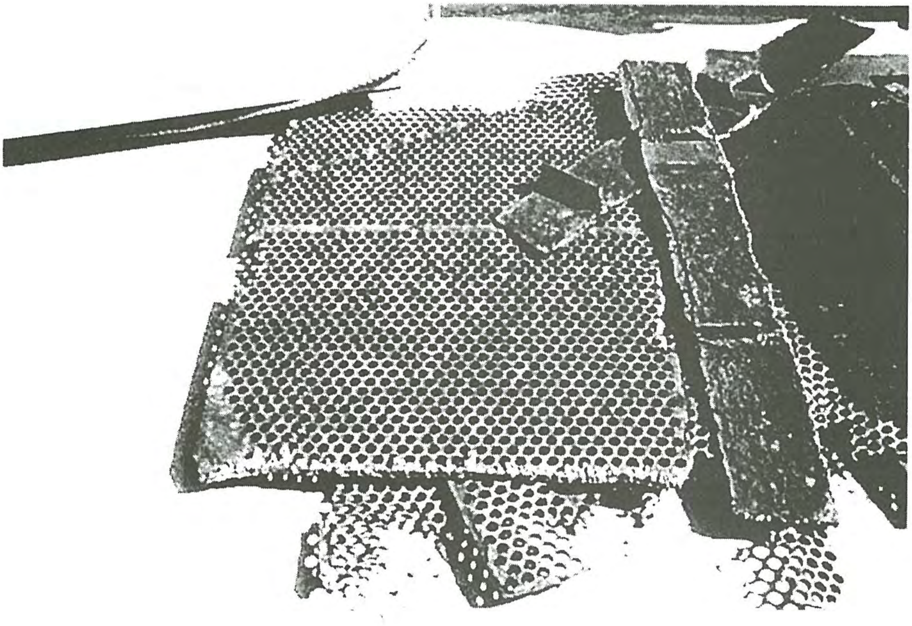

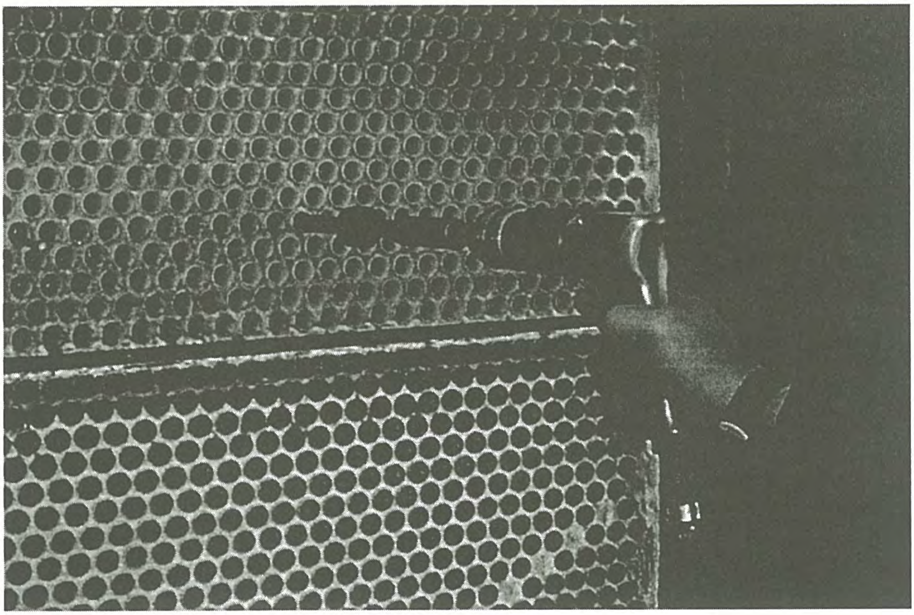

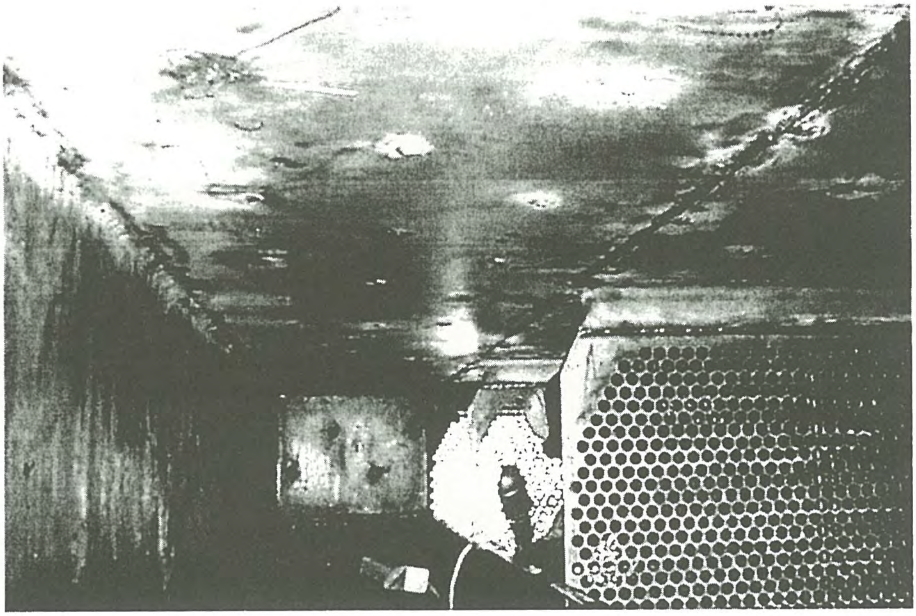

Fifteen Years of Operating Experience on Multi Effect Distiller (MED) Desalination Plants in SWCC- Satellite Plants

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FIFTEEN YEARS OF OPERATING EXPERIENCE ON MULTI EFFECT DISTILLER (MED) DESALINATION PLANTS IN SWCC- SATELLITE PLANTS

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ABSTRACT

Saline Water Conversion Corporation – SWCC, has been operating eight medium capacity desalination plants, called Satellite Plants, in the Red sea coast of Saudi Arabia. It employs various technologies such as Reverse Osmosis (RO), Multi Stage Flash (MSF) and Multi Effect Distiller (MED) for the desalination. Out of our operating experience on various processes, we found Multi Effect Distiller–Thermo Compression type (MED-TC) process is an ideal option for medium capacity plants.

Satellite Plant, Aziziah, has been operating 3 Nos. of 1500 T/day capacity MED–TC units since 1987. The over all performance of these units are quite satisfactory . Even after 15 years of service, the actual performance of plant is fairly matching with design conditions. The operation is simple, the maintenance is very low and Azizah plant is hardly facing any O&M problems. Another plant , Al-Wajh is operating 7 Nos. of old MED–TC units of smaller capacities. These units are 18 to 24 years old, originally installed & commissioned at different locations, later on shifted to Al-Wajh after some years of service and no previous record of operation & maintenance history is available for these units. Hence the study doesn't cover much about Al-Wajh units and it mainly focuses on Aziziah units.

This paper outlines the main design features, selection of materials the actual running conditions of MED units and discusses about various operational experiences of MED plant. The scaling problem, corrosion problem and other operational problems encountered so far has been discussed in detail. The various performance details are analysed. The salient features of MED plants are also discussed. Finally the paper discusses about the specific advantages of MED units over MSF & RO units for the medium capacity plants.

KEY WORDS: Multi Effect Distiller-Thermo Compression (MED-TC), Multi Stage Flash (MSF), Saline Water Conversion Corporation(SWCC), Satellite Plants,

INTRODUCTION

Today , large desalination still based on MSF process however for small and medium capacities, stiff competition is going on between MED and RO technologies. Both these process are less expensive when compared to MSF, as a result of lower investment and better performance. SWCC, one of the largest provider of potable water in the world, has been operating eight satellite plants of medium capacities (2000 T/d – 5000 T/d), in the red sea coast of Saudi Arabia , for more than 15 years. All these eight plants are not using the same process for desalination instead different processes such as RO, MSF & MED, are being used in these plants.

Out of more than 15 years operating experience on RO, MSF and MED, we found MED is an ideal option for medium capacity plants because of its over all advantages over other processes. Satellite Plant, Aziziah, has been operating 3 Nos. of 1500 T/d capacity MED-TC units and Al-Wajh plant has been operating 7 Nos. MED–TC units of small capacities. All the seven units of Al-Wajh are 18-24 years old and were not originally installed at Al-Wajh, they were shifted from other locations and no previous record of operation and maintenance history is available for these units. Hence our experience mainly focuses on MED units of Aziziah. Following table (Table-1) describes about various MED-TC units in SWCC-Satellite Plants

TABLE : 1

DETAIL OF **MED-TC** UNITS IN SWCC- SATELLITE PLANTS

Plant	Desalination units	No of Effects	Capacity T/D	Date of commissioning	Original installation at	Year of shifting & commissioning	No of years of service
Al- Wajh	Sasakura-1	2	2x480	1978	Ummlujj	1986	24
	Sasakura-2	2	1x480	1982	Al-Khafji	1989	20
	Sasakura-2	2	1x360	1982	Al-Khafji	1989	20
	Sasakura-2	2	2x180	1982	Al-Khafji	1989	20
	Sasakura-3	2	1x480	1984	Causeway	1999	18
Aziziah	Phase 1	4	3x1500	1987	Aziziah	-----	15

SWCC's Aziziah plant, operating on MED-Thermo compression process, supplied by M/s Sasakura-Japan, was commissioned in 1987 and since then it has been operating with consistent performance, without any major operation or maintenance problems. The availability of the plant can be ensured for more than 98%.

The objective of this study is to outline various design features of MED-TC units, compare the design and actual performances and to discuss about various operational and maintenance problems so far encountered. The choice of MED over other processes are also discussed in this study.

PROCESS OF MULTI EFFECT DISTILLER – MED

The MED process is composed of multitude of steps whereas the total energy introduced into the system at the top temperature is converted in each step into latent heat by evaporation. Such process step is called effect. The vapour generated in each effect condenses as product water . In each effect there is a heat exchanger between the condensation side and the latent heat of condensation is converted again to latent heat generated vapour.

The MED unit consists of a Thermo compressor and a multi effect evaporator. Thermo compressor is a simple steam-jet ejector driven by a small quantity of boiler steam. The ejector sucks in low temperature vapour from the evaporator's last effect and delivers the hotter, compressed mixer of the steam and vapour to the first effect. The multi effect evaporator has a thin film of sea water sprayed on to the outside of the horizontally arranged heat exchanger tubes. As the hotter vapour condenses inside the tubes, forming the fresh water product, it simultaneously causes the cooler sea water film on the outside to boil, thus generating new vapour for ducting to the next lower effect. The condensation /evaporation process is repeated from the hottest to coolest effect. All MED-TC plants operate at low temperature to avoid problems of scale formation without having to use acid for operation or for cleaning. As an additional precaution , the sea water is dosed with a small quantity of scale inhibitor.

PLANT DESCRIPTION[1]

All the three units Aziziah plant are 1500 t/d capacity Multi Effect Distiller – Thermo compression type desalination units. The units were supplied by M/s Sasakura –Japan and the plant was commissioned in 1987. The plant can be divided into following major system.

i) Sea Water Intake System
ii) Desalination Units
iii) Boiler Units for Steam Supply
iv) Product Water Treatment Unit for Potablization.

The raw sea water is pumped to the desalination unit by centrifugal pumps. The sea water is chlorinated at sea water intake by chlorine dosing equipment. The MED-TC unit combines the principle of multi- effect, horizontal tube, spray film evaporation and compression by steam ejector. Figure 1 illustrates the principle of the process.

The sea water is fed to the heat rejection section as coolant to carry off the excess heat from the evaporator. On leaving the heat rejection section certain amount of sea water is fed to the top of each effect and sprayed onto the outer surface tubes, and the remainder is returned to the sea. Heating steam through the ejector compressor is supplied to the first effect , where it condenses and releases its latent heat inside the tubes. As a result , the sea water film outside the tubes is partially evaporated in the first effect. The remainder of the feed water (called brine) , falling to the floor of the first effect , flows into the bottom of the second effect through the U-shaped loop. The vapour produced in the first effect is led to the second effect at lower temperature than the first effect and condensed in the heating tubes to evaporate the feed water outside tubes. The condensed vapour for as a part of the product water.

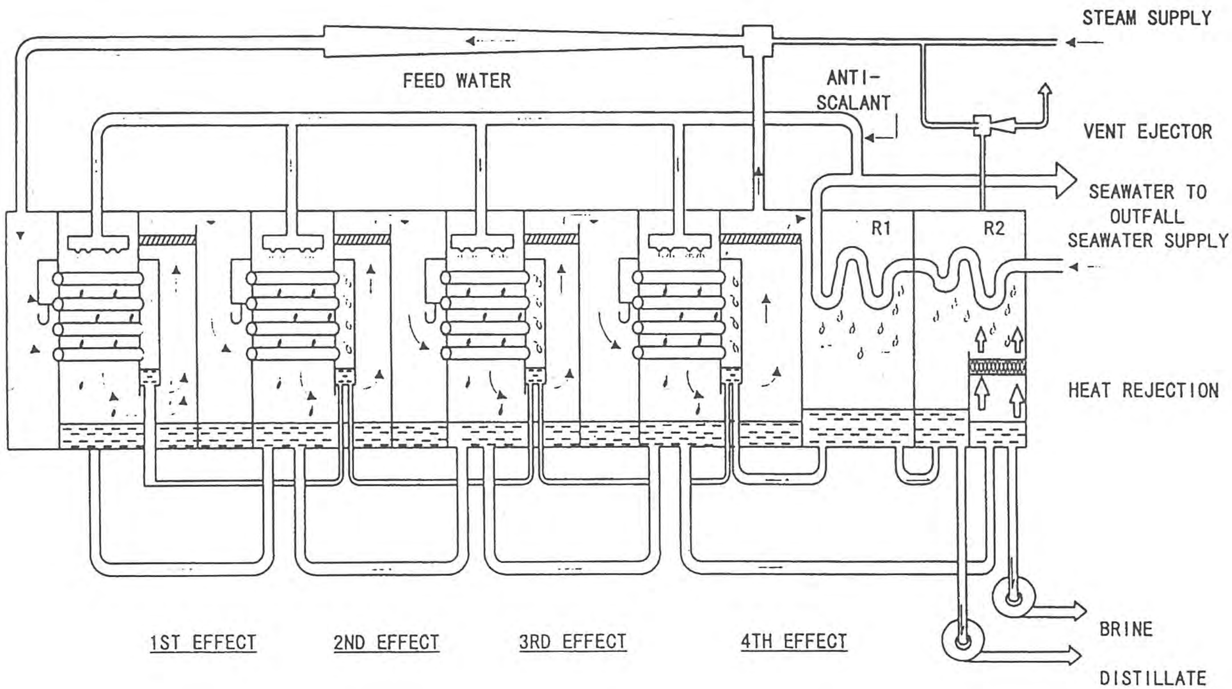

FIG-1 TYPICAL 4-EFFECT RH PROCESS ILLUSTRATION

Steam condensate in the first effect and vapour condensate in other effect are led to the succeeding effect releasing heat in the product water. In the same manner , the evaporation and condensation process are repeated from 1st effect up to the 4^{th} effect. Part of the vapour produced in the 4^{th} effect is led to the heat reject condenser R1 and condenses on the outer surface of the tubes and finally rejected to sea. Finally, the product water in the R1 flows to the condenser R2 in which it is reduced its temperature by flashing due to high vacuum of the plant and releases the heat before with drawn by the product water pump. The remaining vapour is withdrawn by the ejector compressor where it is compressed and mixed with the motive steam from the boiler.

On leaving the ejector the mixed steam and vapour flows to the first effect as heating steam in which it is condensed and transmit a sufficient heat to evaporate the feed water as mentioned above. The brine in 4^{th} effect is flashed into a separate compartment in the condenser R2 and the vapour generated is condensed outside the tubes to produce a further amount of product water.

The excess brine in the condenser R2 is extracted by the brine blow down pump. The low pressure vacuum in the plant is initially created and then maintained by removing air and other non-condensable gases air are constantly discharged to the atmosphere. The feed water is dosed with scale inhibitor (Belgard) to prevent soft scale formation on the surface of the tubes. The distillate water produced at desalination unit is treated for potablisation and after treatment is transferred to product water storage tank.

MATERIALS USED

The choice of material, in the design and construction of desalination units, is playing a vital role in the operation and maintenance of MED plants. The materials used for Aziziah units are of superior quality. The evaporator shells are fabricated from stainless steel SS 316L . For the effect tubes and R1 condenser tubes, Cu-Ni 90/10 material is used which is best suited for sea water application. The tube sheets of the above tubes are made of naval brass and the tubes are held in the tube sheets by tube end expansion. Titanium (TTH 35W) is used for condenser tubes in heat rejection R2 stage which can withstand the erosion effect of high velocity of sea water . The ejector and the nozzle materials are made of stainless steel SS304. Recent inspection on evaporator internals reveals that the materials are still in very good condition and its metallurgical integrity is proved intact. The corrosion thickness survey of the shell plates shows that there is hardly any sign of metal loss due to corrosion .

Table-2

MATERIALS USED FOR AZIAIAH MED UNITS

DETAIL	MATERIAL
Evaporator Shell plate, spray tray	SS 316 L
Effect vapour chamber	SS 304
Effect tube	90/10 Cu-Ni
Effect tube sheet	Naval brass
R1 condenser tube	90/10 Cu-Ni
R1 condenser tube sheet	Naval brass
R2 condenser tube	Titanium (TTH35W)
R2 condenser tube sheet	Titanium (TP49)
Ejectors and nozzles	SS 304

PERFORMANCE DETAIL OF THE DESAL UNITS

The performances of the desalination units are continuously monitored every week. The following table explains the various performance details of the desalination units and also it compares actual performances against their designed performance figures. The *Heat and Mass Flow Diagram* (Fig-2) explains the various flow parameters at different stages.

Table-3

WEEKLY PERFORMANCE CHECKS OF AZIZIAH UNITS [2]

No	**Item**	**Unit**	**Design at rated load**	**Desal**		
				A	B	C
1	Steam to main ejector	T/hr	*7.81*	7.36	7.81	7.36
2	Steam pressure	kg/cm^2 G	*8.0*	8	8	8
3	Steam Temperature	°C	*175*	175	175	175
4	Enthalpy of steam at 8 kg/cm2	KJ/kg	*2772*	2772	2772	2772
6	Sea water supply to evaporator	T/hr	*438*	445	320	440
7	Sea water feed flow to 1st effect	T/hr	*52.5*	51	52.5	54
8	Sea water feed flow to 2nd effect	T/hr	*52.5*	55	53	54
9	Sea water feed flow to 3rd effect	T/hr	*52.5*	53	51.5	55
10	Sea water feed flow to 4th effect	T/hr	*52.5*	54	52.5	55
11	Vacuum at the last effect	mm Hg	*-72*	-72	-72	-72
11	Product from desal	T/hr	*71.24*	75	78	74
12	Product to boiler feed water	T/hr	*8.74*	5.537	9.8	5.854
13	**Net product water flow**	T/hr	*62.5*	69.463	68.2	68.146
14	Product water temp	°C	*43*	43	43	43
15	Enthalpy of product water	KJ/kg	*180*	180	180	180
16	**Gain Output Ratio (GOR)**		*8*	9	8.7	8.9
17	**Performance Ratio (PR)**		**6.715**	7.55	7.3	7.44

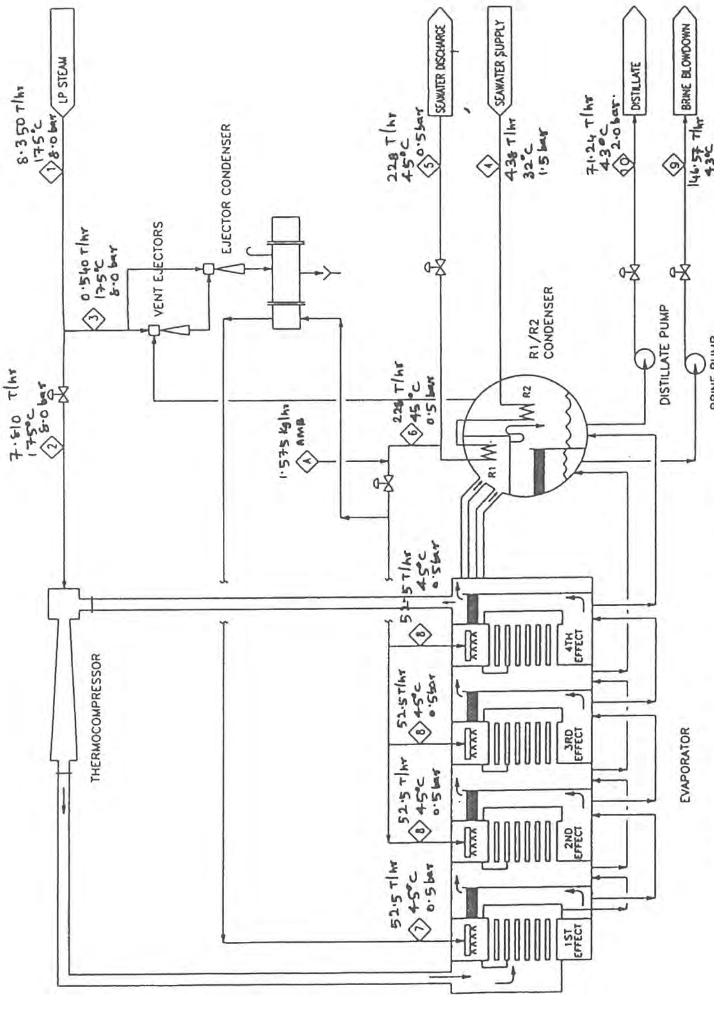

FIG -2 HEAT AND MASS BALANCE DIAGRAM OF 1500 T/D DESALINATION UNIT

OPERATIONAL EXPERIENCE

The operating performance of Azziah's three MED-TC units are quite satisfactory and consistent over the long period of service . Even after 15 years, the actual performance is still matching with design conditions and even demonstrated more than the .design figures. The trouble free operation of the units can ensure the availability of the plant more than 98%. The units offer flexibility in operation and even in the wide range of turn down capacities , the performance indices are closer to the design values .

The Gain Output Ratio (GOR) of the running units is more than the design value of 8.0. The Performance Ratio(PR) is more than 7 against design PR of 6.715. Under full load operation the production goes up to 110% of the designed output. Table-3 describes the performance detail of the running units under full load operation. The performance of these units, even at part load, is closer to the design values which can be best understood from Table-4

Table-3

PERFORMANCE RATIOS [3] OF THE AZIZIAH- MED UNITS UNDER FULL LOAD CONDITION

PERFORMANCE DETAIL	DESIGN AT RATED LOAD	DESAL -A	DESAL-B	DESAL-C
Distillate Production (T/d)	**1500**	1643	1602	1541
GOR- Gain out put ratio	**8.0**	8.8	8.5	8.2
PR – Performance ratio	**6.715**	7.9	7.7	7.4

Table-4

PERFORMANCE RATIOS [3] OF THE AZIZIAH-MED UNITS UNDER PART LOAD CONDITION

PERFORMANCE DETAIL	DESIGN AT RATED LOAD	DESAL -A	DESAL-B	DESAL-C
Distillate Production (T/d)	**1500**	994	977	1069
GOR- Gain out put ratio	**8.0**	8.5	8.4	8.0
PR – Performance ratio	**6.715**	7.7	7.6	7.3

The operation of these units are trouble free. There are only less instrumentation and no moving parts in the evaporators. The unit is fully automatic in operation. The start up of the units are simple; simply open the steam valve, press the pump start buttons and adjust the initial settings; there are no critical levels, temperatures, pressure or flows; hence no complicated control adjustments. The stable process balances itself smoothly and can be left unattended for long periods.

The potential advantage of multi effect distiller process is its lower energy demand compared RO and MSF processes. The power consumption is only 2.2 $kWhr/m^3$ of water production at Aziziah and this includes sea water intake pump and boiler feed pump.

Another outstanding features of these units are extremely low tendency for scaling. The low operating temperature lowering the corrosion and scaling and the top brine temperature is less than 60 deg C. In addition all these units are dosed with Belgard-EV2030 scale inhibitor at a rate of 2.0 ppm. Earlier the plant observed more scale formation in the 1st effect of the three units and in 1995 some modification was carried out in the scale inhibitor the dosing system. In addition to the existing one dosing point, one more point was introduced near 1st effect ; the scale inhibitor was changed from Belgard EVN to Belgard-EV2030; after this modification , the scaling problem was completely stopped. In the fifteen years service of Azziah plant , acid cleaning was carried out only 2 times in Units B &C and only one time in Unit–A. Routine inspection is being carried out, once in six months and so far no major scaling problem was noticed.

In 1995, the plant noticed some problem of salt accumulation near the main ejector entry point of 4th effect. The salt started falling and accumulating on the R1&R2 condenser tubes affecting the heat transfer. In order to avoid the salt accumulation on condenser tubes, the plant carried out some modifications, stainless steel trays were introduced above the condenser tubes . During these period each unit was under shut down, more than two weeks, otherwise there was no forced shutdown in any of these three units for more than 3 days. Even the yearly routine maintenance doesn't take more than 10 days.

The heat exchanger tube material exhibits very good corrosion resistance property and so far no tube leakage problem was noticed in the effect tubes. In the last three years, the plant noticed some leakages in the *titanium condenser tubes* of heat rejection section R2 . The total number of tubes plugged is less than 2% in each unit. Rise in the conductivity level of the distillate is the indication of condenser tube leakage.

MAINTENANCE EXPERIENCE

Each unit is taken for routine maintenance once in a year for 10 days. Cleaning, scale removal and internal inspection are being carried out during this period. Replacement of Zinc anodes in all the effects, inspection of ejector nozzles, checking of all the valves, replacement of effect gaskets and thickness survey of the evaporator plates are the routine maintenance activities.

Once in two years, the units are taken for major overhauling. During this time, the overhauling of the pumps, motors, valves are being carried out.

In the year 1997, plant observed a sudden degradation in the water quality. When the evaporators were opened and inspected , the sea water trays were found with full of mud and sea shells , and the evaporator bottom was with lot of sand particles. This problem might be due to the disturbance of sea water by a contractor working near the sea water intake system. This problem was overcome by introducing a strainer before the inlet of the sea water intake pump.

In February 2002 , the plant faced poor vacuum problem in Desal Unit-B. The internals were checked thoroughly and no reason was noticed. Finally hydrostatic test was conducted and it revealed that there was gasket leak in one of the man hole opening door.

Tube leakages were noticed in the condenser tubes of heat rejection section R2, and the conductivity of the distillate necessitated this checking. Leaking tubes were plugged and the total plugging is less than 2% of the total tubes.

Except the above few problems , the plant has so far not faced any major maintenance problem. MED-TC units are relatively maintenance free, and the expenditures on spares are very minimal compared to RO & MSF units.

ADVANTAGES OF MED-TC PROCESS

MED process is more efficient ,from a thermodynamic and heat transfer point of view. As per Morine's study [4], MED process offers a recovery of almost 50% higher than MSF process for equal performance ratio. The pumping power and specific heat transfer area required for MED system are 20% and 50% [4] respectively that needed for MSF plants. Moreover , instead of making more number of partitions in the MSF plants, only partitions of less than 50% effect are to be made for MED plants having the same performance as that of MSF plants. So, the capital cost of MED system is expected to be about 50% less than that of MSF distillation system.

MED process is competing with RO with respect to simplicity and specific energy consumption. MED process is very simple and the plant occupies very less space. Here there are no gravity filters, pressure filers, Cartridge filters, and high pressure pumps. The specific power consumption at Aziziah MED plant is only 2.2 kWhr /m^3 where as Ummlujj RO plant consumes more than 10kWhr/m^3. Less moving parts, Less instrumentation, no complicated control adjustments make the MED plants very easy for operation and maintenance.

CONCLUSION

The operating experience, on Aziziah MED units, is quite satisfactory, their efficiencies are still better and their performances are more than the expectations. The operation is simple, maintenance is very low and the plant can easily be run with relatively less manpower. Low temperature operation, less corrosion and scaling, low energy consumption, ease of operation and maintenance all these combine to give the MED plant of highest reliability.

Even after 15 years of service, plant at Aziziah seems to be brand new, the internals are intact and there is hardly any degradation of materials. Selection of better material is one of the main reasons for the above conditions. Assessing the existing condition of the plant , units can easily be run for minimum another 20 years. The maintenance expenses are insignificant and the cost incurred on spares is only 2%[5] of the total production cost. Oil is the main consumable for MED plant, which constitutes around 50% of the production cost.

Out of our experiences on various desalination processes, MED is considered as a better option, for medium capacity desalination plants, especially for oil rich Gulf countries.

REFERENCES

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Study of Material Selection and Their Performance in the Al-Jubail SWRO Desalination Plant

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STUDY OF MATERIAL SELECTION AND THEIR PERFORMANCE IN AL-JUBAIL SWRO DESALINATION PLANT

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ABSTRACT

The Al-Jubail Seawater Reverse Osmosis (SWRO) Desalination Plant is the world's second largest SWRO Plant, owned by Saline Water Conversion Corporation (SWCC). It has a capacity to produce 20 millions imperial gallons per day (equivalent to 24 USMGD). The plant consists of three sections: pretreatment, RO and post treatment sections and uses two different RO membrane-configuration systems namely Dupont Twin Permeators (Model 6880T) and Toray spiral-wound membranes (Model SU 822 HP).

The study has carried out detailed survey of materials used for piping, pumps, valves and other major components. It has been noticed that many different materials including fiberglass-reinforced plastics (FRP), stainless steels and high nickel alloys were used. A discussion is also included on the reasons for selection of a particular material for a specific medium.

The plant was commissioned in September 2000 and since then running at different modes of operation, partial capacity and full capacity operation for fifteen (15) months. The behavior of materials in various streams such as seawater, brine, acidified feed water, lime dosed product water and chemicals have been discussed. There were some cases of material failure in the plant, which have been elaborated in detail. The contractor of the project took corrective measures to rectify these failures. Finally, plan is already set for long-term study in order to evaluate the design and selection of materials at a later stage.

1.0 INTRODUCTION

The commissioning of the plant was commenced in the end of 2000 and was completed in January 2001. The plant was constructed in a modular design such that any section or sections of the plant could be operated or shut down for maintenance without interrupting the operation of other sections. The main sections of the plant are:

1. Pre-treatment – 14 Dual Media Filters (DMF) with relevant pipe work valves etc.,
2. Backwash Tank complete with two 5,000m^3/h backwash pumps,
3. Filtered Water Clear well complete with three 8,300 m^3/h Filtered Water supply pumps,
4. 16 Micron Cartridge filter vessels containing 160 cartridges of ten micron size,
5. 15 Reverse Osmosis Trains, Capacity: 253 m^3/h
   (11 trains equipped with Dupont B-10 twin membranes and four trains equipped with Toray spiral wound SU-822 HP membranes),
6. Two 645 m^3 Backflow Tanks,
7. Product Water Clear well tank and three 1800 m^3/h Product Water pumps,
8. Chemical dosing building including chemical preparation and dosing systems,
9. Instrument Air compressors, Chillers and cooling water pumps,
10. Control Room building,
11. Product Water post treatment (Lime addition and CO_2 injection),
12. 2 x 53,000 m^3 product water storage tanks

2.0 CHOICE OF MATERIALS FOR SWRO PLANT

The choice of materials for SWRO Plant can never be completely resolved. In the last twenty years, there has been an increasing trend towards the use of high-grade materials. Site specific environmental conditions such as seawater chemistry and temperatures and the material problems specifically related to the local desalination environment can exert considerable effect on the system design and the subsequent selection of materials [1]

In 1979, the first major SWRO plant was installed at Red Sea Port of Jeddah by Saline Water Conversion Corporation (SWCC). It was mostly constructed of 304/316 stainless steels. From that time and until the year 2000, the time at which Al-Jubail SWRO Desalination Plant was commissioned, the SWCC has gained considerable experience in the field of material selection for SWRO Plants.

The major factors that determine the suitability of materials are their resistance to various types of corrosion in the aggressive chloride-containing environment. Seawater is the dominant environmental factor which influences the corrosion of various alloys used for the desalination equipment and mainly the high-pressure piping, high-pressure pumps and energy recovery turbines. Corrosion data of various alloys, and analysis of materials performance used for different parts and system of SWRO desalination are normally collected from the operating plants. The evaluation of these results is used to define the suitability of these materials for their application in SWRO Plants. The outcome of such an evaluation was used to develop material specifications for Al-Jubail SWRO Desalination Plant.

It is worthwhile to discuss some of the results of the seawater analysis that are most important and affecting the materials. The oxygen content of Al-Jubail seawater is 5 ppm at 35^0 C. The oxygenated seawater is supplied to the Dual Media Filters (DMF), Cartridge Filters, and the high-pressure pumps. High concentration of chloride ions (24,090 ppm) dictates for the utilization of high-grade materials.

2.1 Materials For Different Streams: In the following tables the materials for different streams of Al-Jubail SWRO Plant has been described:

2.1Material For Seawater Feed Stream [2], [3]

The same materials have been used for unfiltered seawater, product water, brine (above ground), filtered seawater, and sodium hypochlorite

Butterfly valves (Sizes 50-240mm) *Body:* *Cast Iron/Ductile Iron/Carbon Steel* *Lining:* *Buna-N Rubber* *Disc:* *Ni-Al-Bronze/Ni-Resist Iron* *Shaft:* *Exposed Stem Design: Monel* *Concealed Stem Design: (ASTM A 240, S 31254)* *Seat:* *Buna N Rubber* *Bearing:* *Teflon/Nylon*	**Lift Check Valves (Sizes 15-40mm)** *Body:* *Bronze, (ASTM B-61 & B-62)* *Disc:* *Monel* *Seat Ring:* *Monel* **Swing Check Valves (Sizes 50-300)** *Body:* *Bronze/Al-Bronze (ASTM B-61, B-62)* *Flapper:* *Buna N. Rubber with internal* *Reinforcing steel plates*
Ball Valve (Sizes: 15-40mm) Body: Bronze/Al-Bronze *Ball:* *Monel* Stem: Monel Seat: Teflon	

2.2 Materials for High Pressure Streams [2], [3]

The same materials have been used for high pressure RO feed water and brine water.

Piping Stainless Steel ASTM A-312, S-31254 Fittings/Flanges Stainless Steel ASTM A-312, S-31254 Gaskets Compressed Asbestos **Gate Valves (Size: 50-100mm)** *All materials: ASTM A 351 CD4 M Cu Duplex Stainless Steel* **Globe Valve (Size 15 – 200mm)** *Body: Duplex Stainless Steel, ASTM A 351* *Trim: Duplex Stainless Steel, ASTM A 351*	**Ball Valves (Size 15 – 300)** *Body:* *Duplex Stainless Steel, ASTM A 351, CD4 M Cu* *Ball:* *Duplex Stainless Steel, ASTM A 351, CD4 M Cu* *Stem:* *Duplex Stainless Steel, ASTM A 351, CD4 M Cu* *Seat and Seals: Teflon* **Butterfly Valves (Size 15 – 300mm)** *Body:* *Duplex Stainless Steel, ASTM A 351, CD4 M Cu* *Disc:* *Duplex Stainless Steel with Monel,* *Shaft:* *Duplex Stainless Steel, ASTM A 351, CD4 M Cu* *Seat:* *Duplex Stainless Steel, ASTM A 351,CD4 M Cu* *Bearing: Teflon*

2.3 Materials for Permeate/Header/Manifold Product Water inside Building [2], [3]

[Also used for Permeate Header, Permeate Manifold, Product Water Piping inside R.O Building, Lime Water (inside the building and above ground), sodium bisulphite (inside the building and above ground).

Ball Valve (Size 15-40mm) *Body: ASTM B-61/B-62 Bronze/Al-Bronze* *Ball: Stainless Steel TP 317 L* *Stem: Stainless Steel TP 317 L* *Seats: Teflon* **Ball Valves (Size ½" – 2")** *Body: PVC, ASTM D 1784,124* *Seat: Natural Rubber (EPDM)*	**Butterfly Valves (Size 50-2400mm)** *Body: Cast Iron, Ductile Iron, and Carbon Steel* *Lining: Buna N-Rubber* *Disc: Stainless Steel TP-317 L* *Shaft: Stainless Steel TP-317 L* *Seat: Buna N or EPDM Rubber* *Bearing: Teflon* **Swing Check Valves (Size 15 – 40mm)** *Body: Bronze ASTM B – 61 / B – 62* **Swing Check Valves (Size 50 – 300mm)** *Body: Bronze ASTM B – 61/B – 62* *Epoxy coated Cast Iron (ASTM A-126B)* *Flapper: Buna N-Rubber with internal reinforcing Steel Plate*

2.4 Materials for Chemical Cleaning System[2], [3]

Also used for, Sulphuric Acid, Sodium bisulphite, Polyelectrolyte, PT-A and PT-B Solution.

Globe Valves (Size ½" – 12") *Body: Stainless Steel ASTM A351 CF 8M* Trim: Stainless *Steel TP316* *Packing: Teflon* **Butterfly Valve (Size 10" – 12")** *Body: Stainless Steel ASTM A351 – CF8M* *Disc: Stainless Steel ASTM A351 – CF8M* *Shaft: Stainless Steel TP316* *Seat: PTFE* *Packing:PTFE*	**Ball Valves (Size ½" – 12")** *Body: Stainless Steel ASTM A351 CF 8M* *Ball: Stainless Steel ASTM A 351 TP 316* *Stem: Stainless Steel ASTM A 351 TP 316* *Seats and Seals: Teflon* **Check Valves (Size ½" – 12")** *Body: Stainless Steel ASTM A351 CF 8M* *Trim: Stainless Steel ASTM A351 TP316*

2.5. Materials for Rotating and Stationary Equipment [3], [4]

Table 1 describes the quality of different streams. It gives the actual values of total dissolved solids (TDS), Chloride content, pH and free chlorine content of the different streams.

Table 2 summarizes the piping materials, which have been used for different streams.

Tables 3 and 4 describe the material of construction for vertical pumps, chemical dosing pumps and storage tanks.

All Chemical dosing pumps, SS 316 Ti for dosing head and vlave seats, SAE 5115 for shaft, and PTFE for Diaphragm is standard materials as shown in Table 4. Table 5 shows the materials of construction for water and storge tanks.

3.0 MATERIAL FAILURES IN AL-JUBAIL SWRO PLANT

The plant was commissioned in September 2000 and since then running at different modes of operation, partial capacity and full capacity operation for fifteen (15) months. The behavior of materials in various streams such as seawater, brine, acidified feed water, lime dosed product water and chemicals have been discussed. There were few cases of material failure in the plant, which have been elaborated to a large extent.

3.1 Failure of the Elastomeric Polyurethane Coating of the Dual Media Filters and the Backwash Tank

By the end of January 2000 all 14 DMF chambers were in operation. Even though the plant was operating satisfactorily during the first few months of 2000 it became apparent that the elastomeric polyurethane coating was not adhering to the walls of the DMF chambers. This was particularly evident in the seawater return channel. Large sections of the coating were peeling off the walls. This was most obvious where the seawater channel wall was opposite to the backwash outlet penstocks, which suffered from direct impingement of a high velocity water stream whenever the backwash out penstock opened during the backwash sequence.

Earlier, it was experienced that in addition to lack of adherence of the elastomer coating to the walls of the DMF, particles were actually flaking off the walls. Black particles were found in various locations such as the backwash tank and the filtered water clear well tank. Fortunately, the RO section of the plant was well protected by 16-micron cartridge filters having a pore size of 10 microns. Although, examination of some of the cartridge filters found that black particles had adhered to their surfaces. To further enhance the protection provided to the R.O. membranes by the cartridge filters, the individual cartridge filter size was reduced to 5 microns. The backwash tank was also coated with the same elastomeric paint as the DMF chambers. Subsequent inspection of the backwash tank showed coating was peeling off the floors, wall and ceiling of the tank.

A number of reasons have been postulated for the failure of this coating namely the presence of atmospheric humidity during application and inadequate preparation of the concrete substrate before application. Subsequently, it has been found that the most likely mode of failure is inadequate preparation of the concrete substrate resulting in voids on the concrete surface. This is the most likely cause of lack of adherence of the elastomeric polyurethane.

It was, therefore, decided that rehabilitation of the DMF section and backwash tank would take place and consequently the R.O. plant was totally shut down in June 2000 to accomplish this. Several methods of removal were tried to speed up the removal of the coating, including heat lamps accompanied by hand scraping and flame removal. Finally a specialist contractor was employed to carry out the task of complete refurbishment of the DMF section, filtered water channel, seawater channels and the backwash tank. Work commenced on the backwash tank early in June 2000 and was completed by the end of August 2000. Hydro-Jetting was successfully employed to remove the defective coating using water pressures up to 2,500 psi. The original coating was replaced with a superior Epoxy coating. Replacement of the coating with Epoxy of both the DMF and backwash tank has proved to be satisfactory and no deterioration or lack of adherence is seen to date.

3.2 Failure of High Pressure Hoses

The High Pressure hoses consist of a rubber hose, which is reinforced internally with steel wire. The hoses are manufactured to DIN specification and are rated at PN 150 (150 bar). The bursting pressure is rated at 500 bar. At either end of the H.P. hose are two stainless steel ferrules one of which is a screwed fitting which fits directly into the permeator vessel and the other is attached to the feed or brine header pipe with a victaulic clamp.

Catastrophic failures of H.P. hoses have occurred on about 22 occasions. Most of the failures have been as a result of the hose blowing out of the ferrules at the screwed end. Since the failures occur on either the feed side or the brine side the pressure can be up to 85 bar. The consequences of these failures is that the waving of the hose in all directions causes damage to the surrounding PVC pipe work such as sample points, permeate hoses and permeate header pipe work. The hose itself is subject to extreme stresses in such a way that the hose self-destructs. Small pieces of reinforcing wire can be found embedded in adjacent H.P. hoses. In addition to this, seawater or brine floods the whole area and can ingress into the electrical equipment and instrumentation cabinets causing damage. If the H.P. hose fails on the brine side, damage to the permeator membrane can occur.

There is a risk to personnel working in close proximity to these H.P. hoses for such purposes as conductivity measurements on individual permeators and sampling. Since conductivity measurements are an extremely important parameter for membrane assessment, a permanent solution must be found. Two solutions have been proposed:

1. To connect each permeator using rigid piping made from Duplex stainless steel. This is considered to be a practical solution for the four Toray trains. But to connect the Dupont trains would be impractical since each pipe would have to be individually site manufactured, bent and fitted. There would be no interchangeability between permeator vessels.

2. Flexible hoses manufactured from duplex stainless steel with ferrules welded at both ends and externally reinforced with metallic mesh. These would be a direct replacement for the existing hoses without the necessity for modifications to pipe-work.

3.3 High Pressure Pump Motor Oil Cooler Failures

Two oil coolers are fitted in the bearing housings at both the pump end and turbine end of the high-pressure pump motors. Originally, cooling water was tapped off from the second stage of the high-pressure pump and distributed to both motor bearing oil coolers. The cooling medium was seawater, which was highly aerated. The cooling medium flow rate was 500 liter/hour and average temperature difference was 0.5 °C.

Approximately 30 oil cooler failures had occurred up to date. Some of the coolers were repaired and refitted back in their original motors. Some coolers failed for a second time and were again repaired and refitted. Failure of an oil cooler carries with it the likely hood of damage to the H.P. pump motor bearing from contamination of the oil with seawater. It was concluded that the level of aeration of the seawater was responsible for the oil cooler failures.

The oil cooler consists of a finned cooling tube, which is connected to long seawater inlet and outlet tubes through a flange. The present failure in the form of a wide pit was observed at outlet of the cooling coil tube just before the weld area. The system was later modified by replacing the seawater with service water in a closed system. A separate chiller was utilized for controlling the cooling water temperature. The corrosion was completely eliminated after this change.

3.4 Failure of Cartridge Filter Caps

Many bottom cap of the cartridge filter assembly and the threaded portion (both male and female) of the stud developed corrosion. The bottom cap of the micron cartridge filter, threaded portions, stud body and welded shaft were all analyzed by EDX technique. The EDX studies of the corrosion products on stud threading (male and female) showed the presence of Mo, Cr, Fe, Ni, Cl^- and O in major amounts and K, Ca, Mg and Na in smaller concentrations.

The pits on the surface of the bottom of cartridge filter and the presence of thick deposits of corrosion products on the threading were indicative of local attack brought about by crevice corrosion. Such a situation arouse as a result of accumulation of water at the interstices of threading for considerable period of time. The slightly lower Cr and Mo contents of the material than the specified composition of 904L might be partially responsible for the crevice corrosion of the components. As the cartridge filter body remains immersed in seawater, seepage of water through the bottom of the cartridge filter to the threading of the stud is imminently possible. Many of the filter cap nuts assemblies and threaded portion were found to be of the wrong material. Approximately 400 were therefore replaced with super duplex stainless steel. Approximately 30 hexagonal nuts (embedded in the FRP filter shell) were also replaced with super duplex stainless steel. A rubber gasket between the filter basket assembly and the shell was fitted

3.5 Failure of Suction Valves of H.P. Pump

Each High Pressure Pump has butterfly type suction valve. The medium through the valve is seawater, pre-treated with Sodium Bisulphite, diluted sulphuric acid (H_2SO_4), ferric chloride ($Fe\ Cl_3$) and polyelectrolite [pH of treated water: 6.8, Inlet valve pressure: 5 bar, flow rate under operating conditions: ($723m^3/h$)].

Physical Inspection: The visual inspection of the bodies of the suction valves to the High Pressure pumps for Train A, B, C and D indicated that the valve discs of Train A and C did not appear to have much deposition and initiation of pits was observed at some locations. Valve disc of Train B showed severe pitting and marks. The surface was covered with white and red deposits. The marks appeared to be as those formed by impingement of seawater. Valve disc Train D showed pits filled with reddish brown deposits and the surface had greenish color. Erosion marks were observed at the edges of the disc.

Composition of the valve disc material: The chemical composition of the metallic sample taken from disc of Train D, was determined by Inductive Coupled Plasma (ICP) technique. The result of the analysis indicates that the material is aluminum bronze.

The visual examination of valve discs of Train B and D showed severe pitting and deposit formations. The pits in disc of Train D were filled with reddish brown deposits indicating rust like corrosion products. The surface was discoloured and had greenish tinge. The edge of the disc showed erosion/corrosion marks. The surface morphological features of Train D based on visual observations indicated that there was a severe chemical attack on the surface. The results of EDX analysis showed abnormally high Aluminium contents in the corrosion products and significantly high concentration of Iron. That clearly indicated leaching of Al and Fe from the aluminum bronze substrate. The disc material under spell of long period of stagnancy in the seawater underwent de-aluminification leaving a copper rich substrate covered with aluminum rich deposits containing iron, this was followed by initiation of pitting of the substrate alloy in a high chloride environment. The Disc of Train B appeared to have similar features but the surface was covered with pox like bigger pits. Whitish grey constituents surrounded the mouths of the pits. The discs from valves of Train A and C did not show significant corrosion but shallow pits were noted. The severe corrosion and pitting in discs of Train D and B could be attributed to de-aluminification of aluminum bronze material in seawater under stagnant conditions.

Stagnancy of the upstream seawater should be avoided by insertion of an isolating valve prior to suction valve followed by flushing with low conductivity water during shut down of the system (down stream of the isolating valve). As the currently used valve disc material made of aluminum bronze is subjected to corrosion in seawater under stagnant condition, better alloys like Monel or high stainless steels should be considered [6].

3.6 Failure of RO Train High Pressure Control Valves

In order to achieve stable and accurate control of an RO train four main high-pressure control valves are installed as per the design in the system as follows:

1) An RO feed flow control valve installed on the discharge side of the high pressure feed pump
2) An energy recovery turbine (ERT) priming valve
3) An ERT by-pass valve installed in parallel with the ERT
4) A brine flow control valve again installed in parallel with the ERT.

All these control valves are of the ball type with central passages and baffles known as "Q-Trims." The body of the valve is manufactured from Super Duplex Stainless steel. The valve ball material conforms to ASTM A890 Gr. 5A- tungsten-chromium carbide (W/Cr) C. The valve seat is manufactured from N-Stellite ASTM A351 Gr.CK3McuN (254MC) + (W/Cr) C.

During normal operation of an RO train the feed control valve controls the total feed flow at 723 m^3/h. The two brine valves the coarse and fine valves set the recovery rate to 35% which gives a permeate production of 253 m^3/h. Commissioning of the RO plant commenced in January 2000 and operation continued throughout that year. After operating the trains for some time it was found that some of the control valves were sticking. This was particularly noted with the RO feed valve during the train start up sequence. It became necessary during the start up sequence to pre-open the RO feed control valve to 15 to 20% immediately prior to the start of the H.P. feed pump as a temporary solution. This prevented sticking of the valve and the consequent aborting of the start up sequence. This indicated that some damage had occurred to the internals of the control valve. The damage observed is listed below:

S. NO	Item	Defect
1	RO feed valves	Corrosion in wear sleeve-bearing housing. Holding bolts of Q-Trim and coating of ball damaged
2	ERT Priming valves	Coating of ball damaged. Damage to baffle in one valve
3	ERT by-pass valves	Erosion of Q-Trim baffles, ball coating damaged
4	Brine flow control valves	Erosion of Q-Trim baffles, ball coating damaged

The defect as explained above applied to all fifteen trains. Investigation of the surface defects of the valve trim parts showed that a common feature of the surface damage was that the ball coating had disappeared mainly on the points lying under the seat rings, the valve being in the closed position. The type of damage observed was consistent with crevice corrosion. In some cases corrosion of the substrate Super Duplex stainless steel had occurred. Corrosion was localized because outside the sealing ring area the coating was in good condition and was adhering well to the substrate. The mechanism of crevice corrosion was that in areas where there were tight clearances or crevices, conditions were different from an open surface. The oxygen content in the crevice was diminished compared to other surfaces. This created a potential difference where crevice points became less noble than the larger free surface. This started preferential corrosion of crevice areas. In addition, the chloride concentration in the crevice area was higher than elsewhere.

Tungsten chromium carbide is a corrosion resistant coating having a nickel binder and is generally very resistant to seawater and brine. Other such failures of this type of coating have not been reported. It is possible that a long set-up and commissioning time had created more severe conditions than expected during the design phase. Another indication of harsh conditions was that the highly alloyed Super Duplex and Super Austenitic stainless steels were also partially attacked. The scope of the repair work was as follows:

RO feed valves: replacement of all damaged parts, re-coating the ball, welding of the Q-Trim holding bolts and insertion of an additional baffle plates on the outlet of the RO feed valves

ERT by-pass and Brine control valves: replacement of the Q-Trims and modifying the baffle plates.

The objective behind the insertion of an additional baffle plate on the RO feed valve and modifying the baffle plates on the brine valves was to achieve a large valve opening during normal operation of the trains thus preventing any erosion of the valves due to turbulence within the valve bodies. Repair of the valves proved to be effective and no further sticking in normal operation has occurred. Insertion of an additional baffle plate at the exit of the RO feed valve and modifications to reduce the open area of the baffle plates of the ERT by-pass valve and brine control valve has produced larger opening angles of the valves during normal operation. By this modification the erosion of the valve internals has been eliminated to a large extent.

3.7 Failure of Rubber Lined Process Valves

Many of the process valves installed on the 20 MIGD RO plant at Al-Jubail were specified in the original plant design to be rubber lined to resist the aggressive nature of seawater and brine. During the commissioning of the plant many of the valves showed signs of corrosion on the metallic parts particularly the flange faces. The rubber lining inside was not adhering to the valve body. A total of three hundred and twenty five valves were affected. The process fluid was able to migrate behind the rubber lining. This was despite a full-face gasket being fitted in all cases. Ingress of seawater between the valve body and rubber lining caused the lining to become detached from the valve body. A notable complete failure of a rubber-lined valve was in the case of the RO feed header drain valves. Severe leakage of these valve bodies resulting from corrosion was evident. All such valves were removed and re-lined. Also the rubber lining was extended to partially cover the flange faces. After relining, the valves were replaced in the various locations but in some cases the re-lining proved to be ineffective and again some of the valves were found to be leaking.

The most process sensitive valves were completely replaced with valves of a slightly different design. In this design a shallow groove was cast into the valve flange face. This groove was specifically there to retain the rubber lining and to prevent migration of the medium between the valve body and the rubber lining. The following table lists the most process sensitive valves that were replaced:

Serial No.	Size (mm)	Description	
1	350	Cartridge filter outlet valve	16
2	350	Cartridge filter inlet valve	16
3	50	Cartridge filter drain valve	16
4	350	Filtered water to RO train suction	15
5	50	RO test room inlet isolation valve	1
6	150	RO train low TDS flushing valve	15
7	150	Half train permeate valve banks 1 and 2	30
8	200	Permeate to backflow tank	15

The remaining process valves, which had been rubber-lined locally are performing satisfactorily and are left in situ. The replaced valves with the improved design are also performing satisfactorily.

4.0 CONCLUSIONS AND RECOMMENDATIONS

Considering material cost, installation, maintenance, and corrosion resistant, the large size pipes of Reinforced Thermo Setting Resin Pipe (RTRP) have been selected for low pressure streams, and for high pressure streams, super duplex stainless steel S-31254 has been specified. Control valves used for throttling purposes, generally experience cavitations, hence as a result, duplex stainless steel S-31254 (CD4MCu) was selected. Performance of the epoxy coating for concrete surface in wet environment was far superior than the elastometric polyutherane coating. It is also concluded that using low TDS water for cooling system solved the corrosion problem which was faced while using seawater.

ABBREVIATION

RTRP: Reinforced Thermosetting Resin Pipe
PVC: Polyvinyl Chloride (ASTM D 1784, 12454B)
CPVC: Chlorinated Polyvinyl Chloride (ASTM D 1784)
SS 316: Stainless Steel (ASTM A 312 TP 316)
S-31254: Stainless Steel A 312, S-31254
N-08904: Stainless Steel N 08904
ASTM: American Society for Testing and Materials
PVDF: Polyvinyl Idene Fluoride
Ti: Titanium
SS: Stainless Steel
AISI: American Iron and Steel Institute
SAE: Society of Automotive Engineers (USA)
PTFE: Poly Tetra Fluoro Ethylene
TDS: Total Dissolved Solids

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Table 1: Qualities of Different Streams in Al-Jubail SWRO Desalination Plant[5]

No.	Stream	TDS (ppm)	Chloride (ppm)	pH	Chlorine (ppm)
1	Raw Water from Sea	45,320	24,817	8.3	1.0 – 1.5
2	Raw Water Conditioned	45,320	24,817	7.0	1.0
3	Filtered Water to Cartridge	45,320	24,817	7.0	1.0
4	RO Feed Water	45,493	24,817	6.8	0.0
5	Permeate	200	120	5.72	0.0
6	Brine	70,955	38,000	6.93	0.0
7	Product Water	290	150	8.5	0.5
8	Back Wash Water	45,320	24,817	7.0	1.0
9	Low TDS Flushing Water	200	120	5.72	0.0
10	Chemical Cleaning Water	200	120	4.0-11.0	0.0

Table 2: Al-Jubail SWRO Plant Piping Material [2], [3]

S. No	Stream	Material	S. No	Stream	Material
1	Seawater (Unfiltered)	RTR	15	Polyelectrolyte Feed	SS 316
2	Seawater, Filtered	RTR	16	DMF Back Wash	RTRP
3	High Pressure Feed to RO Units	S-31254	17	DMF Air Scouring	SS 08904
4	Product (Permeate)	RTR	18	Sodium Bi Sulphite	SS 316
5	Brine (High Pressure)	S-31254	19	Chemical Cleaning Solution to RO Trains	SS 316
6	Brine (Low Pressure)	RTR	20	Chemical Cleaning Solution from RO Trains	SS 316
7	Product, Passivated	RTR	21	Lime Water Feed (Preparation)	SS 316
8	HP Header Manifold	S-31254	22	CO_2 Lines	SS 316
9	HP Header Brine Manifold	S-31254	23	Lime Water Feed System	RTR
10	Permeate Header Manifold	RTR	24	PT-A Dosing Line	SS 316
11	Sodium Hypo Chlorite	RTR	25	PT-B Dosing Line	SS 316
12	Sulphuric Acid	316 SS	26	Instrument Air	Galv. Carbon Steel A-53 Gr.B
13	Calcium Hypo Chlorite	CPVC	27	Plant Air	Galv. Carbon Steel A-53 Gr.B
14	Ferric Chloride	CPVC	28	Chilled Cooling Water	Galv. Carbon Steel A-35 Gr.B

Table 3: Materials of Construction for Vertical Pumps [4]

Service	Casing	Impeller	Shaft	Suction Bowl	Discharge Bowl	Pump Column
Filtered Water Pumps	AISI 317L	ASTM A 744 CG8M2 X (P306 A/B) ASTM A 744 CG3M 1 X (P306 C)	NITRONIC 50	AISI 317L	AISI 317L	AISI 317L
Filter Backwash Pump	AISI 317L	ASTM A743 C48M	NITRONIC 50	AISI 317L	AISI 317L	AISI 317L

Table 4: Materials of Construction for Chemical Dosing Pumps [4]

Service	Dosing Head	Shaft	Valve Seats	Diaphragm
Polyelectrolyte Barrel Pump	PVC	SAE 5115	Viton B	PTFE
DMF Polyelectrolyte Dosing Pumps	SS 316 Ti	SAE 5115	SS 316 Ti	PTFE
Ferric Chloride Dosing Pump	PVC	SAE 5115	PTFE	PTFE
Sulphuric Acid Dosing Pump	SS 316 Ti	SAE 5115	SS 316 Ti	PTFE
Sodium Bisulphite Dosing Pump	SS 316 Ti	SAE 5115	SS 316 Ti	PTFE
Polyelectrolyte Dosing Pumps For Lamella Separator	SS 316 Ti	SAE 5115	SS 316 Ti	PTFE
PT-A Dosing Pump	SS 316 Ti	SAE 5115	SS 316 Ti	PTFE
PT-B Dosing Pump	SS 316 Ti	SAE 5115	SS 316 Ti	PTFE
Sulphuric Acid Shock dosing Pump For Toray Trains	SS 316 Ti	SAE 5115	SS 316 Ti	PTFE

Table: 5 Materials of Construction for Tanks [4]

S. No.	Service	Material of Construction
1	Ferric Chloride Dosing Tank	RTR
2	Sulphuric Acid Tank	A 285 C (Carbon Steel)
3	Sulphuric Acid Dosing Tank	A 283 C (Carbon Steel)
4	Sodium Bisupphite	SS 316 L
5	Lime Silo	A 283 Grade B (Carbon Steel)
6	Lime Preparation Tank	SS 316 L
7	Lime Hopper	A-126 Class
8	Polyelectrolyte Preparation and Dosing Tank	Polypropylene
9	CO_2 Storage and Dosing Tank	STE 355 (Carbon Steel)
10	CO_2 Transportation Tank	STE 355 (Carbon Steel)
11	Calcium Hypochlorite Tank	RTR
12	Chemical Cleaning Tank	RTR
13	PT-A Dosing Tank	RTR
14	PT-B Dosing Tank	RTR
15	Product Water Back Flow Tank	Glass Coated Mild Steel Galvanized
16	Product Water Tank	Carbon Steel with Cathodic Protection

Water Transfer Versus Desalination in North Africa: Sustainability and Cost Comparison

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WATER TRANSFER VERSUS DESALINATION IN NORTH AFRICA: SUSTAINABILITY AND COST COMPARISON

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Abstract

The North African region is experiencing water scarcity that is getting more severe with time. The regional annual average per capita water availability has been reduced from 2285 cubic meters in 1955 to 958 cubic meters in 1990 and is expected to reach 602 cubic meters by the year 2025. To meet the present and future water demands of the region the available options are limited to either long distance water transfers from the southern aquifers to the coastal areas or to investing in large scale seawater desalination technology. Economic analysis revealed that the cost of long distance water transfer can escalate to more than 0.83 US Dollars per cubic meter. When sustainability considerations are taken into account this figure may reach up to 2.35 US Dollars per cubic meter. While these figures were competitive with the cost of seawater desalination twenty years ago, the situation has been recently shifted in favor of seawater desalination which dropped from 5.5 US Dollars in 1979 to less than 0.55 US Dollars in 1999. It is concluded that sustainable development of North Africa will depend in the future on large scale desalination as a last resort. Presently planned water transfer projects should be substituted by this fast growing technology as the best option.

Key words : water scarcity - water transfer - depetion cost - desaliation

Introduction

The relation between man and his environment in North Africa had been stabilized throughout the past centuries by the establishment of production systems and socio-political structures based on subsistence economics and a simple way of life. The introduction of misguided modern technologies and mutilated production systems imported from the highly developed economies of the humid western countries has shattered the intricate balance between the subsistence economies and the meager natural resources of the region, including water. Conventionally available water supplies on renewable basis are simply insufficient to meet the insatiable water demands of the present modes of economic activities and resource exploitation. Non-conventional water resources have not received the serious consideration they deserve for their full potential development. Thus the whole region is becoming increasingly dependent on the non-sustainable mining of local groundwater aquifers that are presently threatened by pollution and depletion. The search is on for alternative water supplies that are economically viable, environmentally sound and socially equitable. This article endeavours to evaluate the available options in view of the present level of technology and the information gained from real world practices.

The Present Water Resources Situation

The population of North Africa increased from 49.5 million in 1955 to 118.1 million in 1990 and it is expected to exceed 188 million by the year 2025 [1]. The total annual renewable fresh water supplies available in the region has been estimated at the fixed rate of 113.1 Km^3/yr. [2]. According to these figures, the regional annual average per capita water availability has been reduced from 2285 m^3 in 1955 to 958 m^3 in 1990 and is expected to reach 602 m^3 by the year 2025. Thus the whole region is already experiencing water scarcity that is getting more severe with time. As indicated in Tables 1 and 2 however, these regional averages mask the spatial variability of the severity of water scarcity on a country by country basis. Even within the same country water availability varies widely from one location to another.

Table 1. Total renewable available water supplies and population distribution in the North African Countries

Country	Water supply (Km^3/year)	Population (millions)		
		1955	1990	2025
Egypt	58.9	24.7	56.3	87.1
Morocco	28.0	10.1	24.3	36.3
Algeria	17.2	9.7	24.9	40.4
Tunisia	4.4	3.9	8.1	11.8
Libya	4.6	1.1	4.5	12.4
Total	113.1	49.5	118.1	188.0

Source: UNDP [1]

Table 2. Per capita renewable water availability in the North African countries

Country	Per capita water availability (m^3/year)		
	1955	1990	2025
Egypt	2385	1046	676
Morocco	2764	1151	770
Algeria	1770	690	426
Tunisia	1130	540	369
Libya	4103	1017	332
Regional Average	2285	958	602

Source: PAI [2]

The Available Options

Escalating water demands during the past 20 years led to severe pumping and overdraft of the local groundwater aquifers of limited extent and annual recharge. These aquifers have been exposed in several locations to unacceptable levels of piezometric declines and seawater intrusions with disastrous environmental and socioeconomic impacts. However, since almost all surface water supplies have already been developed to their full potential, to remedy the resulting deteriorating situation the available options are limited to either expanding groundwater exploitation in newly developed, previously untapped, aquifers or investing in large scale seawater desalination technology. These two options are discussed in the remaining parts of this article.

Increased Groundwater Exploitation

Most of the significant groundwater resources of North Africa are located in the southern Saharan and Sub-Saharan regions far away from dense population centers and important socioeconomic activities. This situation posed the question of whether to move people and their socioeconomic activities to where groundwater can be explored and economically exploited or to pump water and mass transfer it to where it is most urgently needed. The countries of the region are responding to both alternatives in varying degrees with more emphasis on one alternative than the other. Egypt, for example, is contemplating large scale agricultural settlement projects and industrial centers in the western and southwestern desert with the objective of reducing population pressure in the Nile Valley and exploiting the waters of the Nubian sandstone aquifer system [3]. On the other hand, Libya has emphasized huge mass water transfer schemes through its Great Man-made River project [4]. The other countries may start similar projects when they feel the need and get the means. But since the Saharan and Sub-Saharan aquifers are non-renewable, or their rate of renewal is much less than the planned abstractions of these projects, several issues concerning their sustainability and role in the future development of the region must be raised and satisfactorily settled before heating up the race for their exploitation. These issues include the basis for sharing a most likely non-renewable common pool resource, the need for its cooperative regional study and management, conflict avoidance and risk aversion and socioeconomic integration among the countries sharing the resource.

The question as to whether exploitation in situ, or long distance mass water transfer is more viable, cannot be settled by economic analysis alone, since several strategic and sociopolitical factors are involved. However, as will be explained later, economics does and can be safely used to compare the viability of mass groundwater transfer vis a vis desalination, since both are intended to provide the already established socioeconomic activities and population centers with their escalating water demand.

Large Scale Seawater Desalination

No reliable data is available concerning the total actual capacities concerning desalination units presently operating in the region. It is generally agreed that the annual production of these units is relatively insignificant in proportion to total water demand, and quite modest compared to the production of similar installations in Saudi Arabia and the other Gulf states. But in spite of their limited capacities, their small production volume does satisfy part of the municipal and industrial water requirements of several communities in water shortage areas along the southern Mediterranean coast. Several factors, including poor management and lack of spare parts and local skills for maintenance and repair, have contributed to the low operating capacities of these units in comparison to their full installed potential. These facts clearly indicate that desalination has not been taken seriously in the past. Most of the installed units came about almost through the commercial efforts of sales companies as accessory components to steam power generation plants. Some of them were installed under the expediency of short term drinking water shortages in certain locations. All of them, however, lack a long term rational plan to integrate them with the overall national water supply system.

Desalination technology in the region has been clouded with several misconceptions and lack of understanding its multifarious aspects. Top level decision makers usually associate desalination with international companies of imperialist tendencies that monopolize this technology to extract the highest possible price for its products. As a result only very rich nations that are willing to squander their national wealth can afford the high cost of desalinated water. These misconceptions should be immediately corrected since all available facts and information, as will be demonstrated later, clearly indicate that desalinated water is no longer so expensive as it has been thought and desalination technology is not monopolistic.

Sustainability and Cost Comparison

The only available example of mass water transfers that has been implemented in the region is the Libyan Great Man-made River project. After its completion the project will transfer and redistribute a total of more than 2 billion cubic meters per year. Whenever large-scale mass water transfers are considered, the financial resources available for investment in these projects and the expected cost of the transferred water are of prime concern. It is essential to compare the average unit cost of transferred water with the other potentially available alternate supplies.

The economic analysis performed during project conception estimated the average unit cost of transferred water at about 0.25 US Dollars per cubic meter, which was highly competitive with other alternatives such as seawater desalination estimated at 2.5 – 3.0 US Dollars per cubic meter at that time. Actual economic studies performed after the completion of stage one [5] revealed that the average unit cost of water to the user's gate, with the cost of capital set at 7 percent interest, is 0.83 US Dollars per cubic meter at 1991 prices. It is generally believed that this figure has been dramatically exceeded for the remaining stages of the project since that time.

While there is a clear trend of increasing costs of transferred water with time, the cost of desalinated seawater has witnessed during the last two decades a dramatic revolutionary trend in the opposite direction. The average price of desalinated seawater is today only one-tenth of what it was twenty years ago. It dropped from 5.5 US Dollars per cubic meter in 1979 to less than 0.55 US Dollars in 1999, including interest, capital recovery and operation and management [6]. A Tampa Bay seawater desalination plant in Florida, USA, was contracted in 1999 at a cost of 0.45 – 0.49 US Dollars per cubic meter in the first year of operation. This low cost of desalinated seawater takes on an international significance when compared with a proposed desalination plant in Singapore for which the first year cost of water has been estimated to be 1.5 US Dollars per cubic meter at its worst case [7]. It seems that mass water transfer projects in North Africa, at least as represented by the Libyan Man-made River project, have lost their economic advantages over the fastly developing and expanding desalination technology. When the questions related to sustainability considerations are raised, the advantages of the desalination option become even clearer. For example, the above mentioned cost of transferred water in the first stage of the Great Man-made River project was based on the costs of development, operation and maintenance of well fields and conveyance systems only. But since the exploited aquifers are nonrenewable, and thus nonsustainable, the scarcity value, or for a better term, a "depletion cost" of the mined groundwater resources should be taken into account when calculating the actual cost of the transferred water. A rough estimate of depletion cost can be derived according to the willingness to pay of the would be users, or as the equivalent of the cost of developing the least expensive alternative water supply that can be used to sustain the socioeconomic activities based on transferred water after its pumping and conveyance become uneconomical, or its feeding aquifers are completely exhausted.

In the absence of any sufficient amounts of surface water for development, the only available alternatives to the North African countries, including Libya, are limited to cross-boundary water importation or seawater desalination. Potential sources for cross-boundary water importation are limited to water diversions from Equatorial Africa or southern Europe. There are speculations at the present time concerning the technical, financial and political feasibilities of rerouting the Congo river towards the Northern Sahara, or at least diverting part of the water of its Ubangi tributary towards the river Shari that discharges into lake Chad. But these speculations are in the realm of future dreams and devoid of any practical importance at the present level of socioeconomic planning strategies.

As to the south European source, a new emerging technology promises to provide most of the southern Mediterranean region with good quality water at a reasonable price through water importation by mega-sized plastic bags [8]. These so called "Medusa Bags", having a capacity of 1.75 million cubic meters each can be loaded with water at specially constructed terminals at any southern European water source and tugged across the Mediterranean sea to unload there contents at any water receiving terminals in the southern Mediterranean coasts. The Canadian firm "Medusa Corporation" that develops this technology claims that it can supply the cities of Tunis and Tripoli at a cost of 0.17 US Dollars per cubic meter. Libya is currently involved in assessing this technology and its feasibility for future use in augmenting local water supplies.

But even if the Medusa bags or any other cross-boundary water importing technology proves its competitiveness with desalination, most of the North African countries will exclude the alternative of cross-boundary water importation simply on the mere grounds of national sovereignty and geopolitical considerations. Thus the only remaining alternative is seawater desalination. If we accept the cost of desalinated seawater at the conservative figure of 1.5 US Dollars per cubic meter, then the actual cost of transferred water through stage one of the great Man-made River project may reach up to 2.35 US Dollars per cubic meter inclusive of depletion cost. This is more than four times the cost of desalinated seawater. To achieve long-term sustainability of the transferred groundwater, it should be priced for utilization in production models that can generate the financial and economic resources to be needed in the future for the development of large scale desalination after the fossil groundwater aquifers are depleted. At the above actual price inclusive or exclusive of a depletion cost, it is unlikely to sustain this transferred water unless it is continuously subsidized throughout the project life. When the national treasury becomes unable to provide the required subsidies for any reason, the project either fails to achieve its objectives or will be put out of operation altogether.

Conclusions and Recommendations

Unlike what it used to be during the late 1970's and early 1980's, seawater desalination is becoming more than four times cheaper than transferred groundwater for the Saharan and Sub-Saharan aquifers, at least in the case of the Libyan Great Man-made River project. In view of these radical shift in water costs, the Libyan authorities must reconsider their position on whether to go ahead with completing the remaining stages of the Great Man-made River project and implement the other proposed water transfer projects from the Kufra, Ghadames and Jagbub areas, or stop any further expansion in water transfer projects and substitute them with large scale seawater desalination industry. They should also consider the development of large scale seawater desalination for mixing with the transferred water, especially in stage two of the great Man-made River project where the average nitrate concentration exceeds 60 parts per million. Mixing this transferred water with desalinated seawater at the proper ratio can both eliminate the negative health and environmental impacts of high nitrate concentration and augment the present water supply to meet the ever increasing future water demand. In addition to improving the overall water quality the added desalinated water will significantly reduce the average unit cost of the mixture. Simple economics and the new paradigm of development sustainability clearly indicate that even though water transfers my seem cheaper in the short run, project implementation and real life practical experience have shown that long-term sustainability of growth and development in North Africa will depend on large scale desalination as a last resort for meeting its future water demands. Recent awareness of developments in desalination technology and its strategic importance to the future of the region, especially to Libya, requires more concerted effort on the planning and installation level to put this industry on a firmer and permanent footing. The need for applied research and training in this fast developing field is quite apparent. Programs and plans for action to rehabilitate the present installations and construct new ones should be immediately considered at the present time.

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Thermoeoconomic Analysis of a Power Water Cogeneration Plant, Dr. O.A. Hamed, H. Al-Washmi

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THERMOECONOMIC ANALYSIS OF A POWER/ WATER COGENERATION PLANT

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ABSTRACT

Cogeneration plants for simultaneous production of water and electricity are widely used in the Arabian Gulf region. They are proved to be more thermodynamically efficient and economically viable than single purpose power generation and water production plants. There is no standard or universally agreed upon methodology to be applied to determine the unit cost of electric power and desalinated water produced by dual purpose plants.

A comprehensive literature survey to assess and critically evaluate the different methods, which have been used for cost application in power/water cogeneration plants, is reported in this paper. An in-depth thermo economic analysis will then be carried out for a selected power/water cogeneration plant. The plant employs a regenerative Rankine cycle incorporating a steam generator, back pressure turbine supplying steam to two MSF distillers, a deaerator and two feed water heaters. The turbine generation is rated at 118 MW while MSF distiller is rated at 7.7 MIGD at a top brine temperature of 105°C. An appropriate costing procedure based on the available energy accounting method which divides the benefits of the cogeneration configuration equitably between electricity generation and water production is used to determine the unit costs of electricity and water. The capital charges of common equipment such as boiler, deaerator and feed water heaters as well as boiler fuel cost are distributed between power generated and desalinated water according to the available energy consumption of the major subsystems. A detailed sensitivity analysis was then performed to examine the impact of the variation of fuel cost, load and availability factors as well as capital recovery factor on the electricity and water production costs.

Keywords: Dual-purpose plants, available energy, water and power costs, sensitivity analysis

INTRODUCTION

Cost allocation between power and water for a cogeneration plant has been a controversial issue. Consequently, a number of methods have been recommended for cost analysis of dual purpose plants. Some are based on rigorous accounting procedures in which the cost of each involved energy/exergy stream is determined. Other methods are based on direct cost accounting which allocates all cost components between water and electricity according to certain rules of thumb such as exergy pro-rating, power loss due to extraction of steam to the desalter or cost allocation based on functional considerations.

Combination of second law of thermodynamics with economics (thermoeconomics) using energy or available energy (exergy) for cost purposes provides a very powerful tool for the systematic study and optimization of energy systems. Its goal is to mathematically combine in a single model the first or second law of thermodynamic analysis with the economic factors. The pioneering works in this field were carried out by R.B. Evans, Y.M. El-Sayed, R.A. Gaggioli and M. Tribus in the sixties [1]. However, the comprehensive effort to apply thermoeconomics systematically to the analysis, optimization and design of energy systems did not start until the eighties [2].

The two main approaches which are used for thermoeconomic analysis of dual purpose plants are micro-thermoeconomic analysis method, in which cost of each stream is determined, and direct cost allocation method which is based on certain rules of thumb.

Micro-thermo economic Approach

In this approach the cogeneration plant is divided into an arbitrary number of components which may or may not coincide with the plant physical structure. Cost evaluation of each stream is normally carried out sequentially in two steps. Firstly, carrying out a detailed energy/exergy analysis followed by an economic analysis conducted at each component level. From this, the cost of each stream is calculated using an appropriate energy/exergy costing method such as algebraic cost accounting method or the structural theory of thermoeconomics. In the Algebraic Cost Accounting approach [3, 4] algebraic money balance equations for each plant component or aggregate of components will be used to get distinct average unit cost for each energy/exergy stream. Usually, there are more unknown unit costs of energy/exergy streams than money balance equations and so auxiliary equations are required to be introduced. The rationale for determining auxiliary equations depends upon the purpose of analysis (design, operation, retrofit). When, as is typical in cost accounting, judgment has to be made in order to choose a choice from among seemingly equal reasonable alternatives. More than one choice can be made and the results compared. Consistency between different methods provides evidence of their validity.

The structural theory of Thermoeconomics which is developed by Valero et al, [5-10], permits to obtain a set of characteristic equations modeling the behavior of the components, from which the costing equations are obtained. Structural theory of Thermoeconomics provides a general mathematical formulation using a linear model. Plant's physical model is first transformed into a productive structure, which is a graphical representation of resources distribution through out the whole plant. Thus, the flow streams entering the component are always its fuels and the flow streams leaving the component are its products. Apart from the components representing the equipment items of the plants, two types of fictitious components appear in the productive structure: Junctions (represented by rhombus), where the products of two or more components are united to form the fuel of another component, and branching points (represented by circles), where an exergy flow is distributed between two or more components. The main objective of the productive structure is to determine explicitly the energy conversion efficiency for each subsystem. Depending on the aggregation level and on the nature of the thermoeconomic equations, the model will contain physical information about the actual system behavior with different accuracy degrees.

The productive structure is then mathematically described by three types of linear characteristic equations: those relating each fuel (exergy input) of a component to its corresponding product (exergy output), structural equations to describe the productive models of junction and branches and capital costing equations. The characteristics equations can be used for calculating the costs of all flows in the productive structure. The productive structure can be designed in different aggregation levels which are based on the functionality of the component, e.g., heater, pump, turbine. The total thermoeconomic cost of a flow will be the summation of the monetary cost of the fuel exergy needed to produce it and capital and maintenance costs generated in the productive process.

Direct Cost Allocation Methods

In direct cost allocation approach, capital and fuel costs are distributed between power and water on certain rules of thumb or criterion such as:

(i) Cost apportionment on the basis of exergy consumption of aggregates of components responsible for either water production or power generation [11&12].

(ii) Allocating all cost components among water and electricity according to functional considerations [13].

(iii) Calculating the cost of the two commodities on the basis of the lost electric power resulting from the quantity of steam passed to the desalination plant instead of being expanded in the turbine to generate more power [14-16].

(iv) Distribution of expenditures to water and electricity according to the deviation from an ideal point [17 &18]. The ideal point marks the point at which equivalent power is generated with steam demand to the desalination plant in an identical single purpose power or desalination plant. At this point all expenditures are shared solely to the product they serve.

Since production costs of power and water are site specific, it is thus intended in this paper to carry out a detailed thermo-economic analysis for a recently operated power/water dual purpose plant in the Kingdom of Saudi Arabia. The flow diagram of the selected power/ water cogeneration plant is shown in Figure 1. It consists of a regenerative Rankine cycle incorporating a boiler, backpressure turbine supplying steam to two feed water heaters, deareator and two MSF distillers. The maximum continuous rating (MCR) of the turbine/generator is 118 MW.The two MSF distillers have a total water rated capacity of 15.4 MIGD. Each MSF distiller has 13 recovery stages and 3 rejection stages. It is also designed to operate at a top brine temperature of 105°C with the combined use of scale control additive and on-line ball cleaning.

COST ALLOCATION METHODOLOGY

The cost allocation method which is selected for this study is based on exergy pro-rating. The capital and operating costs of each component are charged directly to the products being produced by that component. Capital costs of components which are directly responsible for electricity generation (turbine/generator) are allocated entirely to electricity generation. Capital charges of desalination plant are allocated to water. Cost of common equipment (boiler, feed water heaters, deaerator etc.) are apportioned between electricity and water production in proportion to exergy dissipated for power production and that consumed in the distillation process

The total water production cost will be the summation of the capital cost of MSF plant, capital cost allocated to water production for common equipment, fuel cost allocated to water production, spare and maintance cost, chemicals cost and operating and administrative personnel cost. On the other hand the total power generation cost will be the summation of the capital cost of turbo generator, allocated capital cost of common equipment, fuel cost allocated to power generation and other associated operation & maintenance costs.

COST ANALYSIS AT MAXIMUM CONTINUOUS RATING

The unit production cost of water and electricity of the selected cogeneration cycle were determined when the plant is operating at maximum continuous rating (MCR) generating 118 MW of power and producing 15.4 MIGD of water. The total capital cost of the cogeneration cycle is distributed into three separate components, which represents the cost of the distillation plant, turbine/generator system and the common equipment. The costs of the first two components are allocated entirely to water and power costs respectively. While the costs of common equipment are divided between water and power in proportion to the total exergy consumption of the distillation and power generation plants respectively.

A micro-exergy analysis was then carried out to determine the breakdown of the boiler fuel energy among the major subsystems of the cogeneration cycle. A specific simulator is used to calculate the exergy content of the main flow streams of the cogeneration plant. The results of the exergy analysis are shown on Figures 2 and 3. Figure 2 shows the breakdown of the fuel energy into the major subsystems of the cycle. The two useful output products are the net electrical output of 104 MW and 15.4 MIGD of desalinated water inheriting 2.29 MW of available energy. Summary of the fuel available energy distribution between power and water are shown in Figure 3. Out of the 447.37 MW of fuel available energy supplied to the cogeneration cycle 96.15 MW (21.5 %) is dissipated in the MSF distillation plant, 114.595 MW(25.6 %) in the turbine/generator and 236.63 MW (52.9 %) in the common equipment (boiler, feed water heater, dearator). The available energy consumption of the common equipment is then distributed between water and electricity in proportion to the available energy consumption in the MSF distiller and the turbine/generator system. Figure 2 shows that the total fuel energy allocated to power generation and water production are 246.05 MW and 201.316 MW respectively which represent 55 and 45 percent of the cycle fuel energy input.

The cost of common equipment as well as the boiler fuel energy consumption are apportioned between water and power according to the total available energy consumption of the distillation and power generation plants.

The unit water and electricity costs at MCR base-line economic and cost data assumptions [plant life of 25 years,7% interest rate, fuel cost of $3/GJ and 90% plant availability] are then determined. The total water production cost is around $1.66/m^3$and breakdown cost is shown in Figure 4. The steam cost represents 52 percent of the total cost, capital depreciation 29 percent, electricity cost 6 percent and other operational and maintenance costs 13 percent.

The high steam cost of the MSF plant is the result of the combined effect of the fuel cost and the distiller energy consumption. A design parameter which influences both the fuel and capital costs is the distiller gain output ratio (ratio of mass of water produced and steam consumed). The MSF distiller which is considered for this study has a relatively low performance ratio of 6.5 which resulted in high fuel energy consumption at the expense of the low initial capital cost of the unit.

The total electricity cost is around $ 0.035 / kWh. Breakdown of the total electricity at base line assumptions is shown in Figure 5. The fuel cost accounts to 70 percent, capital charges 24 percent and 6 percent for other operational and maintenance expenditure.

SENSITIVITY ANALYSIS

A comprehensive sensitivity analysis was performed to examine the impact of the variation of the base line assumptions considered in the preceding section on water and electricity costs. The most important factors which influence water and electricity costs are plant life time, annual amortization rate (which account for the depreciation of the capital cost), plant load factor and availability and fuel cost.

Most of the MSF plants of the Saline Water Conversion Corporation (SWCC) of Saudi Arabia which were installed 20 years ago are still operating with excellent thermal performance and high reliability [19] revealing that a life time of more than 30 years can be achieved. As shown in Figure 6, increasing the plant life time from 20 to 35 years and keeping other base line economic and technical parameters constant will reduce water and electricity cost by 5.9 and 4.6 percent, respectively.

The annual capital depreciation cost is dependant on the annual amortization rate (investment annuity) which is function of interest rate and plant life time. Figure 7 shows increase of investment annuity from 7 to 10 percent will increase water and electricity costs by 8.6 and 6.7 percent, respectively.

Figure 8 Shows reduction of plant availability from 90 to 75 percent will increase the respective water and electricity costs by 6.1 and 4.76 percent. As exhibited in figures 9 and 10 operation of desalination plant with 100 percent load factor, which is matching 40 percent power load factor will increase water and electricity costs by 21.9 and 47.3 %, respectively.

Figures 11 and 12 show that water and electricity costs are highly sensitive to fuel cost. Increase of fuel cost from $1/GJ to $5/GJ will increase water and electricity costs by 119.7 and 179.3 percent respectively. At the high fuel cost of $5/GJ (corresponding to oil price of $30/bbl) the respective fuel cost of water and electricity represents 63 and 80.2 percent of the production and generation costs compared to only 27.7 and 44.8 percent at relatively low fuel cost of $1/GJ.

CONCLUSIONS

1. The exergy pro-rating cost allocation method is an appropriate and rational method for estimating unit water and electricity cost of a power/water cogeneration plant.

2. The impact of the variation of plant lifetime, availability and load factor, annual amortization rate and fuel cost on the costs of water and electricity of a selected dual purpose plant was examined at length.

3. Water and electricity costs are highly influenced by fuel costs and consumption. The economic viability of power/water cogeneration plants can be significantly enhanced by the selection of a cheap fuel source.

4. Research efforts have to be focused to improve the thermodynamic efficiency of thermal desalination processes.

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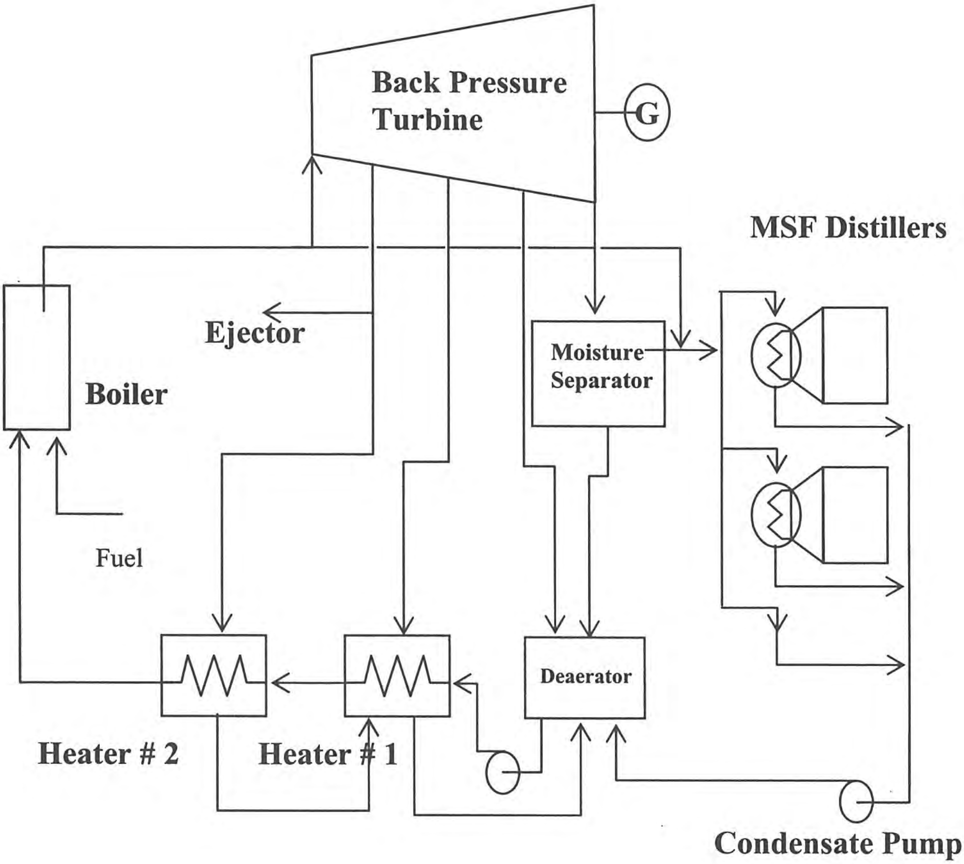

Fig. 1. Schematic diagram of power / water cogeneration plant

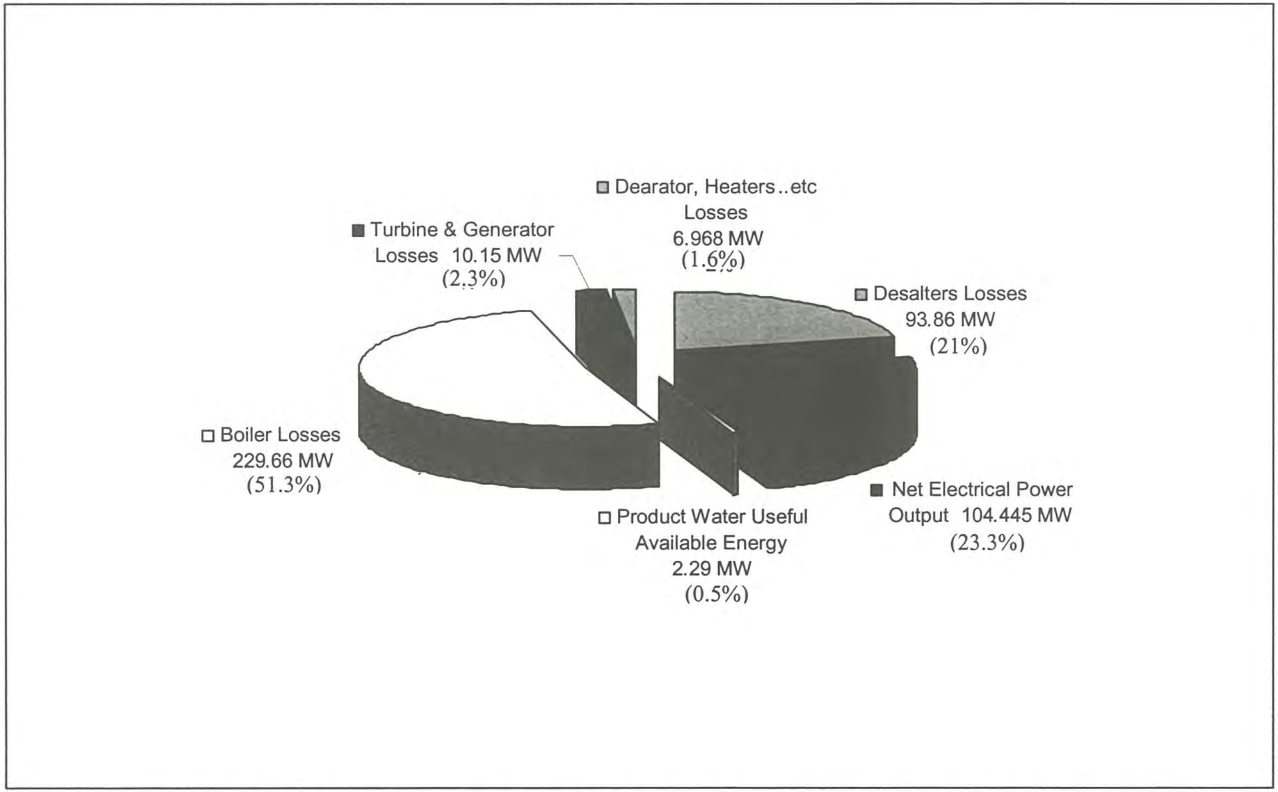

Fig. 2. Breakdown of Boiler Fuel Energy (447.37 MW) Among The Major Subsystems

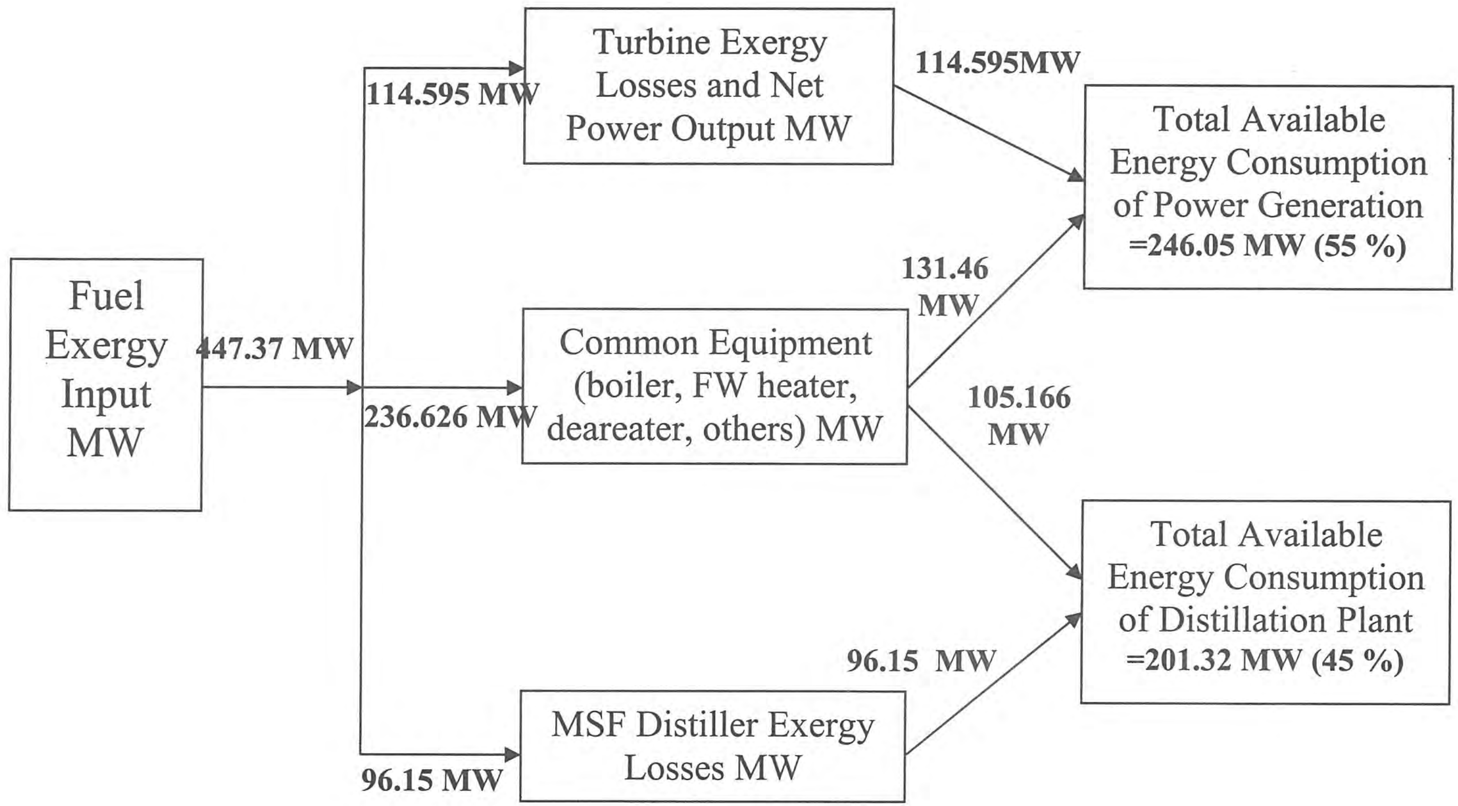

Fig. 3. Fuel Available Energy Allocated Between Power And Water

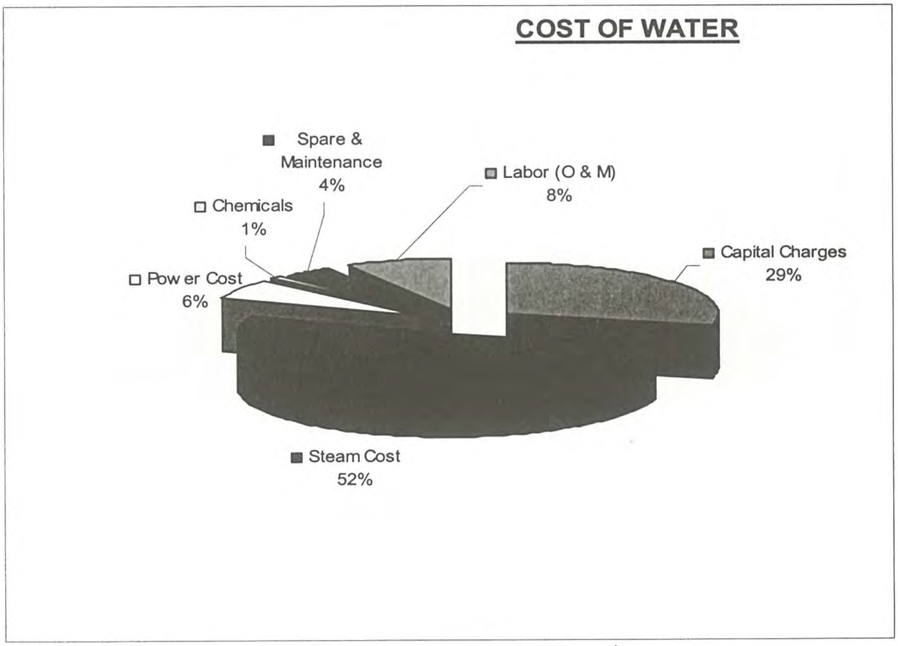

Fig. 4. Breakdown of water production cost at baseline conditions

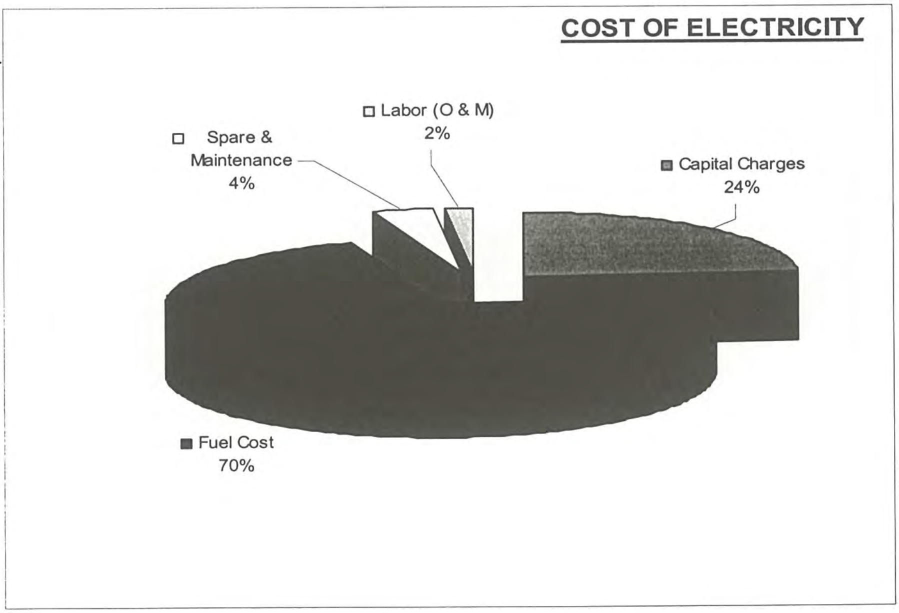

Fig. 5. Breakdown of power generation cost at baseline conditions

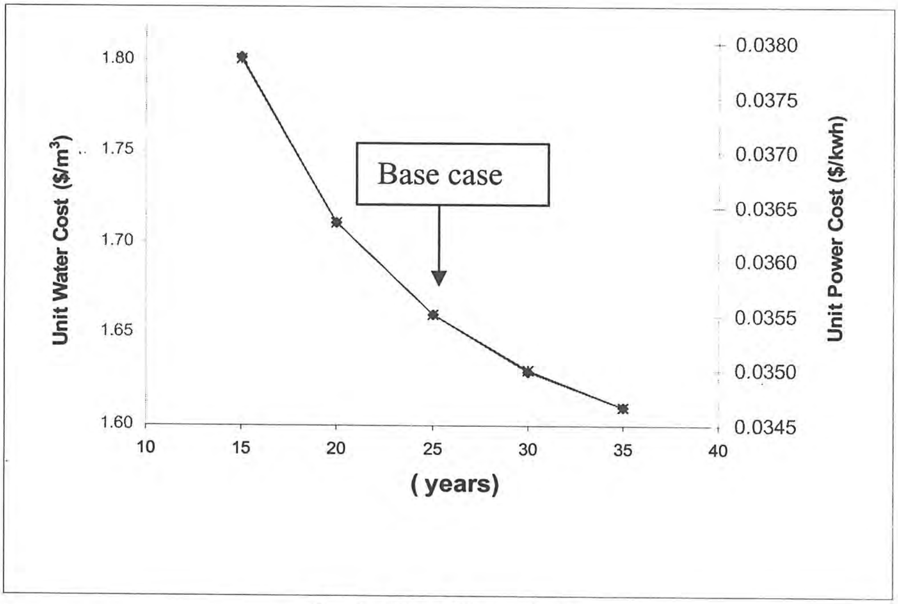

Fig. 6. Plant life sensitivity

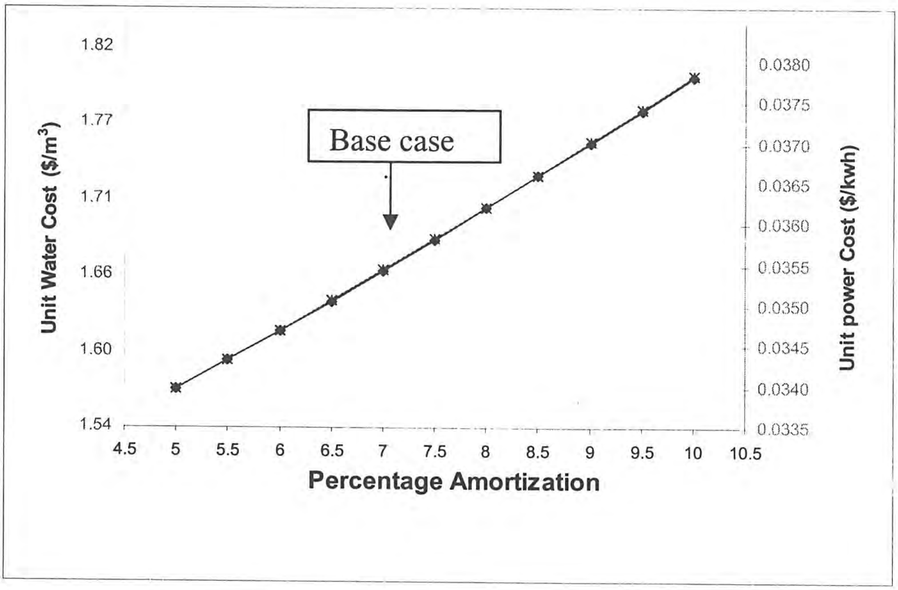

Fig. 7. Amortization sensitivity

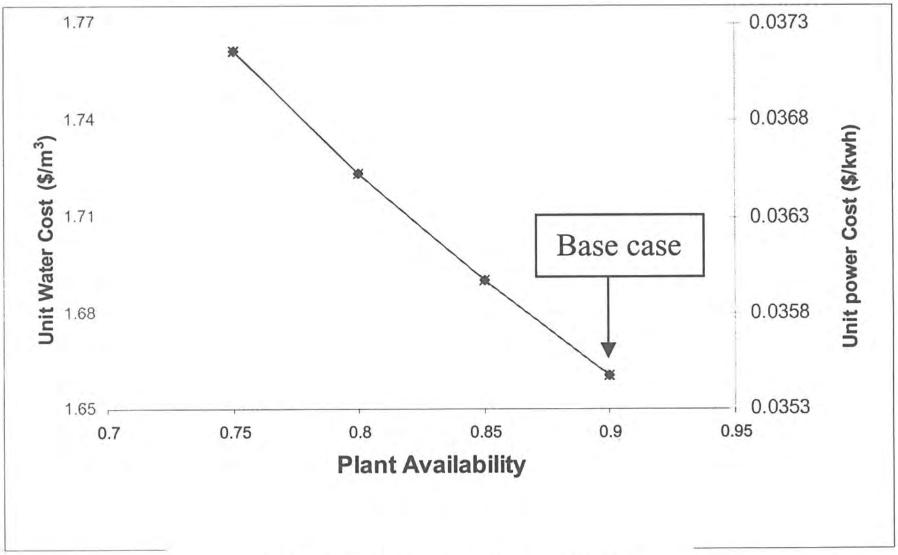

Fig. 8. Plant availability sensitivity

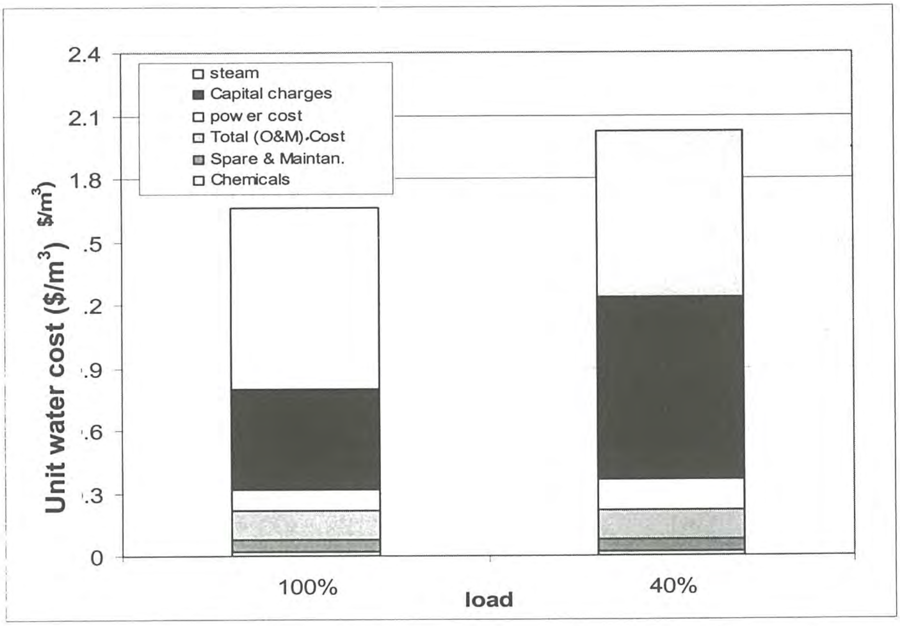

Fig. 9. Impact of partial load operation on unit water cost

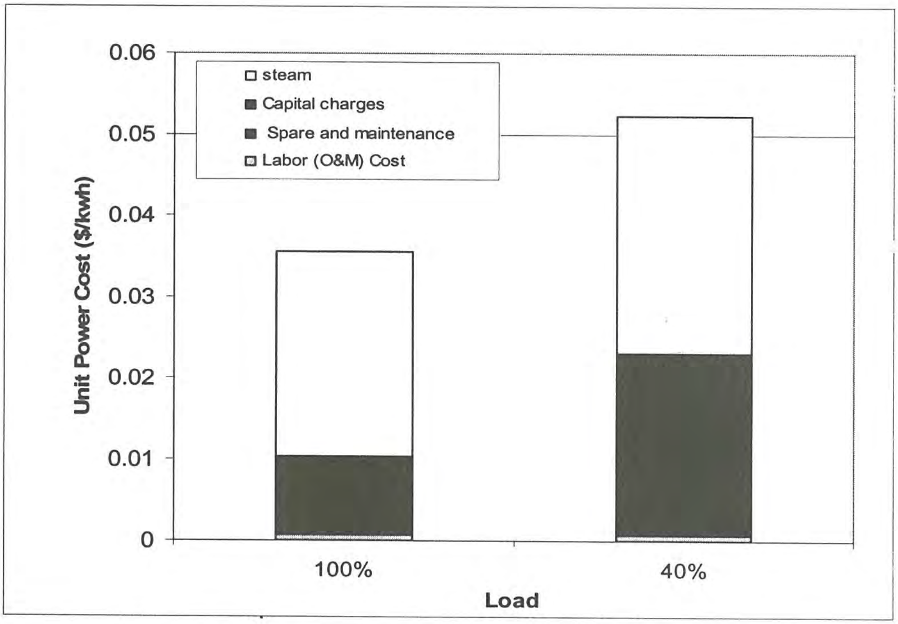

Fig. 10 Impact of partial load operation on unit power cost

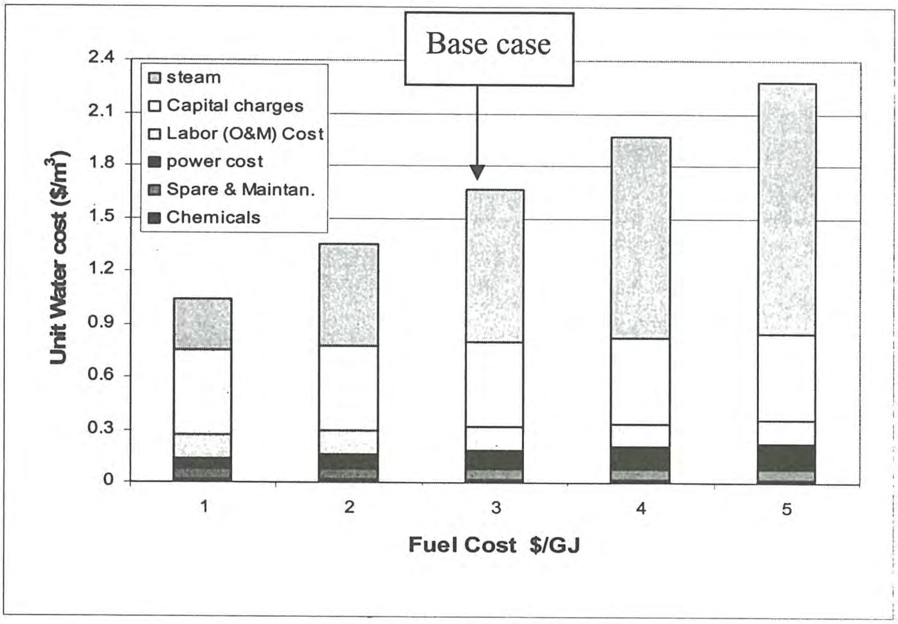

Fig. 11 Impact of variation of fuel cost on unit water cost

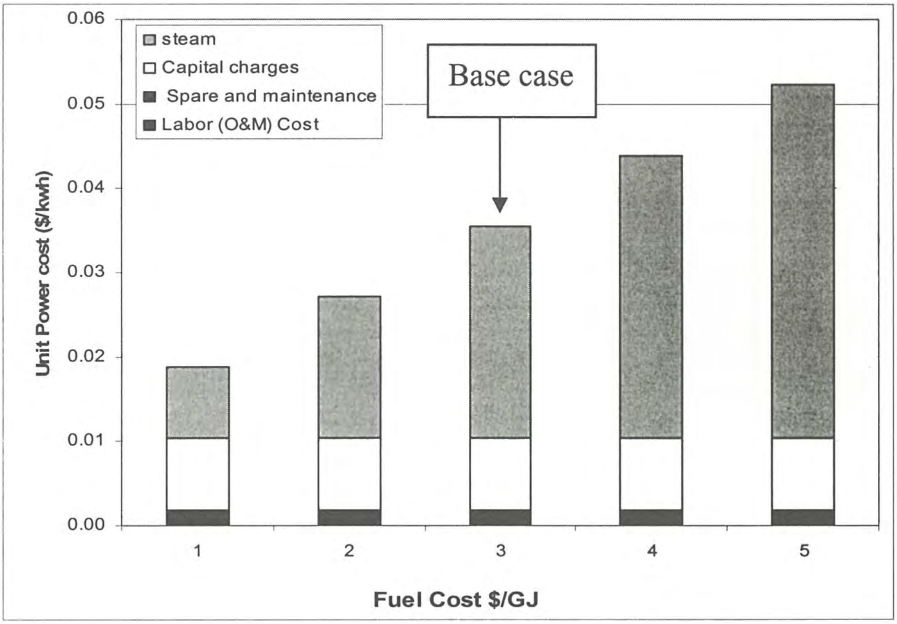

Fig. 12. Impact of variation of fuel cost on unit power cost

Using Dynamic Membranes for Treatment of Synthetic Waste and SWRO Feed Pre-Treatment

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Using Dynamic Membranes for Treatment of Synthetic Waste and SWRO Feed Pre-Treatment

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ABSTRACT

This paper presents the results of a preliminary work aimed at the evaluation of the performance of dynamically formed membranes (DFM) as a method for pre-treatment of feed water for desalination processes. Two types of feed water were tested, namely, sea water and water with synthetic foulant. The later type of feed was prepared from distilled water with 2.5 g/l sodium chloride and 100 g/l dried egg white as a source of protein foulant. An experimental rig was set-up incorporating a high pressure cell to manufacture the membrane in-situ using a 150 ppm solution of potassium permanganate on a thermally bound non-woven polypropylene/polyethylene fibers substrate. The dynamic membranes were formed using pH values ranging from 5 to 7, in a dead-end mode at a pressure ranging from 5 to 6.5 bars. The duration of membrane formation was set to 50 for tests on sea water, and 4 hours for tests on egg white/water samples. The permeation tests were performed in a cross flow mode at a pressure of 2 bars. Membranes formed at a pH of 5 resulted in a permeate of lowest turbidity and highest permeability. This result was true for both types of membranes. With the membranes used for egg white separation, 92% of turbidity removal and 57% UV retention were achieved.

Keywords: dynamic membrane, microfiltration, pre-treatment, albumin, potassium permanganate, sea water, secondary waste water

1. Introduction

Dynamic membranes are a class of membranes that can be formed in-situ using various types of colloidal materials on porous supports. A wide range of colloidal materials have been used to form dynamic membranes by various workers since dynamic membranes were first introduced in 1960s. Zirconium oxides, MnO_2 and polyvinyl alcohol are some of the materials that have been employed for this purpose [1]. Among the support materials utilized are micro-porous sintered stainless steel, alumina and polyethylene tubes, woven fibers and non-woven fabrics. The type of separation achieved can vary depending on the type of chemical used in the formation of the membrane and the operating conditions. Behaviours similar to reverse osmosis (RO), nano-filtration (NF), ultra-filtration (UF) or micro-filtration (MF) have been reported by various authors [1-5].

The objective of this work was to evaluate the suitability of a non-woven support fabric to form dynamic membranes by depositing MnO_2 from a potassium permanganate solution. The performance was evaluated by testing sea water and water with a model protein foulant, namely, dried egg white.

2. Experimental
2.1 Experimental Set-up

Fig. 1 shows a schematic diagram of the experimental setup. The heart of the process was the pressure vessel which houses the membrane. The pressure vessel was machined from a solid brass cylinder and consisted of a top and a bottom part with a perforated brass plate to hold the membrane support. The internal diameter of the pressure vessel was 90 mm and the height of the feed channel was 10 mm. The module can be operated in dead-end mode by closing the outlet valve on the exit of the feed side, hence allowing water to pass only through the membrane. In cross flow operation, this valve is opened. The feed was pressurised by two 1 hp Davey pumps connected in series, thus supplying a maximum pressure of about 6.5 bar.

The feed solutions were mixed with a stirrer in a 300 l polyethylene feed tank. The permeate and concentrate flow rates and pressures were monitored as well as temperature of the solution in the feed tank. Samples were taken for analysis using a Metrohm conductivity meter, a HF Scientific DRT-15CE turbidimeter and Shimadzu UV-1601PC UV-visible spectrophotometer.

2.2 Materials

The membrane support material used was a Viledon FO 2430 non-woven fabric of non-woven random thermal-bound polypropylene and polyethylene fibers supplied by Freudenberg Faservliessoff KG (Weinheim, Germany). This type of support material has been employed with success with zirconium oxide membranes [3].

The dynamic membrane was formed by depositing MnO2 particles on the membrane support fabric. The MnO_2 particles were precipitated from a potassium permanganate solution with a concentration of 150 ppm.

Two types of samples were tested, namely, sea water and samples prepared by dissolving dried egg white in water. The egg white consists of 88.2% protein, with ovalbumin of a molecular weight of 45000 making up 54% of the protein [3].

2.3 Experimental Procedures

Dynamic membranes were prepared using pH values of pH 5 and 7 and a potassium permanganate concentration of 150 ppm. The pH was adjusted using HCl. Dynamic membrane formation was carried out using the dead end mode by closing the concentrate valve (V1), thus allowing only the permeate flow. The initial pressure drop across the membrane was about 5 bar and the trans-membrane pressure increased until a value of 6.5 bar, which was the maximum pressure obtainable with the pump. Membranes were also prepared at a lower pressure and feed flow rate, with a starting pressure of about 3 bar and a maximum pressure of 5 bar. The formation period was set at 30 minutes for the early membranes (which were used to test sea water) and later increased to 4 hours to allow more time for forming the membrane. The formation characteristics were monitored by measuring the permeate flow rate at several intervals during the test. The flux decline was calculated as the test proceeded.

Following the membrane formation, the permeation tests were started during which the sea water and egg-white/water samples were processed in a cross flow mode by opening the concentrate valve. The pressure in this case was set to 2 bar. The duration of the permeation test was 2 hours.

The performance of the dynamic membrane was monitored by tracing the permeate quality, and flux decline. The permeate quality was monitored by taking samples at different to measure the turbidity using a turbidity meter and the absorbance using a Schemadzu spectrophotometer at a wavelength of 280 nm. The raw sea water turbidity was 12 and the turbidity of the raw egg white/water samples was 11.5. The UV absorbance of the raw egg white/water samples was 0.17.

3. Results and Discussion

Fig. 2 shows the increase in trans-membrane pressure drop and the decline in the flow rate during the formation of one of the membranes used for sea water treatment. It can be seen that a steady state pressure and flow rate is almost reached after 50 minutes. The membrane formation time reported in the literature [2] is 20 to 30 minutes for a dead end operation. One reason for the longer time required is the type of support material used in the current work, namely, non-woven fabric.

Figs. 3 and 4 show the results of permeation tests of sea water using membranes produced at pH values of 5 and 7. A steady turbidity is reached after about 5 minutes, while the flow rate reached a steady value after about 15 minutes. It can be seen that the membrane formed at pH 5 resulted in a higher flux while the turbidity of the samples treated with two membranes was almost the same. As a result, the performance of the membrane formed at pH 5 was considered to be better than the membrane formed at pH 7.

Fig. 5 shows the permeate flow rate decline and trans-membrane pressure increase for the membranes used to treat egg-white/water samples. In this case, the pump feed valve (V3 in Fig.1) was not fully open. The maximum pressure obtained was 5.7 bars and the flow rates was less those seen in Fig. 1 for which V3 was fully open. Steady flow rate was obtained at a time of about 120 minutes, as can be seen in Fig. 5. The formation of the membrane was extended to 4 hours as a precaution to allow enough time for membrane formation.

The results of permeation tests on egg-white/water samples are shown in Figs 6 to 8. The turbidity of the feed samples was 4.5 NTU. Fig. 6 shows that steady turbidities in the vicinity of less than 1 NTU are obtained with the membranes formed at the three pH values.

The minimum turbidity was 0.7 NTU with the membrane formed at pH = 7. This value corresponds to an 84% reduction in turbidity. The UV retention is shown in Fig. 7. The retentions for pH 5 and pH 7 membranes are close with values of about 32% and 34%, respectively, whereas the retention of pH 9 membrane was 24%. As a result, the performance of pH 5 and pH 7 membranes in terms of quality of permeate are similar and better than the pH 9 membrane.

However, the steady state permeability for the membrane formed at pH = 5 was 0.36 m^3/m^2.h.bar compared to 0.15 and 0.21 for membranes formed at pH 7 and 9, respectively. It should be noted that the permeabilities of the membranes formed are in the range of microfiltration membranes. However, the partial rejection of the proteins shows that some ultrafiltration capability is also obtained with these membranes.

4. Conclusions

Dynamically formed membranes were produced using a non-woven fabric as a support and a 150 ppm potassium permanganate solution as a membrane forming material. The MnO_2 membrane was used to treat sea water and water with a synthetic foulant prepared from 100 mg of dried egg white per liter of saline water. The membranes used to treat the sea water were formed by circulating potassium permanganate solution for 50 minutes through the membrane support cloth. The membranes used to treat separate the egg white from water were formed by circulating the potassium permanganate solution through the support fabric for 4 hours. Membranes formed at a pH of 5 resulted in a permeate of lowest turbidity and highest flux. This result was true for both types of membranes. With the membranes used for egg white separation, 84% of turbidity removal and 34% UV retention were achieved.

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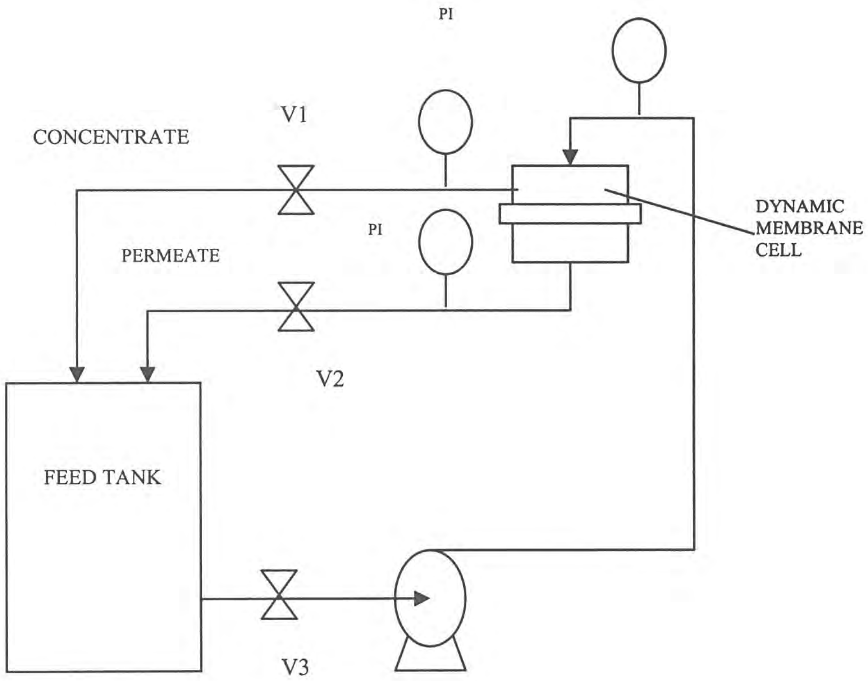

Fig. 1 Schematic diagram of the dynamic membrane experimental setup.

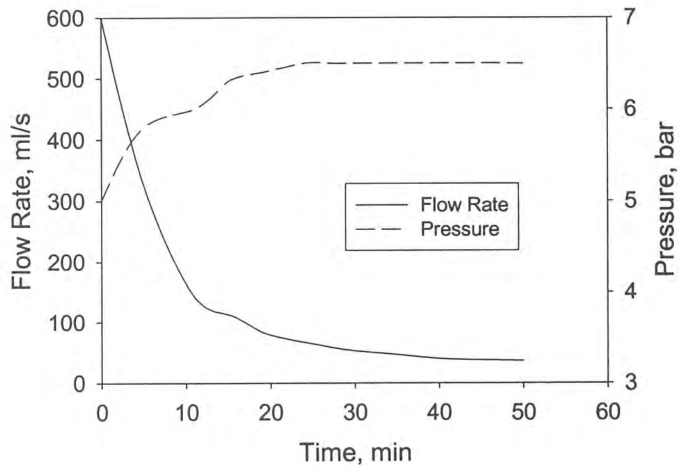

Fig. 2. Pressure drop variation and flux decline during the formation of the membrane at pH = 5.

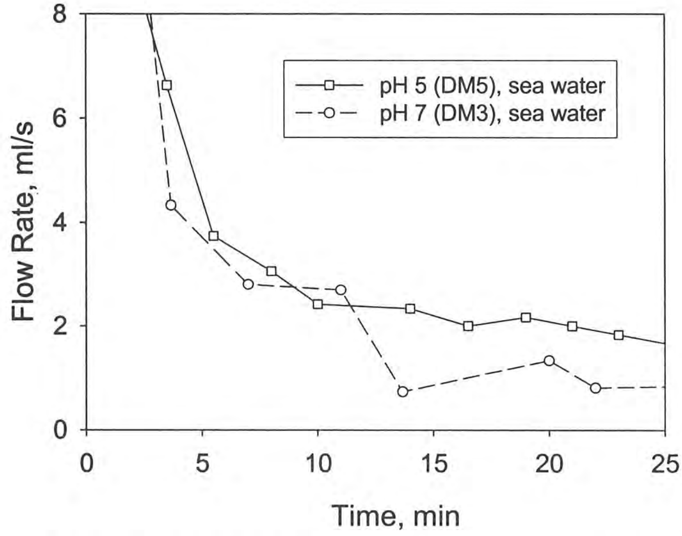

Fig. 3. Flux decline for the permeate of sea water treated with DFM membranes formed at pH Values of 5 and 7.

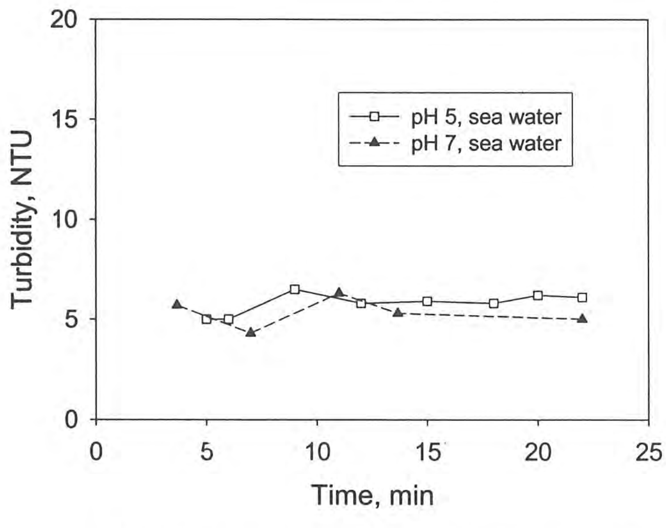

Fig. 4. Turbidity for the permeate of sea water treated with DFM Membranes formed at pH values of 5 and 7.

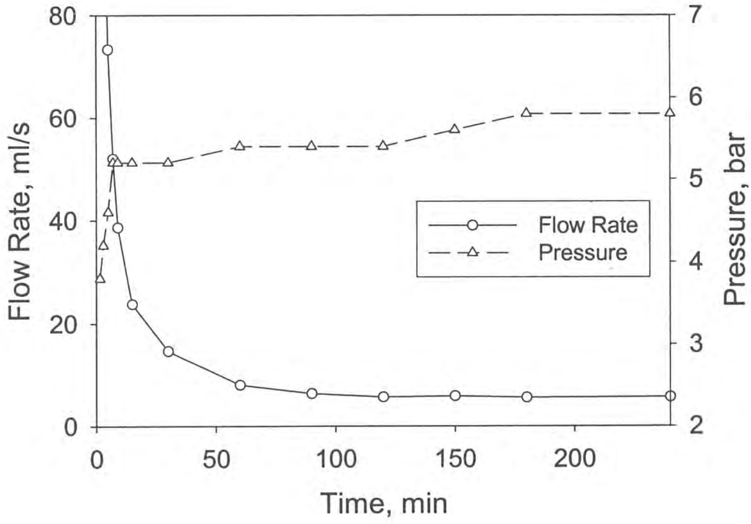

Fig. 5 Flux decline and pressure variation for the formation of membrane DFM 10 prepared using pH = 5.

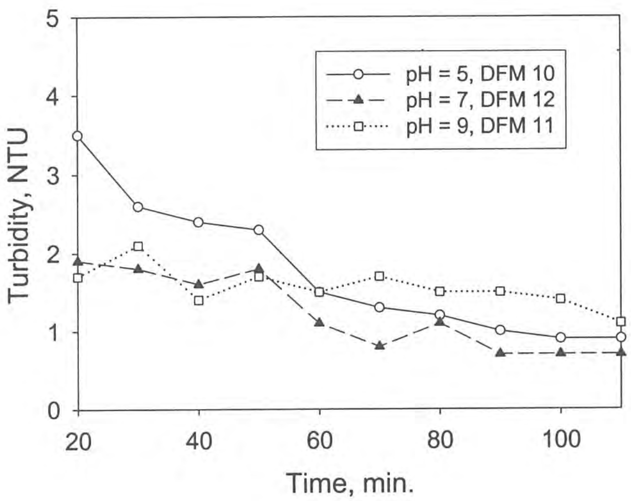

Fig. 6 Turbidity of the permeate of egg white foulant samples treated with membranes formed at different pH values.

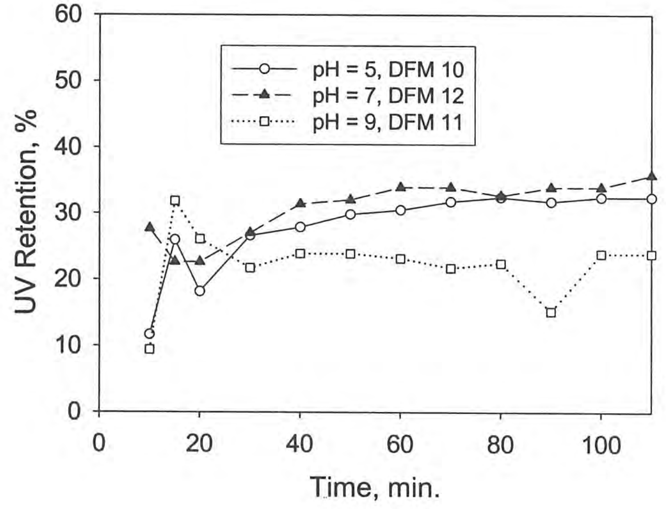

Fig. 7. UV retention of the membranes formed at different pH values.

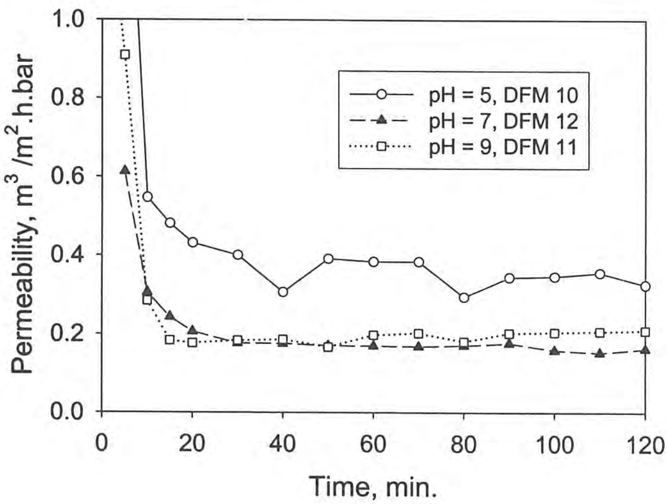

Fig. 8 Permeabilities of the membranes formed at different pH values.

Investigation of a Solar Still Coupled with a Flat Plate Collector

Dr. M. Abdelkader (Egypt)

INVESTIGATION OF A SOLSR STILL COUPLED WITH A FLAT PLATE COLLECTOR

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ABSTRACT

In this paper a solar still coupled with flat plate collector (active solar distillation system) is designed, manufactured and out door tested. A simple transient mathematical model is presented for water, glass cover and productivity. It is based on analytical solution of the energy-balance equations for different parts of the still. Numerical computations have been carried out for Port Said climatic conditions (31°17' N latitude, 32°12' E longitude). The thermal performance of the still has been investigated both experimentally and theoretically. Good agreement between experimental and theoretical results is observed. The theoretical and experimental investigations show that, the productivity is optimum when the collector inclination is 20°, the still glass cover inclination is 10° and the water depth in the basin is 0.075 m. It was observed also that the accumulative productivity of active solar desalination system is higher than that of the traditional one. The increase of productivity reaches to about 70% and it has a daily thermal efficiency of 44%.

Key words: solar energy- solar desalination- solar still- solar collector- active solar still.

INTRODUCTION

Many areas in the Middle East and elsewhere have little or no natural water supplies which can be used for human consumption and, therefore, depend heavily on water produced by desalination. In recent years desalination of water has been one of the most important technological undertakings of many countries in the Middle East. Multi stage evaporation, reverse osmosis, and electrodialysis are the three methods that are mainly used for desalination purpose. However, the abundance of sunshine in Egypt can also be effectively used to desalinate the seawater. Solar stills can partially support the man's need of drinking water with free energy, simple, cheap technology and clean environment, particularly in remote areas. Solar stills, on the other hand, act also as water natural dis-infection device, that uses natural solar ultra-violate rays, without any chemical additives. Solar stills has demonstrated their suitability when the weather conditions are suitable, the demand is not too large, source of fresh water and fuel are not available or difficult to be transport and the technical capabilities of users are limited. The problem of low daily productivity of the solar still s triggered scientists to investigate various means of improving the still productivity and thermal efficiency [1,2]. Solar desalination generally classified as a passive and active desalination system. The work on passive solar desalination has been reviewed by Malik et al [3]. Later on, some work on the active solar desalination system was carried out by some researchers [4]. Non of them has investigated the active solar system experimentally. The schematic diagram of the active solar distillation system is shown in Figs.1&2. The system consists of a basin solar still coupled with a solar collector by means of a pump. It has been designed, manufactured and outdoor tested at the solar energy laboratory, Faculty of Engineering, Port Said, (31°17' N latitude, 32°12' E longitude), Suez Canal University, Egypt. The basin type solar still is basically a pan of water covered with transparent glass cover. The brine water is admitted into the basin where is heated by absorption of solar energy. The base of the tray is blackened to facilitate this absorption. Since the water is substantially transparent to the short wave radiation from the sun, therefore the water liner always at a high temperature with respect to the basin water. As the water temperature increases, the motion of the water molecules become more vigorous and they are liberated from the surface in increasing number. Convection on the air above the water surface carries the vapor molecules away to the glass cover. As the glass cover temperature is always at a relatively lower temperature than the vapor temperature, therefore the vapor starts to condense on the under side of the glass. The glass cover is adjusted with certain inclined angle to the horizontal to prevent the falling of the formed water droplet back to the basin, and allowed only to run down to the trough. The condensed water is discharged out the unit as fresh water. After vapor condenses on the glass, the carrier air is now cooled due to releasing the latent heat of condensation to the atmosphere. The cooling air becomes heavier than the hot air at the water free surface, thus the convection current will continue to reach the thermodynamic balance inside solar still. A flat plate solar collector is coupled with the still by means of a pump. Flat-plate collectors are the most common collectors for water-heating installations. A typical flat-plate collector is an insulated metal box with a glass cover called the glazing. The glazing can transmits a high percentage of the total available solar energy. The glazing allows the light to strike the absorber plate but reduces the amount of heat that can escape. The sides and bottom of the collector are insulated, further minimizing heat loss. A copper water-closed circuit between the still and the collector transfers the heat from the collector to the brine in the still by forced convection. In this paper a theoretical and experimental investigation has been carried out on the active solar desalination system to determine the optimum solar collector angle and solar still angle which causes the maximum productivity. A comparison has been also made between the active desalination system and the traditional type basin solar still under the same climatic conditions to determine the enhancement in both the daily productivity and efficiency.

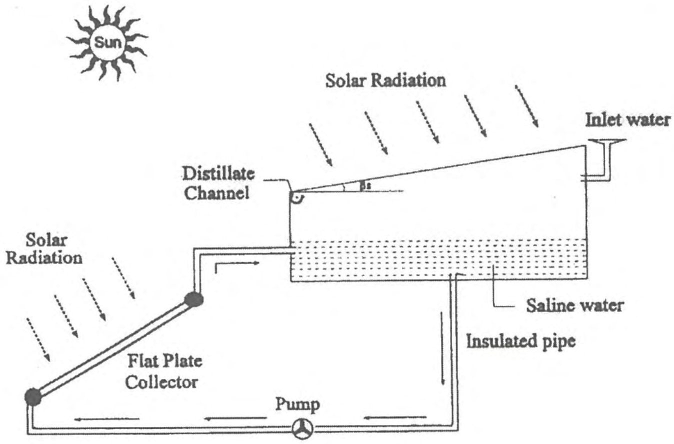

Fig.1 Schematic view of a solar still coupled with flat plate collector (active solar desalination system)

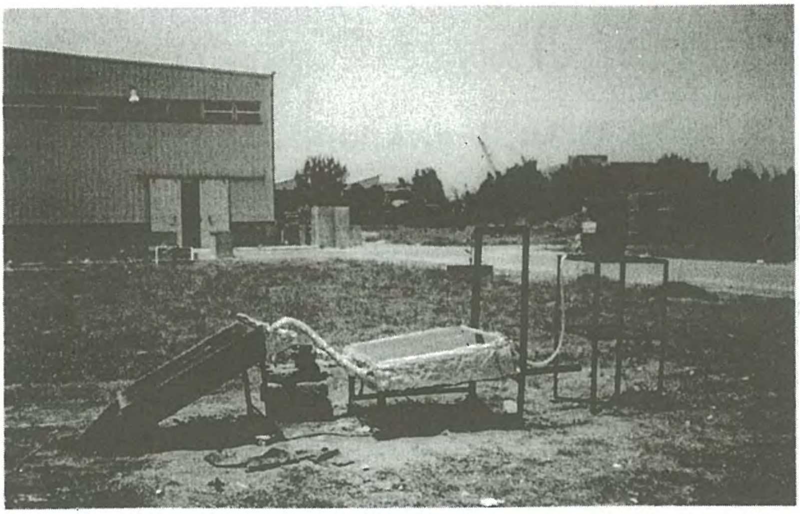

Fig.2 Photo of the test rig

THERMOECONOMIC ANALYSIS OF A POWER/ WATER COGENERATION PLANT

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ABSTRACT

Cogeneration plants for simultaneous production of water and electricity are widely used in the Arabian Gulf region. They are proved to be more thermodynamically efficient and economically viable than single purpose power generation and water production plants. There is no standard or universally agreed upon methodology to be applied to determine the unit cost of electric power and desalinated water produced by dual purpose plants.

A comprehensive literature survey to assess and critically evaluate the different methods, which have been used for cost application in power/water cogeneration plants, is reported in this paper. An in-depth thermo economic analysis will then be carried out for a selected power/water cogeneration plant. The plant employs a regenerative Rankine cycle incorporating a steam generator, back pressure turbine supplying steam to two MSF distillers, a deaerator and two feed water heaters. The turbine generation is rated at 118 MW while MSF distiller is rated at 7.7 MIGD at a top brine temperature of 105°C. An appropriate costing procedure based on the available energy accounting method which divides the benefits of the cogeneration configuration equitably between electricity generation and water production is used to determine the unit costs of electricity and water. The capital charges of common equipment such as boiler, deaerator and feed water heaters as well as boiler fuel cost are distributed between power generated and desalinated water according to the available energy consumption of the major subsystems. A detailed sensitivity analysis was then performed to examine the impact of the variation of fuel cost, load and availability factors as well as capital recovery factor on the electricity and water production costs.

Keywords: Dual-purpose plants, available energy, water and power costs, sensitivity analysis

THERMAL ANALYSIS

In order to write the energy balance for different components for this system, the following assumptions have been made [4]:

- the solar distiller unit is vapor-leakage proof and is in a quasi-steady state;
- the absorptivity of the water and glass cover is negligible;
- the head capacity of the glass cover, insulating materials of the solar still and collector is also negligible;
- each component of the system, viz bottom/sides of the solar still and the collector , is perfectly insulated including connecting pipes;
- the flat plate collector is disconnected from the still during off-sunshine hours.

Energy balance:

The energy balance for different components of an active solar still are :

- **Glass cover**

$$\alpha_g I(t) A_g + h_w (T_w - T_g) A_w = h_{1g} (T_g - T_a) A_g \tag{1}$$

- **Water mass**

$$\dot{Q}_U + \alpha_w (1-\alpha_g) A_w I(t) + h_w (T_g - T_w) A_b = (m_w C_w)\frac{dT_w}{dt} + h_{1w}(T_w - T_g) A_w \tag{2}$$

- **Basin liner**

$$\alpha_b (1-\alpha_g)(1-\alpha_w) A_b I(t) = [h_w (T_b - T_w) + h_b (T_b - T_a)] A_b \tag{3}$$

Where

$$\dot{Q}_U = A_C F_R [(\alpha T)_c I'(t) - U_L (T_w - T_a)]$$

And

$$m_w = A_b \text{ x } d_w \text{ x } p$$

The expressions for various respective heat transfer coefficients and method for calculating I(t) and I`(t) for each month are given in Appendix 1[4] .

Since $A_b = A_g \cos \beta_s$, the equation can be rearranged as follows :

$$T_g = \frac{\alpha g\, I(t) + h_{1w} \cos \beta_s T_w + h_{1g} T_a}{(h_{1w} \cos \beta_s + h_{1g})} \quad (4)$$

From Eq. (3) one gets

$$T_b = \frac{\alpha_b (1-\alpha_g)(1-\alpha_w) I(t) + h_3 T_w + h_b T_a}{h_3 + h_b} \quad (5)$$

With the help of Eqs. (4) and (5), Eq.(2) can be written in the form of a first-order differential equation [6] as:

$$\frac{dT_w}{dT} + \alpha T_w = f(t) \quad (6)$$

Where

$$a = \frac{U'_L}{m_w C'_w}, \quad U'_L = A_c F_R + U_{1b} A_b + U_{1g} A_b$$

In order to obtain an approximate solution of Eq.(6), the following assumptions have been made:

1. The time interval of $\Delta t (0<t<\Delta t)$is small.
2. For a given time interval, the average value of solar intensities I(t),

$$f(t) = \frac{[A_c F_R (\alpha T)_c I'(t) + (\alpha_w + \alpha_g h' + \alpha_b h) I(t) A_s] + U'_L T_a}{m_w C_w}$$

I`(t) and ambient temperature T_a has been taken into account .

$$h = \frac{h_w}{h_w + h_b} \quad \text{and} \quad h' = \frac{h_{1w}}{h_{1w} + h_{1g}}$$

3. a is constant during the time interval Δt.
4. f(t) can be considered as f(t).

The internal heat transfer coefficient, h_{1w}, can be evaluated at known values of initial water and glass temperatures at t=0, i.e., $T_{wt=0} = T_{wo}$ and $T_{gt=0} = T_{go}$.

The solution of Eq. (6) can be written as

$$T_w = \frac{f(t)}{a}[1 - \exp(-at)] + T_{w0} \exp(-at)$$

And the average value of T_w will be

$$\overline{T}_w = \int_0^t T_w dt$$

$$\overline{T}_w = \frac{f(t)}{a}\left[1-\frac{1-\exp(-a\Delta t)}{a\Delta t}\right]+T_{w0}\left[\frac{1-\exp-(a\Delta t)}{a\Delta t}\right] \quad (7)$$

Now, substituting the value of T_w in Eq.(4) , we get the value of the glass cover temperature which acts as the initial temperature for the next set of computations, and so forth for 24th.
The hourly yield per unit area can be evaluated from known values of water and glass temperatures, and it is given by

$$\dot{m}_{ew} = \frac{h_{ew}(T_w - T_g)x3600}{L} kg/m^2 - h \quad (8)$$

Where L is the latent hat of vaporization (J/Kg) and is given by the expressions [7]:

$L = 3.1615x\ 10^6(1-7.616x10^{-4}\ T)$

For a temperature of <70° C and

$L = 2.4935x10^6[1-9.4779x10^{-4}\ T + 1.3132x10^{-7}\ T^2 - 4.7974x10^{-9}\ T^3]$

For a temperature of ≥70° C

The average daily yield can be obtained as

$$M_w = \sum_{i=1}^{24} \dot{m}_{ewi} \quad (9)$$

TEST RIG DESCRIPTION

A schematic diagram of the active solar distillation system is shown in Figs 1&2. It consists of a basin type solar still coupled with a flat plate solar collector by means of a pump and close water cycle to transport the heat from the solar collector to the brine in the still to increase the evaporation rate. The still has an area of 1 m^2. The bottom and sides are insulated against heat loss to surroundings by glass wool insulation. The surface of the basin facing the sun is painted black for maximum absorption of solar radiation. A 0.0025 m single tube copper coil lay on the bottom of the still to perform a part of the heating closed circuit which transform heat from the collector to the brine in the still. The second part of the single tube copper coil lay on the absorber surface in the solar collector. The still cover is made of 0.003 m thick ordinary window glass. The yield is collected in an Al channel attached to the lower end of the glass cover and is taken outside using a water tap and measured directly by a measured jar. A PVC pipe is used for the supply of seawater. The whole system is almost vapor-tight; silicon rubber is used as a sealant because it remains elastic for quite long time.

The still is coupled with a flat plate collector by means of a 0.5 kW water pump to form the active distillation system. The flat plate collector panel used in water heating is an insulated weatherproof box containing a dark solar absorber plate under one transparent cover (0.003 m thick ordinary window glass). The box is made of galvanized iron sheet (0.003 m thick) formed by bending and assembled by soldering. The dark absorber (galvanized iron sheet 0.003 m thick) soaks up heat from sunlight that passes through the cover, and then gives the heat up to the fresh water flowing in a copper single tube coil past the absorber surface. Experiments have been carried out outdoors during summer of 2001. The global solar radiation on a horizontal surface is measured using a silicon cell pyranometer model (3120). Calibrated NiCr-Ni thermocouples are used to measure the temperatures of different pans of the basin still and solar collector, e.g. basin liner, basin seawater, enclosure vapor, the flat plate absorber and the inner and outer sides of the glass cover of both the still and collector. The ambient temperature and wind speeds have been also measured.

RESULTS AND DISCUSSION

A computer program was prepared for the solution of the energy balance equations for the active solar distillation system. The input parameters to the program include Climatic, design and operational parameters. The climatic parameters are the ambient temperature, wind speed and solar intensity. The values of these parameters are taken from their measured values for Port Said (31°17' N latitude, 32°12' E longitude) during summer of 2001. The design parameters for the above computer program are [4]: C_w = 4190 J/kg, $\alpha_w = \alpha_g$ = 0.0, h_w = 100 W/m^2 °C, h_b = 0.8 W/m^2 °C, F` = 0.8, U_L= 8 W/m^2 °C, $(\alpha\tau)_c$ = 0.7, ω = 15°/h, I_{sc} = 1367 W/m^2 As=1m^2, Ac= 0.85m^2. Figure 3 shows the measured solar intensity of 13th July 2001. The typical measurements of wind speed of 13th July 2001 is presented in Fig. 4. The effect of water depth on the daily productivity for a still inclination angle (β_s) =10° and a solar collector inclination angle (β_c)= 20° is shown in Fig.5. One can conclude that the yield is maximum at a water depth equal to 0.075 m as the immersed copper coil diameter is 0.025 m. It can be noticed from the figure also that the productivity decreases with an increase of water depth due to the storage effect. This effect is similar to that observed earlier for daily productivity by many researchers. Figure 6 shows the effect of collector inclination on the daily productivity for different glass cover inclination angles. It is clear from the curve that the productivity is maximum at a still inclination angle (β_s) =10° and a solar collector inclination angle (β_c)= 20°. The effect of glass cover inclination on the daily productivity for different solar collector inclination is presented in Fig.7. It is evident from the above curve that the productivity is maximum at a still inclination angle (β_s) =10° and a solar collector inclination angle (β_c)= 20°. Figure 8 shows the theoretical and experimental hourly variation of daily productivity of 13th July 2001 for the active system. It can be seen from the curve that there is a good agreement between the theoretical and experimental results for the accumulative daily productivity of the active system. It can be observed from the curve also that the daily productivity of the active system is higher than that of the basin still (traditional type) by about 70%. Figure 9 shows the hourly variation of the basin seawater Tw, glass cover Tg and ambient Ta temperatures of the basin still of 13th July 2001. The hourly variation of the absorber Tb, glass cover Tg and ambient Ta temperatures of the solar collector 13th July 2000 is presented in Fig.10. The hourly variation of the total, evaporative, convective and radiative heat transfer coefficients of 13th July 2001 is shown in Fig.11. It was observed that radiative and convective heat transfer coefficients do not vary greatly in comparison to evaporative heat transfer coefficient. This indicated the strong dependence of evaporative heat transfer coefficient (h_{ew}) on the operation temperature Tw of the still. Figure 12 shows the hourly variation of daily thermal efficiency of both the active system and the basin type. It is evident from the curve that the thermal efficiency of the active system is 44 % and it is 26 % for the basin still. It can be observed from the figure also that the efficiency increases with the increase of productivity and vice versa.

CONCLUSION

An active distillation system was fabricated and outdoors tested during summer of 2001. Analytical expression for water and glass cover temperatures and daily productivity have been derived in terms of design and climatic parameters. Numerical computations have been carried out for Port Said (31°17' N latitude, 32°12' E longitude). On the basis of the results and discussion, it was observed that for maximum daily productivity, the optimum collector inclination for a flat plate collector is 20° and for the still glass cover is 10°. It was observed from the experimental results that, the daily productivity of the active system is higher than that of the basin type by about 70% and it has a daily thermal efficiency of 44%.

NOMECLATURE

A	Area , m^2
C_f	Specific heat of fluid through the collector , J/kg °C
C_w	Specific heat of water in the solar still, J/kg °C
d_w	Depth of water mass , m
F_{RN}	Collector heat removal factor
F`	Collector efficiency factor
h_b	Overall heat transfer coefficient from the basin liner to an ambient air through bottom and side insulation, W/m^2 °C
h_{lg}	Connective heat transfer coefficient from the glass cover to an ambient W/m2 °C
h_{lw}	Total heat transfer coefficient from the water surface to the glass cover W/m^2 °C
h_w	Connective heat transfer coefficient from the basin liner to the water, W/m^2 °C
h_{cw}	Connective heat transfer coefficient from the water surface to the glass cover, W/m^2 °C
h_{ew}	Evaporative heat transfer coefficient from the water surface to the glass cover, W/m^2 °C
h_{rw}	Radiative heat transfer coefficient from the water surface to glass cover, W/m^2 °C
I(t)	Solar radiation available at the plane of glass cover of the solar still, W/m^2
I`(t)	Solar radiation available at the plane of the absorber of the collector W/m^2 .
I_{sc}	Average value of the solar constant , W/m^2
K	Thermal conductivity, W/m °C
L	Latent heat of vapourization, J/kg
m_w	Mass of water in basin, kg
m	Flow rate through the collector, kg/h
m_{ew}	Instantaneous yield of still per unit area, kg/m^2
n	Day of the year
P_g	Partial vapour pressure at glass temperature, N/m^2
P_w	Partial vapour pressure at water temperature, N/m^2
Q_U	Rate of useful energy from collector W
T	Temperature, °C
T	Average temperature, °C
T_a	Ambient air temperature, °C
T_{fi}	Intel temperature of fluid to collector, °C

T_{fo}	Outlet temperature of fluid to collector , °C
T_R	Turbidity factor
t	Time, s
Δt	Time interval, s
U_L	Heat loss coefficient for collector, W/m^2 °C
$U_{L'}$	Overall heat transfer rate, W/°C
v	Wind velocity, m/s

Greek letters

α	Absorptivity
α_s	Solar altitude angle, °
$(\alpha T)_c$	Product of absorptivity and transmission of collector
β	Slope of surface w.r. to horizontal
γ	Solar azimuth angle , °
δ	Declination angle, °
ε_{eff}	Effective emissivity, dimensionless
θ_I	Angle of incidence radiation, °
ϕ	Latitude of the place , °
ω	Hour angle, °
A_ω	Surface azimuth angle
σ	Stefan Boltzman constant, $5.67x10^{-8}$, $W/m^2 k^4$

Subscripts

b	Basin liner
c	Collector
g	Glass cover
s	Still
w	Water

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Appendix I [4]:

In Eqs. (1)-(3) , different heat transfer coefficients are as follows:

$h_{22} = 5.7 + 3.8v$

$h_{1w} = h_{cw} + h_{rw} + h_{ew}$

$$\mathbf{h_{cw} = 0.884\left[T_w - T_g + \frac{(P_w - P_g)(T_w + 273)}{(268.9x10^3 - P_w)}\right]^{1/3}}$$

$$\mathbf{h_{rw} = 0.884\varepsilon_{eff}\sigma\left[\frac{(T_w + 273)^4 - (T_g + 273)^4}{(T_w - T_g)}\right]}$$

$$\mathbf{h_{ew} = 16.273x10^{-3}h_{cw}\left(\frac{P_w - P_g}{T_w - T_g}\right)}$$

Where the expression for saturated vapour pressure as a function of temperature (°C) are as follows [7]:

$$\mathbf{P_w = \exp\left[25.317 - \frac{5144}{T_w + 273.15}\right]}$$

$$\mathbf{P_g = \exp\left[25.317 - \frac{5144}{T_g + 273.15}\right]}$$

The useful energy of the collector is

$$\dot{Q}_U = \dot{m}C_f(T_{f0} = T_{Fi})$$

Where

$$T_{fo} = \left[\frac{(\alpha T)_c I'(t)}{U_L} + T_a\right]\left[1 - \exp\frac{(-AU_L F'}{\dot{m}C_f}\right] + T_{fi}\exp\frac{(-A_c U_L F')}{\dot{m}C_f}$$

Then

$$\dot{Q}_U = A_C F_R[(\alpha T)_c I'(t) - U_L(T_{fi} - T_a)]$$

Where

$$F_R = \frac{\dot{m}C_f}{A_c U_L}\left[1 - \exp\frac{(-A_C U_L F'}{\dot{m}C_f}\right]$$

In the above equation, $T_{fi} = T_w$; then

$$\dot{Q}_U = A_C F_R[(\alpha T)_c I'(t) - U_L(T_w - T_a)]$$

Appendix II [4] - Solar radiation calculation on inclined surface

The dependence of extraterrestial solar radiation on the time of year is given by

$$I_{ON} = I_{sc}\left[1 + 0.0334\cos\left(\frac{360xn}{365}\right)\right]$$

Taking all the atmospheric factors into account, the terrestrial direct normal solar radiation is given by .

$$I_N = I_{ON}\exp\left(\frac{-T_R}{0.9 + 9.4\sin\alpha_s}\right)$$

Where the monthly average of the turbidity factor (T_R) for cities is given in table II.1.
The solar altitude angle is given by,

$$\sin\alpha_s = \sin\delta\sin\phi + \cos\delta\cos\phi\cos\omega$$

After knowing the above parameters, the various solar radiation intensities, namely the beam, the diffuse and the global on a horizontal surface, are given as:

By using the Liu and Jordan relation for the angle of incidence, θ_I

$$\cos\theta_i = \sin\alpha_s \cos\beta + \sin\beta \cos\alpha_s \cos(\gamma - A_\omega)$$

One can estimate the various intensities on an inclined surface of any slope and any orientation.

$$I_{HB} = I_N \sin\alpha_s$$

$$I_{HD} = \frac{1}{3}(I_{ON} - I_N)\sin\alpha_s$$

$$I_{HG} = I_{HB} + I_{HD}$$

Table 1:

Monthly average of turbidity factor

Month	T_R
January	3
February	3.2
March	3.5
April	3.9
May	4.1
June	4.2
July	4.3
August	4.2
September	3.9
October	3.6
November	3.3
December	3.1

By using the Lui and jordanrelation [8] for the angle of incidence, θi

$$\cos\theta i = \sin\alpha \cos\beta + \sin\beta \cos\alpha \cos(\gamma - A\omega)$$

one can estimate the various intensities on an inclined surface of any slope and any orientation.

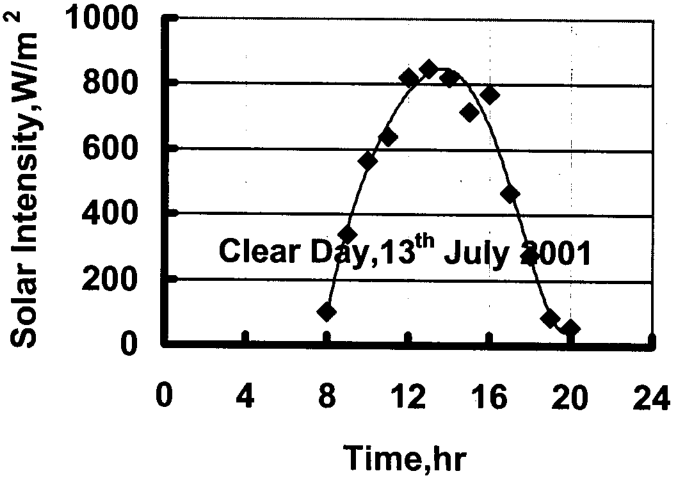

Fig.3 Typical measurements of solar intensity of 13th July 2001

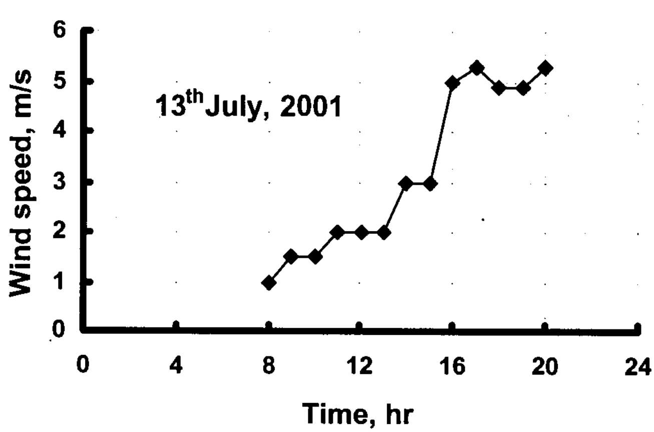

Fig.4 wind speed of 13h July 2001

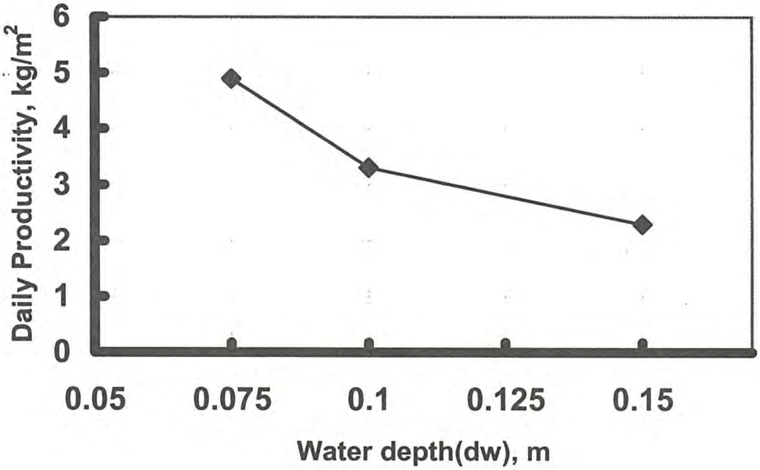

Fig.5 The effect of water depth on the daily productivity (β_s= 10°, β_c= 20°)

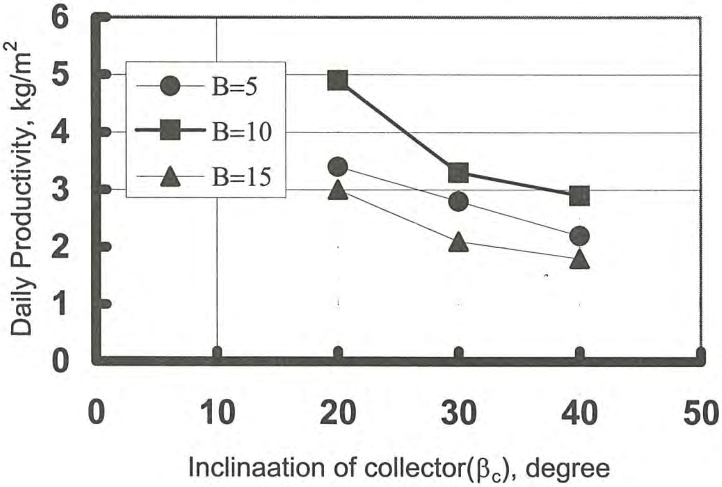

Fig.6 The effect of collector inclination on the daily productivity

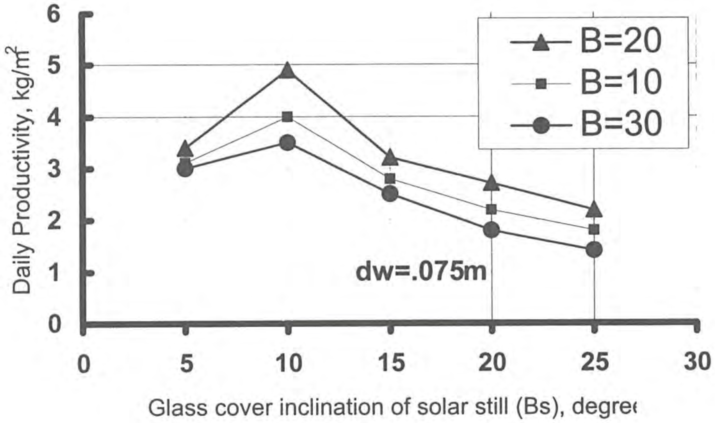

Fig.7 The effect of glass cover inclination on the daily productivity

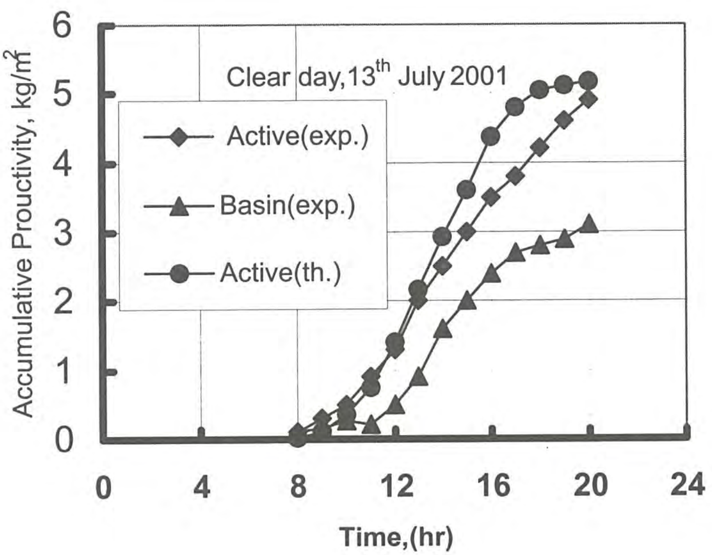

Fig.8 The theoretical and experimental hourly variation of daily productivity of 13th July 2001for the active system

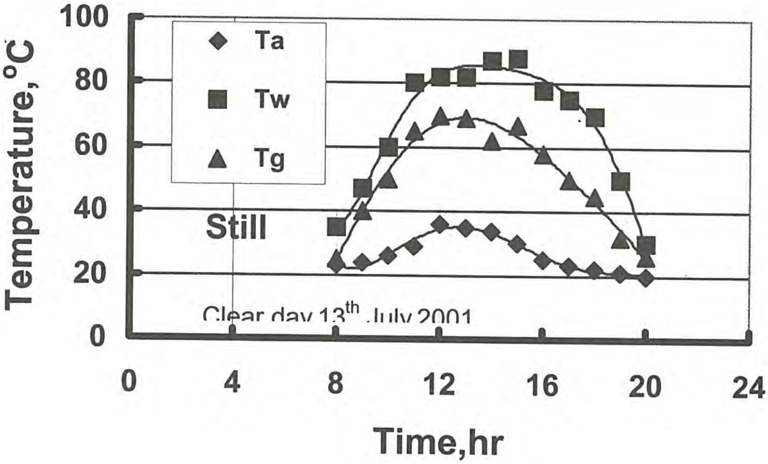

Fig.9 The hourly temperature variation of the solar basin still of the active system (13th July 2001)

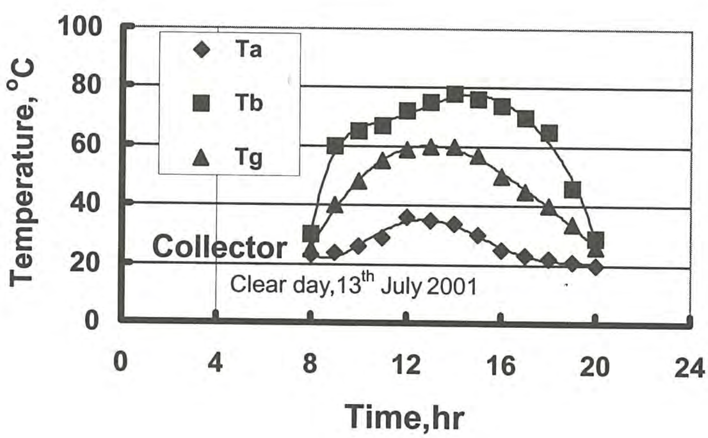

Fig.10 The hourly temperature variation of the solar collector of the active system (13th July 2001)

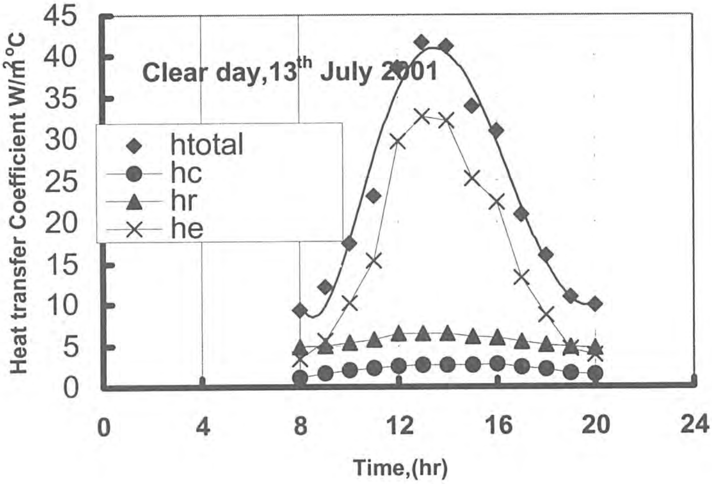

Fig.11 The hourly variation of the total, evaporative, convective and radiative heat transfer coefficients (13th July 2001)

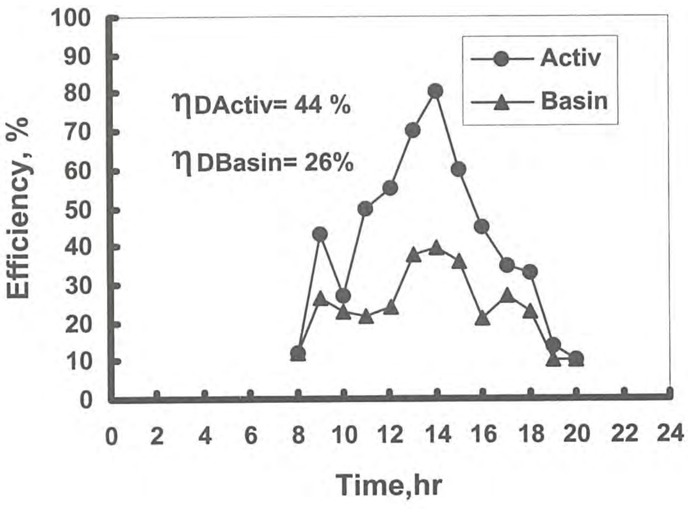

Fig.12 The hourly variation of the efficiency (13th July 2001)

Domestic Wastewater

Microbial Genetic Control of Heavy Metal Pollution from Wastewater

Dr. K.A. Zaied (Egypt)

MICROBIAL GENETIC CONTROL OF HEAVY METAL POLLUTION FROM WASTEWATER

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ABSTRACT

Standards have been set and guidelines proposed by many countries and several intergovernmental organizations to determine the acceptable human exposure to certain environmental pollutants in drinking water. Factory effluents polluted river water was tested for the removal of their heavy metals contents, using microbial biomass of genetic engineered bacteria and yeast strains. Microbial biomass of most bacterial strains and transconjugants can successfully remove higher concentration of cadmium, cobalt and arsenic in the presence or absence of sugarcane refuse in solutions. Some of them could oxidise arsenic to arsenate, which is more easily precipitated from wastewater by Fe^{3+} than is arsenite with a decrease in toxicity and relevance wastewater treatment. Microbial cells of bacterial strains and transconjugants are shown to be more efficient in the removal and recovery of total heavy metals from industrial effluents. There is no clear relationship between the ability of bacterial strains or transconjugant to absorb cadmium from the effluents and its capacity for selective absorption of cobalt and arsenic. Furthermore, the transfer of DNA^- by conjugation certainly makes many of the transconjugants much more capable of uptaking heavy metals than its parental strains. Extremely high ability of total heavy metals uptake was newly found in most of yeast hybrids. In addition, hybrid cells of yeast differed in their removal efficiencies of total heavy metals uptake. Many of yeast hybrids, in the presence of sugarcane refuse, showed greater removal of total heavy metals from industrial effluents. The recognition that genetic engineering could adapt the microbial strains to the effluents resulted from a new chemicals industry led researchers, especially geneticists, who developed biotechnology for use in pollution control of hazardous wastes.

Key words : Arsenic, cadmium, cobalt, hybrid cells, industrial effluents, *Saccharomyces cerevisiae,* transconjugant.

INTRODUCTION

Man today is concerned very much with pollution of the environment, the slow poisoning of his surroundings by his own activities. This is the major global health hazard. Many metals are essential for microbial growth in low concentrations, but they become toxic in high concentrations. Some microorganisms, exposed to high levels of heavy metals, have involved resistance mechanism(s), such as active exclusion (42), forming cysteine-rich proteins (23), increasing ω - cyclohexyl fatty acids level in the membrane (39), detoxification by redox conversion (10), and producing hydrogen sulfide (13) and extracellular polysaccharide (4). This enables them to maintain their functions in the presence of high concentrations of heavy metals. The cysteine-rich, metal-binding protein (30) has putative functions in the regulation of essential elements, metal detoxification, and protection against oxidative stress (9). The most compelling evidence for a role of metallothionein (MT) in protection against metal toxicity is provided by studies on yeast (22) and mice (34), which demonstrated disruption or deletion of the MT gene resulting in the inability to express MT and resist metal toxicity (Cu toxicity in the case of yeast and Cd toxicity in the case of mice).

The removal of radionuclides, metal or metalloid species, compounds and particulates from solution by biological material, particularly by non-directed physico-chemical interactions, is now frequently termed "biosorption" (44). Although virtually all biological material has biosorptive properties (33), most work are up to date has been directed towards microbial systems. Biosorption, and related phenomena, are of importance because the removal of potentially toxic and/or valuable metals and radionuclides from aqueous effluents can result in detoxification and, therefore, safe environmental discharge (32). Furthermore, appropriate treatment of loaded biomass can enable recovery of valuable elements for recycling or further containment (5). This paper reports on the application of biotechnology for maximal accumulation of heavy metals from factory effluents by genetically constructed of various microorganisms.

MATERIAL AND METHODS

Genetic material: Yeast and bacterial strains used in this study are listed in a previous work by Kosba *et al.* (28). Media for growing microorganisms and other culture conditions have been described previously by Horikoshi *et al.* (25). Precultured cells were used for the following uptake experiments.

Factory effluents: The present study was undertaken with the finishing industry of wastewater resulting from ammonia unit at Talkha Fertilizer Factory (TFF) (Dakhlia Governorate). Polluted water was collected from the main pipe of the factory before being mixed with water in the river. This collection was done through January and June from every year (1995 and 1996). Sugarcane refuse was used for its residual sucrose to use as a sole carbon source in some of biosorption experiments.

Uptake experiments: In the heavy metals uptake test, precultured cells were suspended in 250 ml conical flasks containing 100 ml minimal medium of yeast (12) and bacteria (43) supplemented with factory effluents instead of distilled water and incubated under a static conditions at 30°C for six days. Thereafter, the cells were collected by filtration on membrane filter (pore size 0.45 μm) and the other by centrifugation. Amounts of metals taken up by the cells were determined by measuring metal contents in the filtrate, using Atomic Absorption Spectrometer at Chemistry Dept., Faculty of Science, Mansoura University, according to Nakajima and Sakaguchi (37).

RESULTS AND DISCUSSION

Heavy metals uptake by parental strains of bacteria: Microorganisms can accumulate heavy metals and radionuclides from their external environment (2). Amounts accumulated can be large and a variety of physical, chemical and biological mechanisms may be involved, including adsorption, precipitation, complexion and transport. The cells of seven parental strains of bacteria were suspended in a solution containing factory effluents resulted from Talkha Chemical Fertilizer Factory. The results obtained with representative strains are shown in Tables (1, 2 and 3). From Table (1) it can be seen that the amounts of heavy metals (cadmium, cobalt and arsenic) absorbed by the bacterial cells differed markedly in different strains of bacteria. Of the seven bacterial strains tested, extremely high cadmium - absorbing ability was observed in *Micrococcus halobius* A and B, *Micrococcus luteus* and *Bacillus subtilis*. These strains resulted in a greater decrease in cadmium concentration, reaching up to 50%. *Micrococcus halobius* A, *Bacillus subtilis* and *Bacillus licheniformis* revealed a greater decrease in cobalt concentration up to 50%. This depends on the ability of microorganisms to effect chemical transformations of heavy metals and their compounds by, e.g. oxidation, reduction, methylation and demethylation (31). Once inside cells, metal ions may be compartmentalized and/or converted to less toxic forms by, e.g. precipitation or sequestration by metal-binding proteins (18). Arsenic removal efficiencies up to 91.67% have been recorded by *Bacillus licheniformis*. Some of bacterial strains could oxidise arsenite As^{3+} to As^{5+}, which is more easily precipitated from wastewater by Fe^{3+} than is arsenite, As^{3+}. These strains included *Micrococcus halobius* A, *Bacillus cereus, Micrococcus luteus* and *Bacillus subtilis,* which increase the ionic concentration of arsenite. These results are in accordance with those reported by Williams and Silver (45), who reported that treatment of arsenic loaded sewage with arsenite oxidase-producing bacteria (which oxidise As^{3+} to As^{5+} can improve certain arsenic removal methods since arsenate, As^{5+}, is more easily precipitated from wastewater by Fe^{3+} than is arsenite, As^{3+}. Microbial transformation of arsenic also, is associated with a decrease in toxicity and may have relevance to wastewater treatment.

Table 1 . Heavy metals uptake by parental strains of bacteria from minimal medium containing industrial effluents.

Strain No.	Cadmium (Cd)		Cobalt (Co)		Arsenic (As)	
	Concen. (ppm)	Removal (%)	Concen. (ppm)	Removal (%)	Concen. (ppm)	Removal (%)
Control	0.08	0.00	0.12	0.00	0.012	0.00
1	0.04	50.0	0.06	50.0	0.022	+83.33
2	0.04	50.0	0.12	0.00	0.004	66.67
3	0.08	0.00	0.12	0.00	0.016	+33.33
4	0.04	50.0	0.12	0.00	0.023	+91.67
5	0.06	25.0	0.12	0.00	0.002	83.33
6	0.04	50.0	0.06	50.0	0.021	+75.00
7	0.06	25.0	0.06	50.0	0.001	91.67

Concen. = Concentration. + = Increase in concentration.

A similar range in absorption ability was observed by the same strains grown in minimal medium containing 1% sugarcane refuse (Table 2). It can be seen that extremely high cadmium-absorbing ability was observed in *Micrococcus lylae, Bacillus subtilis* and *Bacillus licheniformis*, which decreased cadmium concentration up to 40%. Extremely high cobalt-absorbing ability was found in *Bacillus cereus*, cobalt uptake by this strain reached up to 100%. The mechanisms and significance of metal-binding proteins to microbial cells have been recorded in all microbial groups examined, e.g. cyanobacteria, bacteria, microalgae and filamentous fungi (40). Metallothioneins are small cysteine-rich polypeptides that can play an essential role in the ability of strains for heavy metals uptake. They can bind essential metals, e.g. Cu, Zn and Co, as well as non-essential metals like Cd (21). In the presence of sugarcane refuse, most of strains have arsenic removal greater than 50%. In that case, none of strains oxidise As^{3+} (arsenic) to As^{5+} (arsenate), as seen by the same strains when grown without the addition of sugarcane refuse. Oxidation is one mechanism of chemical transformations of heavy metals and their compounds (27).

Amongst the different bacterial strains, there are many of them with a high ability for one or more of heavy metals uptaken (Table 3) and oxidise arsenic to arsenate in the medium, not containing sugarcane refuse. These results are in accordance with those reported by Nakajima and Sakaguchi (37), who found that uranyl, mercury, lead and copper ions were more readily accumulated by cells of bacteria, yeasts, fungi and actinomycetes than the other ions presented in the medium. Indeed, the quantities of zinc, manganese, cobalt, nickel and cadmium absorbed by almost all species of microorganisms, were found to be extremely low. The results suggests that the selective accumulation of heavy metal ions by microorganisms could be determined by interionic competition. On the other hand, the relationship between the uptake of cadmium, cobalt and arsenic was not the same in all strains.

Table 2 . Heavy metals uptake by parental strains of bacteria from minimal medium containing factory effluents and 1% sugarcane refuse.

Strain No.	Cadmium (Cd)		Cobalt (Co)		Arsenic (As)	
	Concen. (ppm)	Removal (%)	Concen. (ppm)	Removal (%)	Concen. (ppm)	Removal (%)
Control	0.10	0.00	0.18	0.00	0.019	0.00
1	0.10	0.00	0.18	0.00	0.003	84.21
2	0.10	0.00	0.18	0.00	0.000	100.0
3	0.08	20.0	0.00	100.0	0.004	78.95
4	0.08	20.0	0.12	33.33	0.006	68.42
5	0.06	40.0	0.12	33.33	0.008	57.89
6	0.06	40.0	0.18	0.00	0.016	15.79
7	0.06	40.0	0.18	0.00	0.004	78.95

Concen. = Concentration.

Table 3 . Concentration (mg/L) of heavy metals uptake by parental strains of bacteria.

Strains	Minimal medium of wastewater from TFF					
	Without sugarcane refuse			With 1% sugarcane refuse		
	Cd	Co	As	Cd	Co	As
1	0.04	0.06	+0.010	0.00	0.00	0.016
2	0.04	0.00	0.008	0.00	0.00	0.019
3	0.00	0.00	+0.004	0.02	0.18	0.015
4	0.04	0.00	+0.011	0.02	0.06	0.013
5	0.02	0.00	0.010	0.04	0.06	0.011
6	0.04	0.06	+0.009	0.04	0.00	0.003
7	0.02	0.06	0.011	0.04	0.00	0.015

\+ = Increase in arsenic concentration of tested sample. , TFF = Talkha Fertilizer Factory.

The data tabulated in Table (4) showed that the total quantity of metal ions absorbed by bacterial cells differed greatly from one strain to another. Extremely high absorption of total heavy metals was observed in *Micrococcus halobius* A, *Bacillus subtilis* and *Bacillus licheniformis*. These strains show greater uptake of total heavy metals, more than 40%. This is in accordance with the results obtained by Nakajima and Sakaguchi (37), who found that the high absorption of heavy metals was observed in *Bacillus subtilis, Actinomycetes flavoviridis, Streptomyces obiraceus, Streptomyces albus, Streptomyces diastaticus, Streptomyces viridochromogenes* and *Mucor javanicus*.

In the presence of sugarcane refuse, *Bacillus cereus* recovered total heavy metals at a high adsorption rate greater than 70%. In addition, the total quantity of metal ions absorbed by microbial cells greatly differed from one strain to another. Extremely lower absorption of total heavy metals uptake was observed in *Micrococcus halobius* A and B rather than the other ones. These results are in agreement with those obtained previously on uranium uptake by immobilized *Chlorella regularis* and *Streptomyces viridochromogenes* (38). These results show that the microbial cells are more efficient in the removal and recovery of heavy metals from factory effluents. Microbial biomass showed higher percent in the removal of total heavy metals in the presence of sugarcane refuse. It appears that the metals are largely bound by the extracellular polymers produced by the microorganisms present, particularly bacteria (19).

Table 4 . Efficiency of biological control of pollutants by parental strains of bacteria on total heavy meals uptake from minimal medium containing factory effluents.

Strains	Concentration (ppm) of Cd, Co and As		Total concentration Tion absorbed (ppm)		Removal (%)	
	I	II	I	II	I	II
Control	0.212	0.299	0.00	0.00	0.00	0.00
1	0.122	0.283	0.09	0.016	42.45	5.35
2	0.164	0.280	0.048	0.019	22.64	6.35
3	0.216	0.084	+0.004	0.215	+1.89	71.91
4	0.183	0.206	0.029	0.093	13.68	31.10
5	0.182	0.188	0.03	0.111	14.15	37.12
6	0.121	0.256	0.091	0.043	42.92	14.38
7	0.121	0.244	0.091	0.055	42.92	18.39

\+ = Increase in total concentration. I = Minimal medium without sugarcane refuse .
II = Minimal medium with 1% sugarcane refuse.

Removal of heavy metals by bacterial transconjugants :

Bacterial transconjugants (Table 5) provide an additional capacity for the removal of cadmium, cobalt and arsenic. Heavy metal ions absorbed by transconjugants differed greatly from one to another. Extremely high absorption, greater than 40% was observed in many of the transconjugants for cadmium, cobalt and arsenic. There results are not a clear relationship between the ability of transconjugant to absorb cadmium from these industrial effluents and its capacity for selective absorption of cobalt and arsenic. These are in accordance with the results obtained by Nakajima and Sakaguchi (37), who found that the amounts of uranium absorbed by the bacterial cells markedly differed in different species of bacteria. The present results, also, are in agreement with those obtained by Gadd (17), who found that living cell biofilms might provide an additional capacity for the removal of pollutants, including hydrocarbons, pesticides and nitrates. A similar range in absorption ability was observed by transconjugants in the presence of sugarcane refuse (Table 6). It has been shown that the amounts of cadmium, cobalt and arsenic markedly differed in different transconjugants of bacteria. Many of transconjugants recovered cadmium and cobalt with a removal efficiencies up to 71.43%. However, many of them could oxidise arsenic to arsenate. This indicated that these strains produce arsenite oxidase, which oxidise As^{3+} to As^{5+}, could improve certain arsenic removal methods, arsenate, As^{5+} , is more easily precipitated from wastewater by Fe^{3+} than is arsenite, As^{3+} (45). These results are in accordance with the results reported by Mergeay *et al.* (36), who demonstrated that correlation between selection pressure exerted by pollutants and plasmid emergency was, in fact, suggested in many cases: plasmids seem to play a major role in the adaptation of bacteria to xenobiotics and in the acquisition of new genetic traits due to pollution. Plasmid-encoded pathways are ecologically advantageous because they provide genetically flexible systems and can be transferred between bacterial species (41). A particularly important aspect is the accurrence of some broad host range plasmids specialized in the degradation of synthetic chemicals (7). Due to their broad transfer and replication range, their introduction into a microbial community could provide the latter with enhanced degradative capacities.

As is shown in Table (7) cobalt and arsenic ions were more readily accumulated by cells of bacterial transconjugants in minimal medium without sugarcane refuse than the other ions of cadmium in the medium. However, all transconjugants tested accumulated large amounts of cobalt ion than cadmium in the presence of sugarcane refuse. This suggests that the selective accumulation of heavy metal ions by transconjugants is determined by interionic competition (37).

Table 5. Heavy metals uptake by bacterial transconjugants from minimal medium containing factory effluents.

Strain No.	Cadmium (Cd)		Cobalt (Co)		Arsenic (As)	
	Concen. (ppm)	Removal (%)	Concen. (ppm)	Removal (%)	Concen. (ppm)	Removal (%)
Control	0.06	0.00	0.36	0.00	1.04	0.00
10	0.04	33.33	0.28	22.22	0.98	5.77
11	0.03	50.00	0.21	41.67	0.47	54.81
12	0.04	33.33	0.21	41.67	0.48	53.85
13	0.03	50.00	0.28	22.22	0.10	9.38
14	0.05	16.67	0.28	22.22	0.97	6.73
15	0.03	50.00	0.21	41.67	0.51	50.96
16	0.02	66.67	0.21	41.67	0.95	8.65
17	0.03	50.00	0.21	41.67	0.85	18.27
18	0.02	66.67	0.28	22.22	1.01	2.88
19	0.04	33.33	0.28	22.22	0.53	49.04
20	0.02	66.67	0.21	41.67	0.97	6.73
21	0.02	66.67	0.28	22.22	0.97	6.73

Concen. = Concentration.

Table 6. Heavy metals uptake by bacterial transconjugants from minimal medium containing factory effluents and 1% sugarcane refuse.

Strain No.	Cadmium (Cd)		Cobalt (Co)		Arsenic (As)	
	Concen. (ppm)	Removal (%)	Concen. (ppm)	Removal (%)	Concen. (ppm)	Removal (%)
Control	0.07	0.00	0.28	0.00	18.03	0.00
10	0.02	71.43	0.14	50.0	18.03	0.00
11	0.03	57.14	0.21	25.0	17.70	1.83
12	0.02	71.43	0.14	50.0	18.90	0.00
13	0.05	28.57	0.21	25.0	16.06	10.93
14	0.04	42.86	0.14	50.0	18.20	+0.94
15	0.04	42.86	0.14	50.0	17.60	2.38
16	0.03	57.14	0.14	50.0	18.70	+3.72
17	0.02	71.43	0.14	50:0	17.80	1.28
18	0.05	28.57	0.21	25.0	16.40	9.04
19	0.05	28.57	0.21	25.0	18.90	4.83
20	0.06	14.29	0.21	25.0	19.10	+5.93
21	0.06	14.29	0.21	25.0	17.10	5.16

Concen. = Concentration.

Table 7. Concentration (mg/L) of heavy metals absorbed by transconjugants.

Transconj-Ugants	Minimal medium of wastewater from TFF					
	Without sugarcane refuse			With 1% sugarcane refuse		
	Cd	Co	As	Cd	Co	As
10	0.02	0.08	0.06	0.05	0.14	0.00
11	0.03	0.15	0.57	0.04	0.07	0.33
12	0.02	0.15	0.56	0.05	0.14	+0.87
13	0.03	0.08	0.94	0.02	0.07	1.97
14	0.01	0.08	0.07	0.03	0.14	+0.17
15	0.03	0.15	0.53	0.03	0.14	0.43
16	0.04	0.15	0.09	0.04	0.14	+0.67
17	0.03	0.15	0.19	0.05	0.14	0.23
18	0.04	0.08	0.03	0.02	0.07	1.63
19	0.02	0.08	0.51	0.02	0.07	+0.87
20	0.04	0.15	0.07	0.01	0.07	+1.07
21	0.04	0.08	0.07	0.01	0.07	0.93

The removal and recovery of total heavy metal pollutants without any addition of sugarcane refuse (Table 8) indicated that many of the transconjugants showed removal efficiencies greater than 40%. The removal efficiencies of total heavy metals measured in this work was up to 71.92%. Recovery efficiencies, obtained in transconjugants, were greater than those observed by parental strains (Table 4). Furthermore, the transfer of DNA by conjugation certainly makes many of transconjugants much more able to uptake heavy metals than the capacity of its parental strains. This is in agreement with those reported by Day (11), who demonstrated that the horizontal gene transfer was of special interest in the communities of polluted soils because specific adaptations to pollutants were often plasmid-bound. In the presence of sugarcane refuse, total heavy metals uptake by transconjugants were weaker than without it. Removal efficiencies of total heavy metal ions up to 11.21% have been recorded. However, parental strains under the same conditions were more efficient for removal other than their transconjugants. These are in agreement with those reported by McClure *et al.* (35), who noticed that a strain with plasmid-borne catabolic genes, introduced into an activated sludge unit, did not enhance the degradation of 3-chlorobenzoate (3CB), while a total breakdown could be achieved in batch cultures. On the other hand, a constructed *Pseudomonas aeruginosa* strain, carrying a degradative plasmid, has been shown to be useful for cleaning up soil contaminated with kelthane residues (20).

The results obtained with representative transconjugants for their ability to uptake cadmium and cobalt are shown in Table (9). It can be seen that all transconjugants revealed positive uptake of heavy metals, related to the mid parents or to the better parent or to both of them. The positive uptake of heavy metals appeared in the presence of sugarcane refuse in minimal medium or without the addition of any carbon source to the medium. It has been shown that, in many cases, transconjugants greatly facilitated the efficiency of heavy metals removal and the use of cells as biological catalysts (16). This is in accordance with the results reported by Apajalahti and Salkinoja (1), who isolated a *Rhodococcus chlorophenolicus* strain capable of degrading polychlorinated phenols. This strain continued to degrade polychlorinated phenols in natural soil when immobilized on biodegradation foam (6). These results suggest that it may be possible to develop practical systems, based on the use of chemical treatment, to detoxify chemicals in factory wastes with biological treatment. There is an urgent need for the removal of heavy metals from industrial effluents rather than with chemical therapy. In this respect, the transfer of DNA by conjugation certainly plays a greater role in the capacity of removal of heavy metals from these effluents (11). The increased knowledge on DNA transfer through conjugation opens exciting new areas in environmental biotechnology. At present, industry complains about high costs of chemical therapy, although the recovery of the effluents and, also, the environment from the pollutants is often extremely difficult with this therapy of chemical methodology.

Recovery of heavy metals by yeast hybrids: As shown in Table (10) many of the heterozygous diploids of yeast were found to be efficient in uptaking and removing cadmium and cobalt (> 33.33 %). Their removal efficiency reached up to 60% and 66.67%, respectively, although the removal of arsenic reached 45.36%. On the other hand, the relationship between the uptake of cadmium and absorption of cobalt or arsenic was not the same in all hybrids. In almost all hybrids of yeast, the removal of arsenic was less than that of cadmium and cobalt. This is in accordance with the results obtained by Nakajima and Sakaguchi (37), who found that, in bacteria and yeasts many species were found to accumulate mercury more abundantly than uranium. The present results indicated that cells of yeast hybrids, newly found to have extremely high ability for heavy metals uptake. There is now great awareness of the potential efficiencies in removal and recovery of environmental pollution by heavy metals through biological control of pollutants by yeast than chemical methods. The biosorbent costs have been analysed by Kuyucak (29). Specifically, cultured biomass, e.g. fungi, yeasts, may cost ~ $ 1-5 Kg dry weight^{-1} with specifically-cultured algae being ~ $ 15-18 Kg dry weight^{-1}. The production cost of yeast (*S. cerevisiae*) by a large company was estimated as ~ $ 1.3 Kg^{-1} with the cost of supply being ~ $ 2-2.6 Kg^{-1} depending on demand, in comparison, with the higher expensive of chemical treatment.

Table 8. Efficiency of biological control of pollutants by transconjugants on total heavy metals uptake from minimal medium containing factory effluents.

Transconjugants	Concentration (ppm) of Cd, Co and As		Removal (%)	
	I	II	I	II
Control	1.46	18.38	0.00	0.00
10	1.30	18.19	10.96	1.03
11	0.71	17.94	51.37	2.39
12	0.73	19.06	50.0	+3.70
13	0.41	16.32	71.92	11.21
14	1.30	18.38	10.96	0.00
15	0.75	17.78	48.63	3.26
16	1.18	18.87	19.18	+2.67
17	1.09	17.96	25.34	2.29
18	1.31	16.66	10.27	9.36
19	0.85	19.16	41.78	+4.24
20	1.20	19.37	17.81	+5.39
21	1.27	17.37	13.01	5.50

+ = Increase in concentration. , I = Without sugercane refuse.
II = In the presence of sugarcane refuse.

In the presence of sugarcane refuse, it has been shown that, many of hybrids showed higher removal efficiencies up to 50, 66.67 and 62.30% for cadmium, cobalt and arsenic, respectively. The investigation of this phenomena for heavy metals uptake capacity by hybrid cells of yeast should, also, be applied to maximize the efficiency of industrial effluents therapy. This is in agreement with the results reported by Fogel *et al.* (14), who demonstrated that the efficiencies of metal removal were due to metallothioneins (MT). They were so small cysteine-rich polypeptides that could bind essential metals, e.g. Cu and Zn, as well as non-essential metals like Cd. Copper resistance, for example, in *Saccharomyces cerevisiae* is mediated by the induction of a 6573 - dalton cysteine-rich protein, copper metallothionein (Cu - MT). It has been suggested that Cu - MT (and analogous proteins) might be of potential in metal recovery since it could bind other metals besides Cu, e.g. Cd, Zn, Ag, Co and Au, although these metals did not generally induce MT synthesis (8). One report has described an inducible Cd-binding protein (9 KDa) in *S. cerevisiae* which was cysteine-rich (18 mol %) and high in Cd content (63 μg Cd (mg protein)$^{-1}$) and showed a high similarity in amino acid composition with Cu - MT (26). The *Cup 1* gene has been cloned into *E. coli* with resulting expression of a functional Cu, Cd and Zn binding protein product and an increased ability for metal accumulation by the bacterium (3). An ultimate aim may be the production of different MT specific for different metals by engineering yeast strains with constitutive expression of MT genes which may, then, accumulate elevated amounts of metals (8).

The total quantity of metal ions absorbed by hybrid yeast cells (Table 11) differed greatly from one hybrid to another. It can be seen in the hybrid cells, derived from the same cross, that they differed in their removal efficiencies of total heavy metals uptake. The results are in agreement with those obtained previously on uranium uptake by immobilized *Chlorella regularis* and *Streptomyces viridochromogenes* (38). On the basis of these results, further studies will be undertaken to devise a practical approach to the recovery of heavy metals from industrial effluents by genetically engineering strains. Total heavy metals removal efficiencies by yeast rised up to 43.90% . Many of the hybrids show in the presence of sugarcane refuse, greater removal of total heavy metals from industrial effluents., Total removal efficiencies up to 57.05 have been recorded. Most of hybrid yeast cells uptake more than 20% of the total heavy metals presented in these effluents. The results indicated that the use of sucrose from sugarcane refuse, as a sole carbon source in pollution control technology by yeast, show a high metal uptake capacities from industrial effluents. It is evident that geneticists should be involved in the development of these strains protocol, especially in relation to the aspects of biotherapy of pollution. Therefore, it is essential that environmental technology in the near future becomes an established business opportunity (24).

Table 9 . Transconjugation vigour for the concentration of heavy metals absorbed by bacterial cells.

Transconj-ugants	Parameters	MM without sugarcane refuse		MM with 1% sugarcane refuse	
		Cd	Co	Cd	Co
10	MP	0.04	0.06	0.02	0.00
	BP	0.04	0.06	0.04	0.00
	TC	0.02	0.08	0.05	0.14
	TCV (MP)	-50	+33	+150	
	TCV (BP)	-50	+33	+25	
11	MP	0.02	0.00	0.01	0.09
	BP	0.04	0.00	0.02	0.18
	TC	0.03	0.15	0.04	0.07
	TCV (MP)	+50		+300	-22.22
	TCV (BP)	-25		+100	-61.11
12	MP	0.04	0.00	0.01	0.03
	BP	0.04	0.00	0.02	0.06
	TC	0.02	0.15	0.05	0.14
	TCV (MP)	-50		+400	+366.67
	TCV (BP)	-50		+150	+133.33
13	MP	0.03	0.06	0.02	0.00
	BP	0.04	0.06	0.04	0.00
	TC	0.03	0.08	0.02	0.07
	TCV (MP)	0.00	+33.33	0.00	
	TCV (BP)	-25.0	+33.33	-50.0	
14	MP	0.02	0.03	0.01	0.09
	BP	0.04	0.06	0.02	0.18
	TC	0.01	0.08	0.03	0.14
	TCV (MP)	-50	+166.67	+200	+55.55
	TCV (BP)	-75	+33.33	+50	-22.22
15	MP	0.02	0.03	0.04	0.03
	BP	0.02	0.06	0.04	0.06
	TC	0.03	0.15	0.03	0.14
	TCV (MP)	+50	+400	-25.0	+366.67
	TCV (BP)	+50	+150	-25.0	+133.33
16	MP	0.03	0.03	0.02	0.00
	BP	0.04	0.06	0.04	0.00
	TC	0.04	0.15	0.04	0.14
	TCV (MP)	+33.33	+400	+100	
	TCV (BP)	0.00	+150	0.00	

Table 9 . Continued

17	MP	0.04	0.03	0.03	0.03
	BP	0.04	0.06	0.06	0.06
	TC	0.03	0.15	0.05	0.14
	TCV (MP)	-25	+400	+66.67	+366.67
	TCV (BP)	-25	+150	-16.67	+133.33
18	MP	0.03	0.00	0.03	0.06
	BP	0.04	0.00	0.04	0.06
	TC	0.04	0.08	0.02	0.07
	TCV (MP)	+33.33		-33.33	+16.67

	TCV (BP)	0.00		-50.0	+16.67
19	MP	0.01	0.00	0.03	0.12
	BP	0.02	0.00	0.04	0.18
	TC	0.02	0.08	0.02	0.07
	TCV (MP)	+100		-33.33	-41.67
	TCV (BP)	0.00		-50.00	-61.11
20	MP	0.04	0.03	0.02	0.00
	BP	0.04	0.06	0.04	0.00
	TC	0.04	0.15	0.01	0.07
	TCV (MP)	0.00	+400	-50	
	TCV (BP)	0.00	+150	-75	
21	MP	0.03	0.03	0.04	0.03
	BP	0.04	0.06	0.04	0.06
	TC	0.04	0.08	0.01	0.07
	TCV (MP)	+33.33	+166.67	-75.0	+133.33
	TCV (BP)	0.00	+33.33	-75.0	+16.67

MP = Mid parent BP = Better parent TC = Transconjugant
TCV (MP) = Transconjugation vigour related to mid parent.
TCV (BP) = Transconjugation vigour related to better parent.

Table 10. Heavy metals uptake by heterozygous diploids of yeast from minimal medium of factory effluents.

Hybrids	Cadmium (Cd)				Cobalt (Co)				Arsenic (As)			
	Concen. (ppm)		Removal (%)		Concen. (ppm)		Removal (%)		Concen. (ppm)		Removal (%)	
	I	II	I	II	I	II	I	II	I	II	I	II
Control	0.05	0.06	0.00	0.00	0.21	0.21	0.00	0.00	0.97	1.22	0.00	0.00
H_5	0.02	0.04	60.0	33.33	0.14	0.14	33.33	33.33	0.53	1.01	45.36	17.21
H_6	0.03	0.04	40.0	33.33	0.14	0.07	33.33	66.67	0.89	0.77	8.25	36.88
H_7	0.04	0.03	20.0	50.00	0.07	0.14	66.67	33.33	0.88	0.98	9.28	19.67
H_8	0.03	0.04	40.0	33.33	0.07	0.07	66.67	66.67	1.01	1.15	+4.12	5.74
H_9	0.03	0.05	40.0	16.67	0.14	0.14	33.33	33.33	0.80	0.53	17.53	56.56
H_{10}	0.03	0.05	40.0	16.67	0.14	0.14	33.33	33.33	0.95	0.75	2.06	38.52
H_{17}	0.02	0.04	60.0	33.33	0.07	0.14	66.67	33.33	0.69	0.46	28.87	62.30
H_{18}	0.04	0.05	20.0	16.67	0.14	0.14	33.33	33.33	1.04	1.10	+7.22	9.84

+ = Increase in concentration. Concen. = Concentration

Table 11 . Efficiency of biological control of pollutants by heterozygous diploid of yeast on total heavy metals uptake from minimal medium containing factory effluents.

Hybrids	Concentration (ppm) of Cadmium, cobalt and arsenic		Removal (%)	
	I	II	I	II
Control	1.23	1.49	0.00	0.00
H_5	0.69	1.19	43.90	20.13
H_6	1.06	0.88	13.82	40.94
H_7	0.99	1.15	19.51	22.82
H_8	1.11	1.26	9.76	15.44
H_9	0.97	0.72	21.14	51.68
H_{10}	1.12	0.94	8.94	36.91
H_{17}	0.78	0.64	36.59	57.05
H_{18}	1.22	1.29	0.81	13.42

In conclusion, there is now great awareness of the potential dangers of environmental pollution by heavy metal compounds which arise in waste waters from fertilizer industry (15). The removal of these pollutants from contaminated solutions by living or dead microbial biomass, and derived or excreted products, can provide an economically feasible and technically efficient means for element recovery and environmental protection (29). The removal and recovery of heavy metals from industrial effluents by genetically engineered microorganisms have several advantages related to their greater absorbing ability, rapidly in their metals accumulation and they are inexpensive. Further development of this area of biotechnology is essential on both environmental and economic grounds, but is dependent upon adequate support from the government and industry.

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Effluent Quality Enhancement Through Tertiary Treatment

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Effluent Quality Enhancement Through Tertiary Treatment

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Abstract

Water is scarce and precious resource in Saudi Arabia. Population growth, rising living standards, and urbanization increase the pressure on the resource. Presently, regulations on wastewater treatment and reuse were issued which state mainly that treatment must produce an effluent with acceptable quality for reuse. Most of the treatment plants in the kingdom employ secondary treatment which has to be upgraded in order to enhance the quality. A laboratory scale study has been carried out to assess the efficiency of a tertiary treatment system. A combination of chemical treatment and slow sand filtration was used to further polish the secondary effluent of Al-Khobar STP. Result shows that the removal of the parameters considered in this study (turbidity, BOD, TOC, total phosphate, ammonia, total coliform) were very high and the levels achieved were meeting the permissible limits for direct discharge of Saudi Arabian Meteorological and Environmental Protection Administration (MEPA).

Keywords: Effluent quality, tertiary treatment, slow sand filtration and nutrients

Introduction

Water quality is an obvious environmental priority and sewage treatment plants are known sources of pollution. Groundwater resources are being depleted in many parts of the Kingdome, through the overuse of renewable aquifers [1]. The general problems associated with treatment plants in the Kingdom of Saudi Arabia have been brought to focus in the recent past. Most of the sewage treatment plants in the Kingdom were designed and built many years ago to handle a certain range of flows and types and concentrations of pollutants [2]. As a community grows, flows and pollutants gradually increase, to the point where treatment capacity is exceeded and the plant no longer works properly.

Standards for wastewater reuse in many countries have been influenced by the WHO health guidelines, US-EPA, and MEPA guidelines. The guidelines or standards required to remove health risks from the use of wastewater and the amount and type of wastewater treatment needed to meet the guidelines are both contentious issues [3]. A royal decree (no. M/6) has been issued to upgrade all existing treatment plants in the Kingdom to a level that can meet the target of safe effluent. Design decisions to be made when designing or upgrading wastewater treatment plants include the unit process selections for primary, secondary, and tertiary treatment. Essentially, the idea is to avoid the huge costs of building new plants by making the best possible use of existing facilities whenever possible, and to select a cost-effective process for upgrading existing plants. Most of the treatment plants remove pollutants in two stages namely primary and secondary treatment. After secondary treatment, some pollutants still remain and the use of conventional approach to remove them is costly [4]. To achieve maximum efficiency with the least cost, it is necessary to explore all options before deciding on a course of action. In this paper use of chemical salts such as alum after secondary treatment followed by sedimentation and slow sand filtration to further reduce the pollutants to an acceptable levels is discussed.

Description of Existing facility:

The Al-khobar sewage treatment plant is located approximately three kilometers South of Al-Khobar city on the western side of Azzizia. It is designed as a carrousel system which can handle a daily flow of 133,300 m3/d (35.25 MGD). The basic process used at the Al-Khobar wastewater treatment plant is the activated sludge process. The principal components of the plant are an inlet structure with screening, grit removal and flow measurement facilities, carrousel type aeration tanks, final clarifiers, sludge recirculation pumping stations, effluent storage lagoons, chlorination facility, sludge thickeners, thickened sludge pumping station and sludge drying beds.

The plant can handle a peak flow of 240,000 m^3/d and has the capability to handle an organic loading of 19,600 kg BOD per day and for suspended solids loading of about 26,700 kg SS/day. Design detention time of aeration tank at average and peak flow is 17 and 9.4 hours respectively.

Another important parameter of the plant is the F/M ratio, which is reported as 0.05 kg BOD/kg MLSS. This plant is designed as an extended aeration system, the oxygen requirement is about 60,123 kg/day and for this purpose 18 aerators are installed in six aeration tanks. Six clarifiers can handle average and peak flow of 133,330 and 233,330 m^3/d respectively. The average detention time of clarifiers is about 3.7 hours to get a clear effluent and a good removal efficiency [5].

Interim Plant Modification:

Tertiary treatment is becoming a standard requirement for effluent discharged to waterways which are sensitive to nutrient enrichment. In tertiary treatment, the secondary treated effluent is further processed using various techniques including flocculation, coagulation, sedimentation and filtration. The main aim is to remove nutrients such as nitrogen and phosphorus and further reduce the small amount of organic material and any remaining harmful microorganisms in the secondary treated effluent.

The primary purpose of improving the quality of the effluent from secondary treatment plant is to provide a cleaner effluent and in some cases, to improve treatment to address local environmental concerns. This may be necessary due to site constraints, regulations, or other limiting factors. The addition of chemical unit followed by sand filters in various configurations is one of many traditional technologies applied to similar systems. These units are located at the effluent site of the clarifiers in order to remove solids. The effluent from the secondary clarifier is adequately treated chemically and pumped into a slow sand filtration unit to achieve a further reduction in nutrients, organics and microorganisms.

The experimental program carried out at the environmental laboratory of civil engineering department comprised two objectives. The first objective was to find out the optimum dose of chemical coagulant needed to further remove the turbidity to an acceptable level and this has been achieved with a dose of 5mg/l of aluminum sulfate. The second objective was to pass the cleared effluent through a one meter deep slow sand filtration unit. Target for upgrading the secondary effluent was removal of Biochemical Oxygen Demand (BOD), Total Organic Carbon (TOC), nutrients, and total coliform.

Performance of the Modified Plant:

Proposed modification in the existing plant was simulated in the environmental engineering laboratory at KFUPM. In this study physical and chemical method of analysis adopted from Standard Methods [6]. Lab scale setup for chemical coagulation, flocculation and sedimentation along with slow sand filtration were fabricated. The schematic layout of the modified plant is shown in figure 1.

a) Phase I: Effect of Chemical Treatment

In the first phase unchlorinated secondary treated effluent was treated with aluminum sulfate. A multiple stirring apparatus with variable speed drive was used to determine the effectiveness of two coagulants, aluminum sulphate and ferric chloride. The results of the jar test indicated alum as more effective than ferric chloride.

Alum was added to this effluent in order to enhance the removal of suspended matter, organic substances, and nutrients such as phosphorus and nitrogen. This chemical treatment also destroyed partially infectious microorganisms. The optimum alum dose found in this study was 5mg/l. Removal in the parameters of concern after chemical treatment is discussed further in detail.

The characteristics of the secondary effluent from Al-Khobar wastewater treatment plant along with the results from chemical and physical treatments are presented in table 1. In the same table a comparison of the results with the permissible limits of Saudi Arabian Meteorological and Environmental Protection Administration (MEPA) is highlighting.

Table .1. Comparison of Effluent from Different Stages of Treatment with the MEPA Standards

Parameter	Secondary Effluent	After Chemical Treatment	After Slow Sand Filtration (8-days run)	*PME Performance Standards for Direct Discharge
Temperature (°C)	23.5	25	23.0	Case by Case Basis
pH	7.22	7.76	7.2	6 - 9
Turbidity (NTU)	5.2	1.8	0.15	75
Total suspended solids (mg/l)	39	28	6.0	15
Ammonia Nitrogen (mg/l)	1.2	0.8	0.1	1.0
Nitrite Nitrogen (mg/l)	0.91	0.46	0.0	--
Total phosphate (mg/l)	4.2	2.6	0.3	1.0
Dissolved oxygen (mg/l)	4.8	5.98	3.35	>2
Biochemical oxygen demand (mg/l)	30	29	8.2	25
Total Organic Carbon (mg/l)	45	25	18	50
Total coliform (MPN/100ml)	$1.4x10^5$	$5.2x10^4$	130	1000 (30-day Average)

* Presidency of Meteorology and environment.

Effect of Chemical Treatment on the Selected Parameters:

The optimum dose of 5mg/l reduced the turbidity of secondary effluent from 5.2 to 1.8 NTU. Nitrogen and phosphorus are the principal nutrients of concern in wastewater discharges. Nitrogen and phosphorus may accelerate the eutrophication of lakes and reservoirs, exert nitrogenous oxygen demand in streams, exhibit toxicity to fish and humans, and may stimulate the growth of algae.

Phosphorus can be removed from wastewater either by precipitation with metal salts or by promoting enhanced biological uptake. Coagulant which has been used for this study removal was aluminum sulfate. With alum the phosphate dropped from an initial value of 4.2 mg/l to 2.6 mg/l with a removal efficiency of 38%.

Ammonia level in the discharged wastewater after secondary treatment is still at a level that can kill fish and deplete oxygen. Nitrification denitrification is the most common biological method to remove ammonia from wastewater but chemical coagulant can also be used to achieve similar results. During this study a slight reduction in ammonia concentration was also observed. Alum dose of 5mg/l decreased the ammonia from 1.2 to 0.8 mg/l.

Total coliform is one of the important indicator microorganism show the quality of wastewater. Chemical coagulants act as oxidizing agents and can reduce the coliform level to a certain level. In this study it was observed that alum dose of 5mg/l decreased the coliform level from $1.4x10^5$ MPN/100ml to $5.2x10^4$ MPN/100ml. This shows that about 63% removal of coliform can be achieved.

b) Phase II: Slow sand filtration

Slow sand filtration was selected because it is well known process to improve the water quality. Slow sand filtration is preferred over the rapid sand filter because it is economical, practical, does not require skilled worker, and easy maintenance. A vertical circular plexiglass column of 18 cm diameter was filled with sand up to a depth of 100 cm. This column was filled with uniformly graded sand using the pluviation technique, creating a sand column of 100 cm height. Physical properties of the sand used are presented in table 2.

Table .2. Physical Properties of the Sand Used in the Study

Property	Value
Effective Grain Size (D_{10})	0.188 mm
Uniformity Coefficient (C_u)	1.85
USCS Classification	SP
Maximum Density, ρ_{max}	1.82 g/cm^3
Minimum Density, ρ_{min}	1.54 g/cm^3
Hydraulic Conductivity, K	0.02 cm/sec

After chemical treatment the treated water was pumped from a storage sump through a 0.25 hp pump into an overhead tank from which influent was provided to the slow sand filtration unit by gravity. In the column there were three sampling ports designated as P1, P2, and P3. Port P1 located 22 cm below the top surface of media, P2 located 60 cm from top and P3 located 100 cm from the top of the media. An overflow port was also provided in the column to divert the excess flow to a storage sump. Detail of the slow sand filtration column is presented in figure 2. The filter was operated by control of outlet flow. The filtration rate was kept to an average value of 0.15 m/hr. The rate of flow was controlled by an outlet valve which had to be opened a bit further as the filter run progresses, to compensate for the increased hydraulic resistance of the filter bed. All these ports were fitted with very fine mesh to prevent the sand flow out of the column.

The duration of the continuous experimental run was eight days. This short run was decided on the basis of findings of a three-year KACST funded project (AR-13-71, 1994-97) on slow sand filtration as a tertiary treatment unit [7,8]. Generally, the criteria for terminating slow sand filters runs is either the break through of turbidity or attainment of terminal head loss which subsequently results in a very dramatic decline of effluent flow rate. For the purpose of this work, however, due to the very low influent turbidity a significant head loss could still sustain the desired filtration rate. Therefore, the criteria for terminating filter runs was based on the ability to maintain the design filtration rate irrespective of head loss and the quality of effluent.

Effect of Filtration on the Selected Parameters:

Selected parameters for this study include variation of pH, turbidity, nutrients, BOD, TOC and total coliforms. Variation of pH with time along the three ports of the filter is depicted in figure 3. From the figure it can be seen that the variation was not significant and it varied between 7.7 to 7.2. In the case of turbidity, after 168 hours of continues operation the values of turbidity from the three ports were almost identical (0.15 to 0.17 NTU). This low level of turbidity is an indication of good performance of the slow sand filter. The highest removal of turbidity has been achieved in port number 3 (81.7%), compared to the other two ports (75% and 80% for ports 1 and 2 respectively) as it is shown in figure 4.

Nutrients investigated in this study comprised ammonia and total phosphate. Al-Khobar wastewater treatment plant is a carrousel type activated sludge treatment system where nitrification and denitrification takes place in the aeration tank. This plant is consistently giving a good quality effluent having low values of nutrients. The total phosphate value from the secondary treated effluent of Al-Khobar wastewater treatment plant is in the range of 4 to 4.8 mg/l. Current standard practices generally produce a phosphate concentration of 0.7 to 1.0 mg/l. This indicated that further removal was needed. The traditional approach suggests that 0.4 mg/l phosphate can be achieved only by using tertiary filtration. A single media slow sand filtration unit was used for this purpose. With this filter the phosphate concentration dropped from 2.6 mg/l to 0.3 mg/l achieving a removal efficiency of 88.5% (figure 5). Variation of ammonia was also observed and found that its concentration at the end of run decreased to 0.1 mg/l from 0.8 mg/l giving the removal efficiency of 90% (figure 6).

Sand filtration system has long being recognized for organics removal. The influent water to the filter had BOD and TOC concentrations of 29 and 25 mg/l respectively. It was found that the filter gave removal efficiencies of BOD and TOC of 71.7% and 28% respectively (figures 7 & 8). It was also found out that the removal efficiency is dependent upon sand depth. In the case of removal of microorganisms, the mechanisms of transport and removal of the same by the slow sand filtration process are biological, physical and physio-chemical [4]. However, because of small sizes of viruses, physical mechanisms of transport and removal are clearly of little importance. Unless there is considerable association with suspended particular matter, the three factors of greatest potential significance in the elimination of viruses in a slow sand filter are microbial predation, absorption to biomass or biofilms to non-biological surface. As seen in figure 9 the removal efficiency of total coliform after 168 hours of operation is 99.75%. This could mainly be attributed to the growth of biofilm on the surface of slow sand filter (Schmutzdecke layer).

Summary and Conclusions:

The treated wastewaters generated in Al-Khobar wastewater treatment plant needs to be reused and/or disposed in a more environmental friendly manner. Improperly treated wastewater can be a serious public health disaster when reused [3,7]. Pathogens have to be inactivated or reduced to the lowest possible risk. A laboratory investigation was conducted at the civil engineering environmental laboratory to study the feasibility of upgrading the existing secondary treatment plant to a tertiary level. A combination of physical, and chemical treatment was applied to the secondary effluent water of Al-Khobar STP. Results show that the removal of the parameters considered in this study was high and all parameters were meeting the MEPA standards (see table 1). Following points summarized the results of some selected parameters:

- Turbidity value achieved in the final effluent after eight days operation was 0.15 NTU with a high removal of 97.1%.
- During treatment overall total phosphate removal was 92.86%.

- Ammonia nitrogen was reduced to 0.1 mg/l achieving a 93.3% removal.
- The average removal of BOD was found to be 72.7%.
- Total coliform removal was also high giving a value of 99.91%.

On the basis of above findings it can be concluded that upgrading of the existing treatment plants in the Kingdome to a tertiary level could be achieved by implementing physico-chemical units. Use of the chemical coagulants along with the slow sand filtration proved to be an attractive and economical option to get a safer effluent. An optimum dose of 5mg/l of alum coagulant will results in a reduction of turbidity and longer filter run. In this study 5mg/l of alum dose along with the slow sand filtration, effluent quality has been enhanced to tertiary level within eight days of operation.

Acknowledgement

The authors wish to acknowledge gratefully the support extended by the civil engineering department, King Fahd University of Petroleum and Minerals, Saudi Arabia for carrying out successfully this study.

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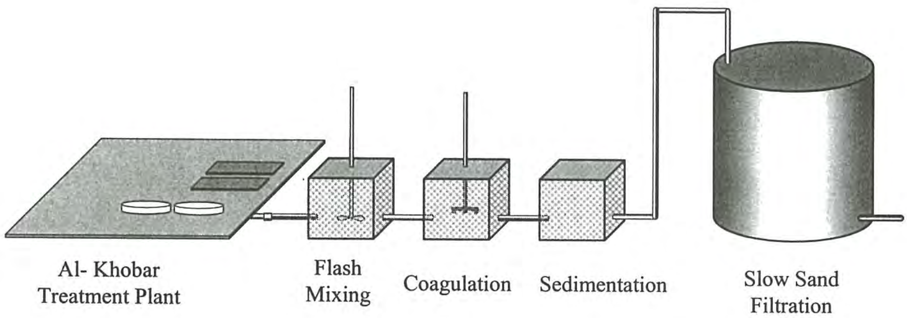

Fig. 1: Schematic Layout of the Modified Plant.

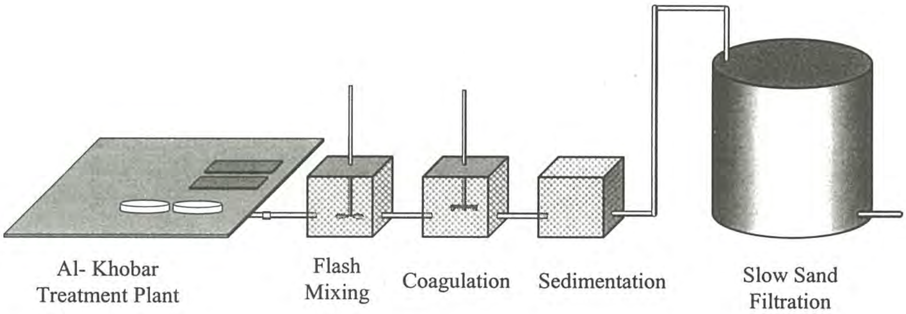

Fig. 1: Schematic Layout of the Modified Plant.

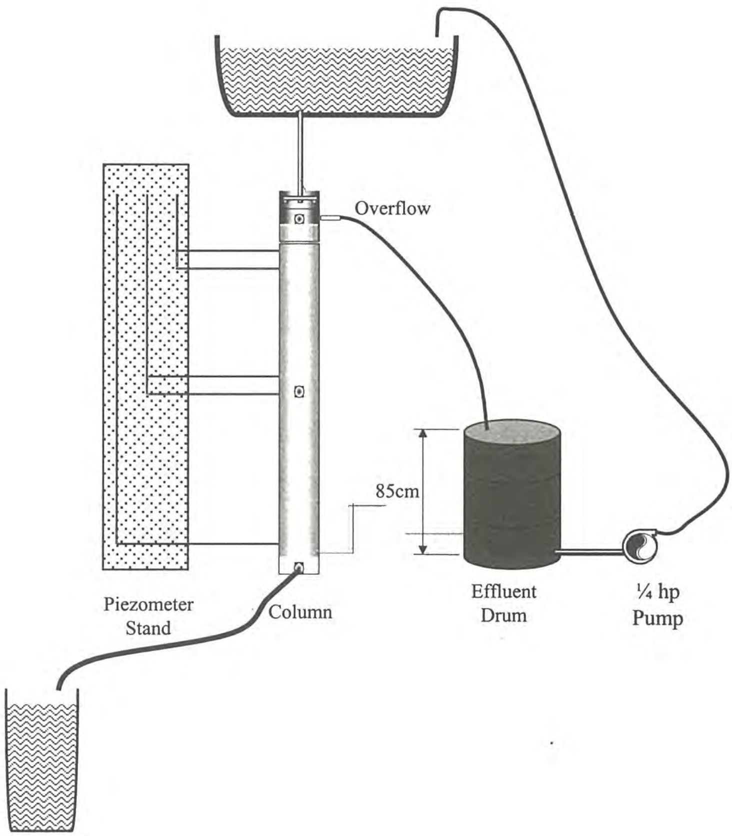

Fig. 2: Slow Sand Filtration Setup for Enhancement of Wastewater Quality

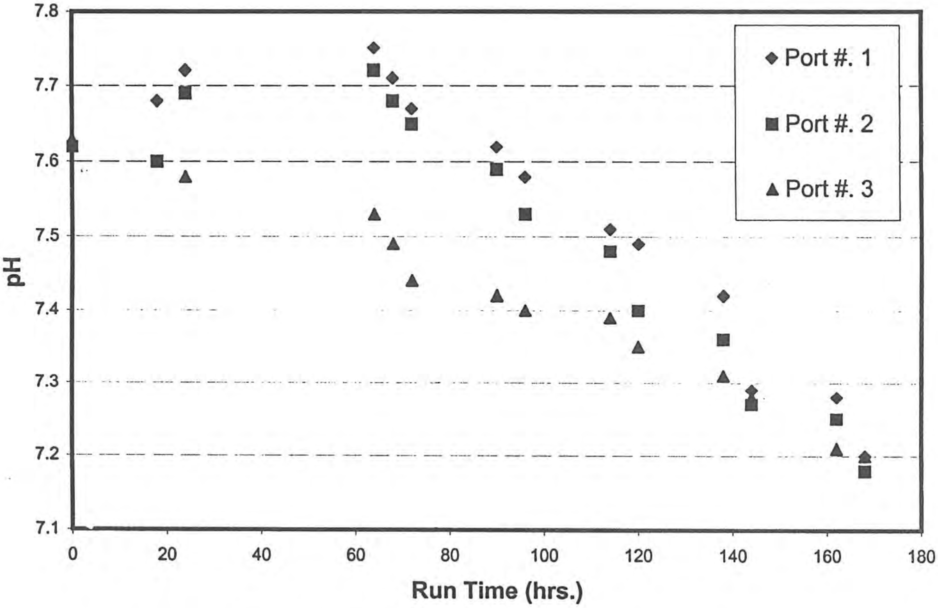

Figure 3. Variation of pH With Time in Different Ports

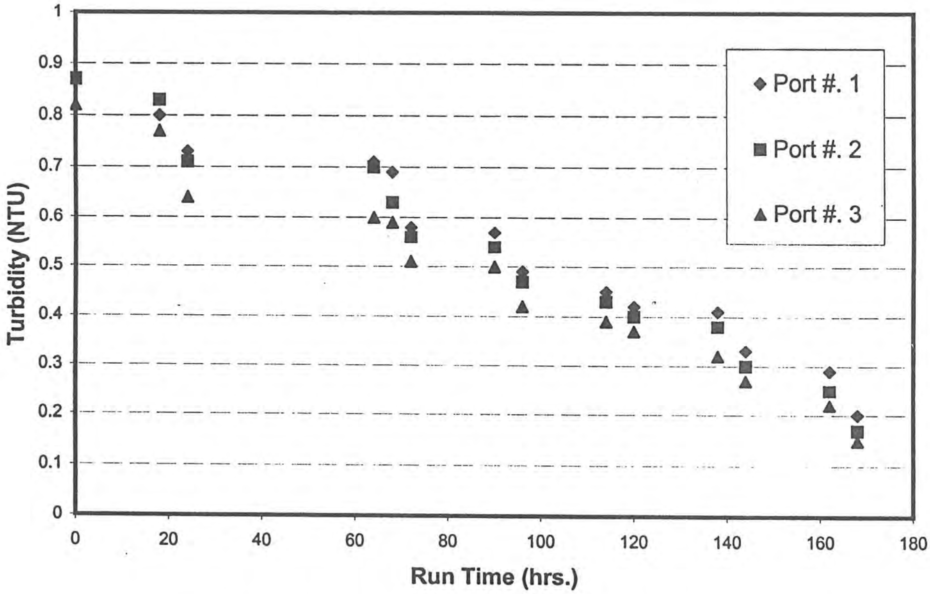

Figure 4. Variation of Turbidity With Time in Different Ports

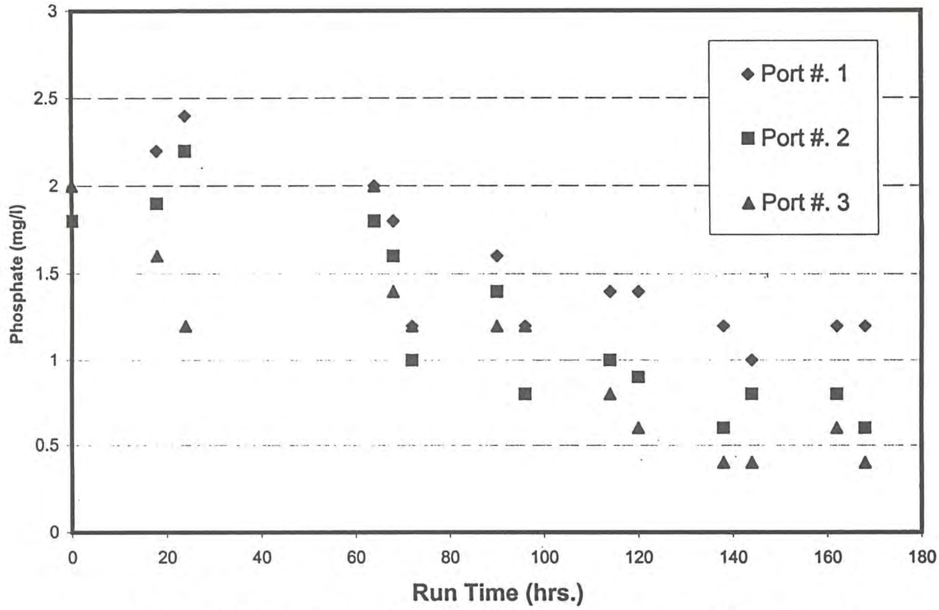

Figure 5. Variation of Phosphate Concentration With Time in Different Ports

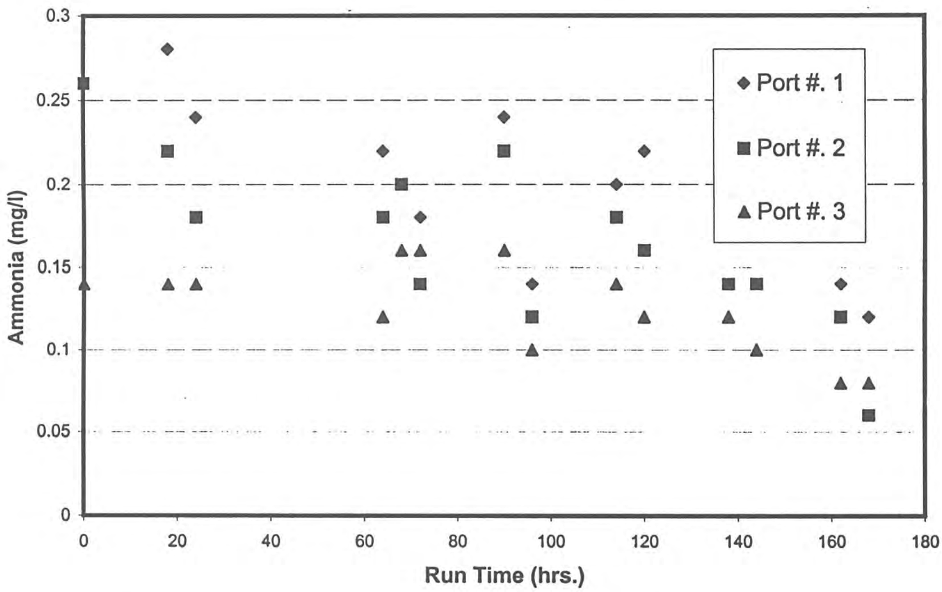

Figure 6. Variation of Ammonia With Time in Different Ports

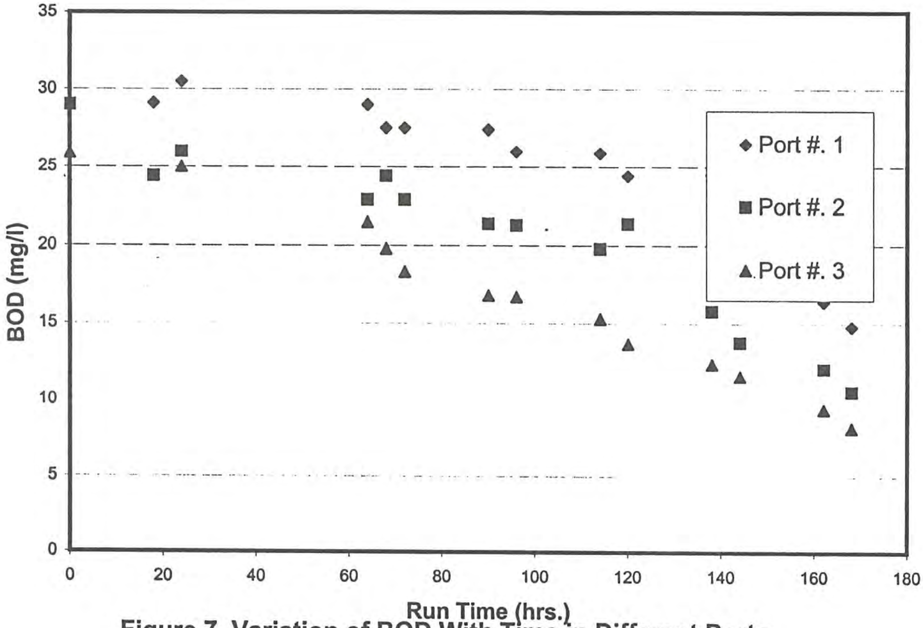

Figure 7. Variation of BOD With Time in Different Ports

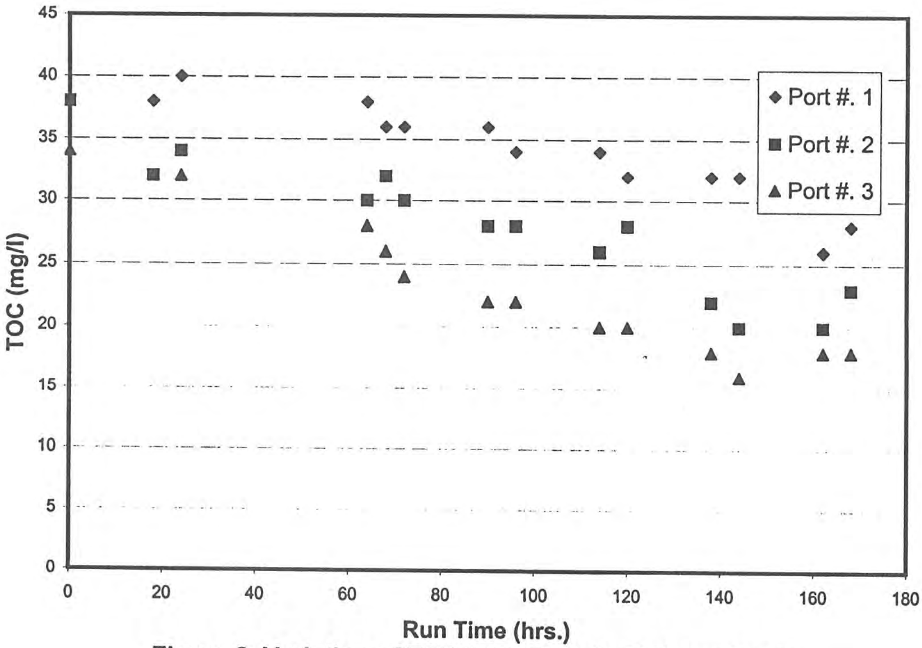

Figure 8. Variation of TOC With Time in Different Ports

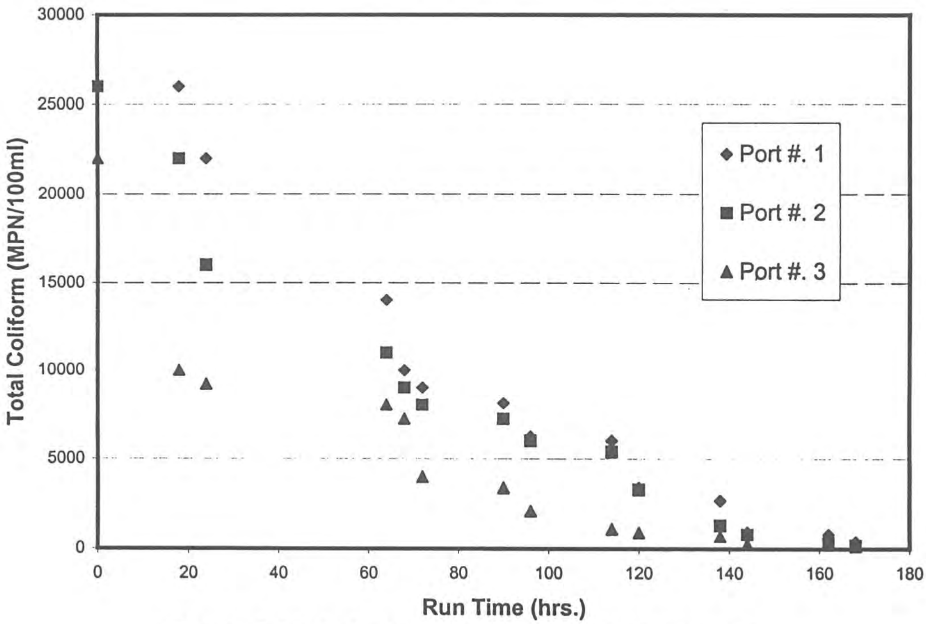

Figure 9. Variation of Total Coliform With Time in Different Ports

Irrigation Water Management

WSTA Sixth Gulf WATER Conference
In concurrence with
Second Symposium on Water Use Conservation
in the Kingdom of Saudi Arabia

Water Irrigation conservation in Sizeable Agricultural Projects, Saudi Arabia

Dr. Abdulla El-Siddiq El-Amin, Jamal K. Nejem
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Water Irrigation Conservation in Sizeable Agricultural Projects, Saudi Arabia

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Abstract

Comprehensive developments in agriculture in the Arabian Peninsula in general and in the Kingdom of Saudi Arabia in particular were accomplished in early 1980s. Irrigated area in Saudi Arabia increased from about 0.4 million hectares in 1971 to about 1.62 million hectares in 1992, which represents 305% increase. Currently about 45 large irrigation schemes are in operation in the kingdom, each covering an area of about 5000 to 35000 hectares. Groundwater is the main water supply source for irrigation. The increase in agricultural area has resulted in considerable increase in groundwater abstractions. The total water consumption increased from about 1,850 million cubic meters (MCM) in 1980 to about 30,000 MCM in 1992. It is obvious that due to heavy pumping, problems associated with water management will only increase. The huge pumping has resulted in the formation of shallow groundwater table due to the presence of impervious layer at about 3 -10 meters below the ground surface in some parts of the Eastern Province of Saudi Arabia. This shallow water table rise has formed artificial lakes, which led to degradation of thousands of hectares of fertile agricultural lands converting into unusable wastelands.

The present study took a unique scientific approach to develop a model that assists in understanding the aquifer system and help in proper management of groundwater, the main water supply source. The conservation and minimization of groundwater use reduces the formation of artificial shallow groundwater table and protects the land from degradation. Several alternative schemes were proposed to minimize the groundwater consumption concurrent to maintaining the agricultural production that ultimately reduces the formation of artificial shallow groundwater table and protect the fertile land for future use.

KEY WORDS agriculture; groundwater: irrigation; groundwater abstraction

Introduction

Humankind required two main resources to survive. These are air and water. Without high quality sources for these two resources, life would not exist as we know. However, countries around the world have treated them both as if they were impervious to contamination and depletion. This study focuses on water and its proper management. Improper water resource management produces three results. It can result in depletion of aquifers, deterioration of water quality, and /or salination of the soil, as a result of a rise in the surface water table; this renders the area useless for agricultural purposes.

Improper water management practices resulted in so many negative impacts around the world. In central Valley of California, United States, Shelton, (1990) concluded that extensive irrigation resulted in over exploitation of 1.85 km^3 of water. In Lima, Peru, South America, over pumping of ground water resulted in a drawdown of the water level of up to 15-30 m (Watkin, et al., 1997). Jenkins (1981) found that millions of Hectares of lands in Australia are now useless due to salination as a result of water table rise.

The Middle East, has not been immune to the effects of improper water management practices. In 1986, Lloyd reported a dramatic rise in the water table in Doha, Qatar, and in Gizan, Saudi Arabia. Currently in Saudi Arabia, there are 45 large irrigation Schemes each utilising between 50 and 500 wells to irrigate from 5,000 to 35,000 Hectares. Total irrigation water consumption increased from about 1,850 million cubic meter (MCM) in 1980 to about 30,000 MCM in 1992 (Dabbagh and Abderrahrnan, 1997). It should be obvious that due to these heavy stresses, problems associated with water management will only increase. In the Eastern Province of Saudi Arabia, when Ash-Sharqiyah Agricultural Development Company (SHADCO) Project Started in 1985 (Study Area, Figure 1), there were no lakes or ponds in the project or at the vicinity. By 1989, and as a result of excessive and improper water management practices at SHADCO Project site, a dramatic rise in shallow water table has resulted in the formation of artificial lakes throughout the project site (Figure 2). The excess irrigation water percolates down the soil profile, accumulating on the top of the impervious layer which extends under the project area at varying depth of about 3-10 m below ground surface. This resulted in converting large fertile lands out of production.

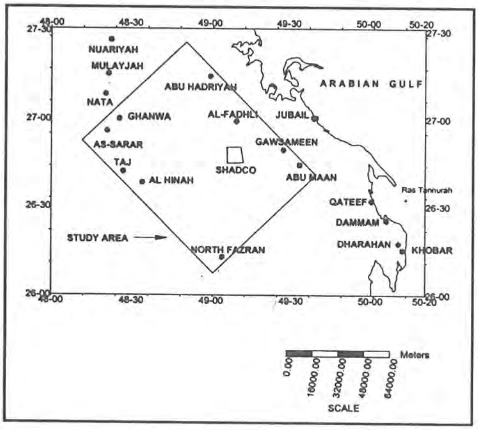

Figure 1: Study Area.

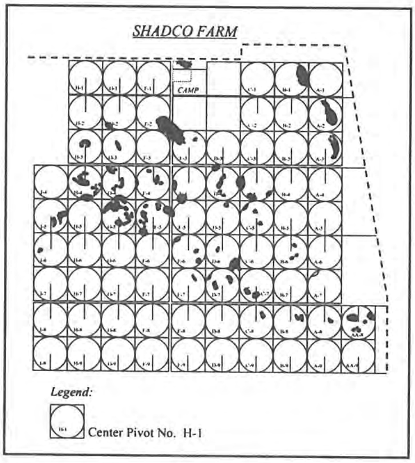

Figure 2: Map Showing the Distribution of SHADCO Center Pivots.

The present study took a unique scientific approach to develop a model that assists in understanding the aquifer system and help in proper management of groundwater, the main water supply source. The conservation and minimization of ground water use reduces the formation of artificial shallow water table and protects the land from degradation.

The selected area of this study covers about 10,235 km^2 (Figure 1). It is bounded on the North by LAT 27° 28' 04" N, LONG 48° 51' 13" E, on the East by LAT 26° 42' 8"N, LONG 49° 39' 50" E, on the South by LAT 26° 12' LONG 49° and on the west by Lat 26° 52' 49", LONG 48° N LONG 48°-11'-04" E. SHADCO owns about 600 km^2 of land in the Central part of the study area other than SHADCO project. The study area comprises some private farms located in As-Sarar, Taj, Al Hinah and Fazran.

Between 1985 and 1989 SHADCO used to cultivate about 5700 Hectares. Since then until the present SHADCO is cultivating only about 3000 Hectares (together with a dairy farm, sheep project and 18 Hectares of vegetables). Which, means the loss in the cultivated land is about 2700 Hectares, which, represents about 47% of the total area. This loss in the cultivated area is mainly due to the formation of artificial lakes (Figure 2). Figure 3 shows the total abstracted groundwater in study area.

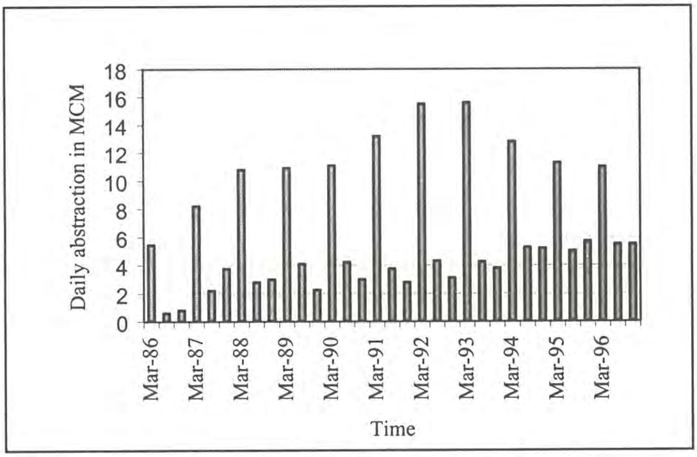

Figure 3: Present Daily Abstractions From UER (Study Area).

Hydrogeological Setting

The kingdom of Saudi Arabia consists of igneous and metamorphic basement rocks known as the Arabian shield, and the sequence of sedimentary layers known as the Arabian shelf, the shield extends along the western part of the Kingdom and contains limited renewable groundwater resources. The Arabian Shelf contains several layered principal and secondary aquifers, formed mostly of limestone and sandstone. They overlay the basement rock formation, and covers about two third of the Peninsula, These aquifers crop out in the western part of the shelf and extend towards the eastern parts. Most of the aquifers possess fossil gradients and hence are classified as depletable aquifers. Significant groundwater resources in these aquifers exist from palaco-recharge of about 20,000 to 28,000 years before present (BP) (Edgell, 1997).

The stratigraphic sequence of the formations cropping out in the Eastern Province of Saudi Arabia, ranges from Palaeogene to Quaternary and recent. According to the official stratigraphic nomenclature, the Palaeocene Eocene sequence has been subdivided into the Umm Er Radhuma (UER) Formation, the Rus Formation and the Dammam Formation. The

Neogene sequence is subdivided into the Hadrukh, Dammam and Hofuf Formations. The generalised lithostratigraphic sequence of the study area is given in Table1.

Table 1: Lithostratigraphic Succession and Hydrogeological Characteristic of the Strata in the study Area (after Powers et al., 1966: Backiewicz et al., 1982).

Age		Formation or equivalent	Member or equivalent	Thickness	Description of formation and lithology	Hydrogeology
Quaternary		Superficial deposits		Very variable, generally less than 30 m	Aeolian sands, wadi-fill deposits, sheetwash deposits, alluvial deposits and sabkhah deposits	Wadi-fill deposits contain localized groundwater. Sabkhas are areas of natural groundwater discharge. Sand dunes induce recharge locally.
Tertiary	Miocene-Pliocene (Neogene)	Al-Hofuf		10-30 m at Al Hassa	Marl with limestone intercalations of fluviatile sands and marls in upper part.	Poor, unconfined, aquifer generally but locally along major wadis may form a more productive aquifer.
		Dam		0 –100 m	Hard, compact microlitic limestone ranging from chalky to marly facies. Extensive fissuring and karstification in the upper part of the formation. Fissures frequently sand-filled.	Excellent aquifer around Al Hassa. Little known elsewhere.
		Hadrukh		25-90 m at Al Hassa	Clean sands at the base followed by marly sands, siltstones and sandy/microlitic limestone. Large lateral facies variations are characteristic.	Excellent aquifer in Al Hassa, especially basal sands. Little known elsewhere.
	Eocene	Dammam	Alat limestone	15-50 m	Light-covered limestone of varying hardness. Chert bands in top part common.	Moderate aquifer.
			Alat marl	10-20 m	Marl, with characteristic light reddish brown ('orange' in literature) colorations.	Aquitard where present.
			Khobar limestone	20-45 m	Light-coloured, crystalline limestone, locally fissured Calcarenitic and dolomitic facies occur at Al Hassa.	Aquifer.
			Khobar marl	5-15 m	Mainly marl, with subordinate shales and thin limestone layers.	Aquitard where present
			Alveolina	Up to 15 m	Thin limestone interbedded with marls or shales.	Complete section forms an aquitard.
			Saila-Midra	5-10 m	Dark-coloured shale. Eroded or missing over small areas of the Ghawar anticline.	Aquitard where present.
		Rus		40-200 m where anhydrite is present; 20-30 m in the absence of anhydrite.	Chalky limestones, anhydrites, dolomitic limestone and shales.	Aquitard.

	Paleocene	UER		250-600 m increasing from west to east.	Limestones and dolomites in varying proportions with anhydrite facies. Locally karstified and infilled with argillaceous sediments. The centre of the aquifer is primarily calcarenitic. Limestones, frequently fissured, and this grades downwards into dolomitic facies and more argillaceous limestones with shale/marls at the base.	Aquifer, Calcarenitic facies constitute an excellent aquifer, particularly if fissuring is well developed. Fine-grained and anhydritic facies constitute a very poor aquifer. Basal shades form aquitard between UER and Aruma. Dolomitic zones are only moderate. aquifer if fissured.
Cretaceous		Aruma		400-600 m	Limestones and shaley limestones are dominant lithologies, with proportion of shales generally increasing in depth	Poor aquifer

Based on the hydraulic properties of various units, the lithologic succession can be divided into aquifers and intervening aquitards namely, the Umm Er Radhuma aquifer, the Rus aquitard with Midra and Saila Shales and Alveolina limestone, the Khobar aquifer, the orange Marl aquitard, and the Alat aquifer, and the Neogene aquifer (Dam-Hufuf and Hadrukh formation) (Table 1). Except for local facies variations, limestones, dolomitic limestones and dolomite represent the main aquifers. Shales, marls and anhydrites represent the aquitards. The thickness of the hydrogeologic units are influenced by Domal and anticlinal structures. The thickness increases from west to east except at the local structural highs. Hydraulic properties of these aquifers show great variation in the study area, which is a common characteristic of carbonate aquifers. Transmissivities and storage coefficients are mainly controlled by facies variations, joints, fissures and solution voids. The detailed description of each hydrogelogic unit can be referred in Powers et al. (1966). Italconsult (1969), BRGM (1977), GDC (1980), Edgell (1997), Rasheeduddin (1999).

Modelling Technique

The present study used a "Visual MODFLOW", The MODFLOW of USGS with an efficient interface for developing three dimensional groundwater flow and contaminant transport models. Visual MODFLOW is an easy to use pre-and-past processor for the MODFLOW of McDonald and Harbough 1988. The general form of the partial differential equation, governing transient, three-dimensional flow of ground water in a heterogonous and anisotropic aquifer can be found in Anderson and Waessener (1992) and McDonald and Harbough (1988).

During the simulation, meshes of 735 m x 735 m in the SHADCO Project site and 2000 m x 2000 m outside the SHADCO farm were used to discretize the study area (89 x 115 km) (Figure 4). Because the field data are limited and the model spacing is fairly coarse, the most important objective was to reproduce the general observed flow pattern.

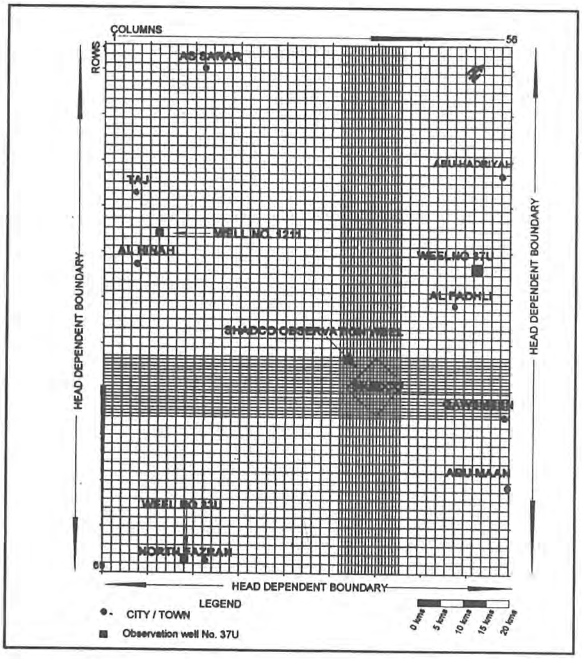

Figure 4: Finite Difference Grid and Boundary conditions of the Groundwater Flow Model.

The selection of the boundary is an important step in model design. The boundaries of the model were determined after a critical review of the available hydrogeologic and water level data. The north-western and south-eastern boundaries of the study area are almost perpendicular to the equipotential lines, so it seems reasonable to represent these boundaries as no flow boundaries (only during steady -state conditions). During transient conditions, however, the heads along these boundaries are subject to changes owing to stresses imposed on the system (pumping). That's why for transient calibration, the same boundaries were considered as 'head dependent boundaries', the south-western and the north-eastern boundaries of the study area were modelled as head dependant boundaries.

Abstraction Rates

Water abstracted from the Umm Er Radhuma aquifer in the study area is used mainly for agricultural activities. Only a small portion of the total water is utilised for industrial and municipal purposes.

The agricultural season has been divided into three stress periods based on the irrigation practices used in the study area. The first stress period is from mid November to mid-March, the second stress period is from mid March to mid July; and the third stress period is from mid July to mid November. This division is based on the fact that the crops cultivated in the study area have different irrigation patterns, i.e. wheat and barley are irrigated during the winter while rhodes is not irrigated and alfalfa is irrigated continuously throughout the year. The winter crops consume about 61% of the total abstraction, while crops that are irrigated during the summer period consume about 39% of the total abstraction.

The total abstracted water increased from 81 MCM (1985-1986) to about 288 MCM (1992-1993). After 1993 the rate of abstraction decreased to 262 M CM.

Management Alternatives

To supply the required amount of water needed for irrigation in the study area, the parameters determined during the calibration and the verification of the model were used to predict the response of the aquifer for future groundwater withdrawal. The prediction stage involved the establishment of the groundwater alternatives feasible for efficient utilisation of groundwater resources without future deterioration in water and soil quantity and quality. These management alternatives must be based on realistic operational practices that are compatible with the economical, legal, organisational, political and environmental aspects.

All the alternatives, two options (namely option A and option B) were considered. Option A, in which the existing practices of groundwater pumping adopted by SHADCO and other farmer in the study area continue. This option i.e. without proper scheduling for irrigation is the main cause for the formation of artificial lakes. While in option B groundwater pumping was used for agricultural activities according to an irrigation schedule program recommended by King Fahd University for Petroleum and Minerals (KFUPM, 1993). In this program, reference crop evapotranspiration, crop water requirements and irrigation schedule for wheat, barley and forage crops were defined on the basis of using centre-pivot sprinkler irrigation system. This irrigation schedule will reduce the water use for different crops by about 30% of the amount used in current (option A) practices and consequently minimize the excess irrigation water that percolates down the soil causing rise in the shallow water table. This schedule was considered as a conservation measure in the present study. Each alternative referred to as Alterative B used 30 to 56 % less groundwater than Alternative A in all pumping schemes discussed further (Table 2).

Table 2: Comparison Between the Quantity of Water Used for Irrigation in Alternative A and B.

Crop	Quantity of water used for Irrigation/day/ha (m^3) Alternative A	Quantity of water used for Irrigation/day/ha (m^3) Alternative B	% Reduction
Barley	100	63	37
Rhodes and corn (Summer)	133	93	30
Rhodes and corn (Winter)	66	29	56
Alfalfa (Summer)	102	75	26
Alfalfa (Winter)	102	62	39

Alternatives IA and IB

This alternative is based on the assumption that SHADCO will increase the existing 1,000 milking cows to 4,000 milking cows within 10 years. The sheep herd will be increased from the existing 5,000 head to 20,000 head within the same period. It is also assumed that SHADCO will not sell fodder for its clients in the Eastern Province of Saudi Arabia and adjacent Gulf countries. Accordingly the alfalfa and rhodes grass centre pivots will increase annually to accommodate SHADCO's annual demand.

The barley centre pivots cultivated in SHADCO will be cultivated in such a way that 6,500 tons will be produced annually. The development plan for other farmers in the study area will continue in such a way that annual increase of 10% is added to the original number of barley centre pivots.

According to the above assumptions the total number of pumping wells operating in the study area was increased from 157 wells during 1996 to 306 wells by the end of planning period in 2006.

The results of alternative IA and IB (Table 3) clearly indicate a saving of about 791.0 MCM of water will be achieved (i.e. about 29% of the total abstraction) if alternative IB is implemented, this quantity may be considered as excess irrigation water, which perculates and contributes in raising the shallow water table, which leads to formation of artificial lakes and consequently decrease the cultivated area. A reduction in the maximum drawdown at the selected observation sites varying from about 44% to about 32% will also be achieved (Figure 5 and 6).

Table 2: Comparison Between Results of Alternative IA and IB.

	Total No. of Pumping wells	Total abstraction MCM	Drawdown at SHADCO (m)	Drawdown at As-Sarar (m)	Drawdown at AL-Hinah (m)
Alternative IA	306	2720	3.91	2.19	5.31
Alternative IB	306	1929	2.68	1.23	3.5
Saving		791	1.23	0.96	2.01
% Saving or Reduction		29%	31.5%	43.8%	37.8%

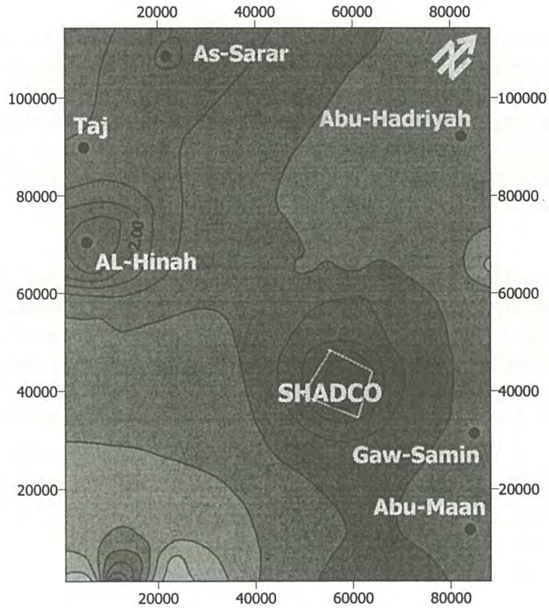

Figure 5: Drawdown Contour map of UER aquifer Alternative I (1996-2006).

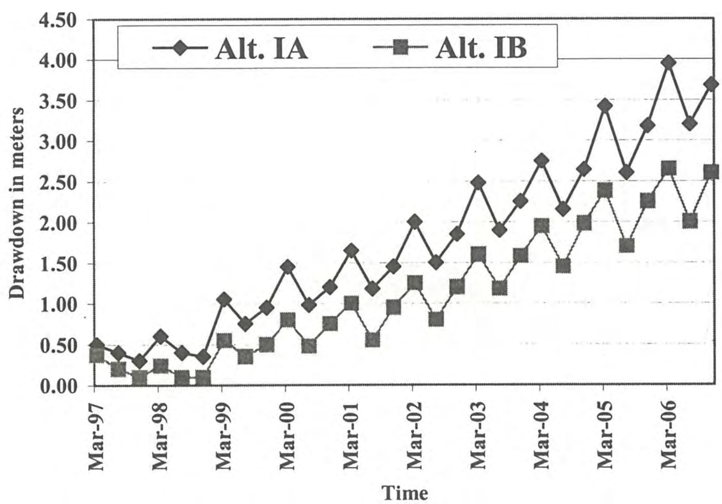

Figure 6: Effect of pumping on drawdown (SHADCO) (alternative I).

Alternatives IIA and IIB

In this alternative it is assumed that SHADCO has planned to increase its fodder sales by 2,000 tonnes per annum apart from its own consumption. The target production at the end of the planning period was bout 20,000 more tonnes of fodder crops than was planned in alternative I. All other conditions mentioned in alternative A will be the same as for SHADCO, but the other farmer in agricultural regions in the study area will increase their barley and fodder centre pivots by 25% per annum. The total number of pumping wells in the study area will increase to 489 wells by the end of the planning period.

If alternative IIB (conservation) is used instead of alternative IIA, reduction in drawdown at pumping field will vary from 22.5 to 42.5% of the total drawdown observed in the study area. Savings in abstraction would be about 1,148 MCM, which amounts to about 30% of the total abstraction (Table 4, Figure 7). Again this saving in a abstraction will have it's positive effect to prevent formation of artificial lakes.

Table 4: Comparison Between Results of Alternative IIA and IIB.

	Total No. of Pumping wells	Total abstraction MCM	Drawdown at SHADCO (m)	Drawdown at As-Sarar (m)	Drawdown at AL-Hinah (m)	Drawdown at AL-Fazran (m)
Alternative IIA	489	3820	5.24	3.14	7.34	5.68
Alternative IIB	489	2672	4.06	2.19	5.26	3.28
Saving		1148	1.18	095	2.08	2.4
% Saving or Reduction		30%	22.5%	30.3%	28.3%	42.25%

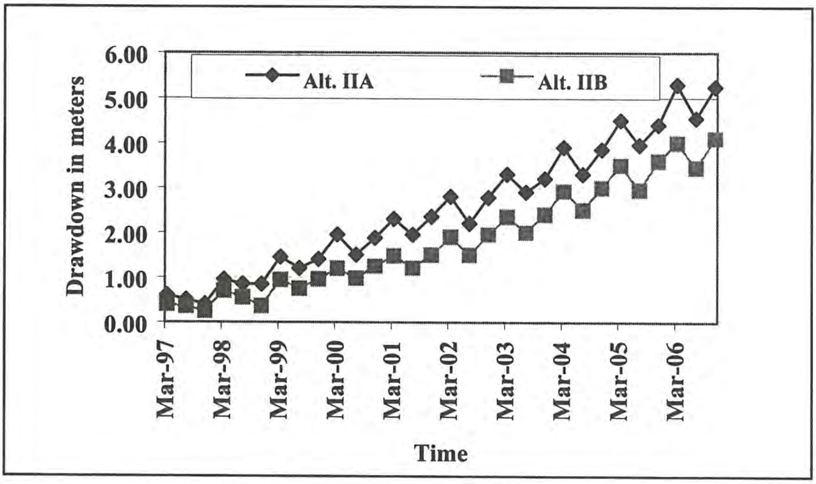

Figure 7: Effect of Pumping on Drawdown (SHADCO) (alternative II).

Alternatives IIIA and III B

In this alternative, it is assured that SHADCO will expand the dairy farm and the Sheep Project to accommodate 10,000 milking cows and 50,000 sheep within 10 years. To feed these animals, SHADCO needs 75 centre pivots cultivated with alfalfa, 18 centre pivots cultivated with corn. It is also assumed that SHADCO will cultivate 75 centre pivots with alfalfa and 18 centre pivots with rhodes grass for sale to its clients in the Arabian Gulf region. Other agricultural areas are assumed to increase their centre pivots by 25% of the original number of pivots per annum. The total number of pumping wells in this alternative was 651 wells. Table 5 shows that a saving of 1,660 MCM (i.e. 28.44% of the total abstraction) will be achieved if Alternative IIIB (conservation) is implemented instead of Alternative IIIA. This saving will help in reducing the hazard of artificial lakes formation. A reduction in the drawdown varying from 24 to about 60% (Table 5, and Figures 8) at the high pumping fields will be achieved, if Alternative III B is adapted.

T able 5: Comparison Between Results of Alternatives IIIA and IIIB.

	Total No. of Pumping wells	Total abstraction MCM	Drawdown at SHADCO (m)	Drawdown at As-Sarar (m)	Drawdown at AL-Hinah (m)	Drawdown at AL-Fazran (m)
Alternative IIIA	651	5836	9.66	3.25	7.6	6.23
Alternative IIIB	651	4176	7.43	2.15	5.45	2.75
Saving		1660	2.23	1.1	2.15	3.48
% Saving or Reduction		28.44%	23.1%	33.8%	28.3%	55.85%

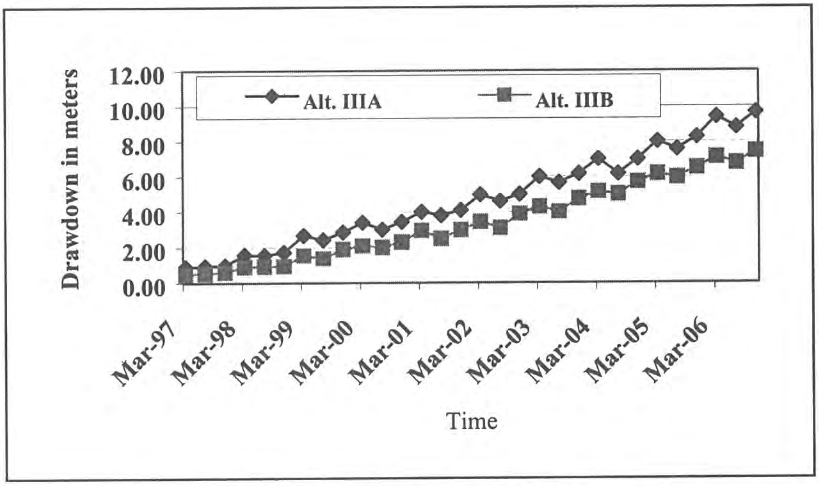

Figure 8: Effect of Pumping on Drawdown (SHADCO) (alternative III).

Conclusions

- Saudi Arabia is an arid country with insignificant renewable water resources and it's rapid agricultural development is dependent mainly on it's groundwater resources.

- Significant abstractions of groundwater have continued since 1958 in Saudi Arabia. There are more than 45 large irrigation schemes each irrigating from 5,000 to 35,000 hectares. The total irrigation water consumption has increased from about 1,850 MCM in 1980 to about 30,000 MCM in 1992. Extensive abstraction from the Umm Er Radhuma aquifer in the study area has continued since 1985. Abstraction rates have increased from 81 MCM in 1985/86 to 262 MCM per year in 1995/96 in the study area.

- Over pumping due to excessive and unplanned irrigation has caused the formation of artificial lakes at the large irrigation project of SHADCO.

- Arid region aquifers have fossil gradients. With very low recharge and high abstraction rates; therefore, proper management of scarce, non-renewable water resources is essential. Based on this need, a finite difference groundwater model was developed to assess the groundwater condition of the Umm Er Radhuma aquifer and to help in reducing the formation of artificial lakes.

- The three alternative scenarios proposed in the study indicated that the application of conservation measures will reduce total abstraction by 30% of the total abstraction and the drawdown will be reduced to about 25% to 40% of the total drawdown during the planning periods.

Recommendations

1. Future location of centre pivots and wells with sufficient spacing will help in minimizing the drawdown and control the spread of large cones of depression.

2. Water conservation measures should be seriously considered to reduce the rise in shallow water table and retard the formation of artificial lakes.

3. The blending of water from artificial lakes with groundwater from Umm Er Radhuma aquifer must be studied for future use.

4. Farmers and water utilizing agencies must be educated about and become familiar with the quantities of optimum water used for their needs.

5. Thorough and more detailed hydrogeological investigations must be carried out on a local scale before implementing any development of pumping projects.

6. The study can be used as a guide for proper management of groundwater in other areas of the same conditions.

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Intermittent Supply Impact on Water Systems (Case Study)

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INTERMITTENT SUPPLY IMPACT ON WATER SYSTEMS
(Case Study)

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Abstract

Water utilities worldwide invests huge amounts of money to fulfill demand requirements, to optimize profits and to provide best services to their customers. In some parts of the world where water is a scarce commodity, this becomes a non-achievable target where economical and political circumstances Intervenes to form obstacles in front of any progress towards development of services.

In some countries, intermittent supply is adopted due to other reasons like under sized networks, Storage capacity, transmission capacity and /or production capacity, where water demand is growing at higher rates than that of water resources and systems development. The tremendously growing developments in industrial and agricultural areas in some Gulf countries are the main reasons for adopting intermittent supply procedures.

Due to deviations between production and demand in water supply, operators find it suitable to adopt intermittent supply procedures to partially fulfill demand requirements under prevailing circumstances. It has been experienced that the wider the gap between production and demand is, the more associated problems are, which grows wider in parallel with the extent of the gap. The link between this gap and the associated problems is a major issue facing operators of water systems in many countries of the world.

Assessment of intermittent supply impact on water systems will be dealt with and evaluated based on analysis and results of data collected from actual field operations of Al Ain water system being operated by Al Ain Distribution Company, one of ADWEA,s group of companies, as a sample representing similar systems operated under similar circumstances, to reflect a clear picture of intermittent supply and its associated problems.

1-Introduction

Intermittent water distribution systems are water networks that operate at intervals i.e. not continuous. These types of systems are adopted as a common method of controlling water demand, usually by necessity rather than by design. It is a fact that the majority of water supply systems in developing countries are water starved and operate intermittently.

Conventionally the design of water distribution systems has been based on the assumption of continuous supply. In most developing countries water supply is not continuous but intermittent, and this could have been foreseen at the design stage. By trying to fit in a system that was designed to operate as a continuous one to operate intermittently results in severe supply pressure problems in the network and great inequities in the distribution of water

The overall shortage in water availability in most developing countries necessitates intermittent supply at a low per capita supply rate. In particular they often lead to inequitable distribution of available water resources. Since these systems are water starved, consumers collect as much water as possible, quantity collected being directly related to pressure at outlets. And since pressures vary greatly in the network, quantity of water supplied is inequitable.

In addition to inequities, low pressures arise because systems are designed based on low per capita allocation and with the assumption that demand is over a 24 hours at about 2.5 times average flow rate. In reality water is drawn in a shorter duration. This implies that the system suddenly becomes undersized because flows in pipes are much greater than anticipated resulting in severe pressure losses. Hence, there is generally a low-pressure regime in the network.

2- Intermittent Supply Scenarios

While setting distribution programs, several factors influence operators to select the most appropriate scenario of intermittent supply to suit their systems and to optimize fulfilling demand requirements of their customers. Some of these factors are:

A- Difference between production and demand.
B -Pumping capacity of pumping units.
C -Transmission capacity of transmission and distribution networks.
D -Storage capacity of storage and distribution reservoirs.
E -Topographical and geographical location of production and consumption sites.
F- Type and age of different system components, which governs the maximum allowable working pressure and head losses in the system.
G- Storage capacity at customers sites, which governs the allowable interval between alternate supplies. This has also a direct link with the average daily consumption of customers which is influenced by climatic conditions, availability of separate irrigation system, existing metering system and applied water tariff.
H- Availability of human resources to operate the system.

Taking above factors in to consideration, one of the following Scenarios may be applied:

A - Variable Flow - Variable Pressure Scenario.

Here the flow and working pressure at pumping stations are changed to have similar pressure at different consumption sites. This is usually applied while Pumping directly to up hill consumption sites located at different altitudes from low located pumping station where the facility of top hill reservoir is not available.Though in this scenario water is distributed equally between customers, but pumping units and distribution networks are operated under variable working pressures, which reduces its survival life.

B-Variable Flow - Fixed Pressure Scenario.

Here the pressure is fixed and the flow is adjusted to keep similar pressure at different consumption sites. This is usually applied in flat areas with different sizes of distribution zones. HILLI, SAROUJ, ZOO and MARKHANIA zones / AL AIN area are being operated adopting this scenario, where the pressure at a pumping station is kept constant (about 3.0 Bar) and flow changes by changing the number of operated pumping units and/ or by throttling of valves down stream of the pump/s. The draw back of this scenario is that fixed speed pumping units are switched on/off several times a day or the valves down stream of the pumping unit/s to be throttled, but in the case of variable speed pumps this problem does not arise.

This scenario is suitable with variable speed pumping units as in ABUDHABI City,While in AL AIN area where it has been applied it is associated with changes in number of operated pumping units and throttling of valves.

C-Fixed Flow - Variable Pressure Scenario.

Where the storage capacity at a production and/ or at an intermediate site is small and water is to be distributed directly to the network, this scenario is usually adopted by constantly pumping the produced quantity at different working pressures depending upon the location of the consumption site/s. Usually this scenario is applied in small and remote villages getting their supplies directly from wells or springs having limited storage facilities.

The drawback of this scenario is that fixed speed pumping unit/s are to be switched on/off several times a day or the valves down stream of the pumping unit/s to be throttled, but in case of variable speed pumps this problem does not arise.

D- Fixed Flow - Fixed Pressure S+cenario.

Here the rate of flow and the working pressure are kept steady through out pumping hours. This scenario is usually applied in flat areas with similar sizes of distribution zones and/or where whole supply area is kept as one distribution zone. In case application of this scenario is not accompanied by throttling of valves or excessive working pressures, it is considered the best to be applied.
After modifying distribution programs, this scenario has been applied in **(POWERHOUSE, SWEIHAN, MILITARY, DAHMA and ZAKHER)** zones/AL AIN area.

3-MOST APPROPRIATE INTERMITTENT SUPPLY PROGRAM.

The most appropriate intermittent supply program is the one, which fulfills the following requirements:

(a)Does not involve alternate switching ON/OFF of pumping units which reduces life of pumping units, requires high voltage to start pumps, involve human errors and subject the pumps and accessories to frequent water hammer.

(b)Does not involve throttling of valves, which reduces its life due to water jetting and causes pressure problems due to malfunctioning valves and fittings.

(c)Maintains full transmission and distribution mains. This is of course necessary to keep fire fighting systems in operation, prevents contamination due to back inflow, prevents cracking of internal lining of system components due to alternate wetting/ drying processes, reduces water losses due to alternate filling/ emptying of mains and facilitates leak detection activities to be carried out.

(d)Minimizes operation of valves. In addition to reducing life of valves, failure of valves and involvement of human errors, it participates in interruption of supplies.

(e)Requires minimum involvement of operational staff. To implement distribution programs without frequent occurrence of supply interruptions, to build up confidentiality with customers and to minimize operational costs, it becomes a necessity to eliminate or optimize human factor involvement.

(f)Provides customers with similar supply duration at the same pressure.

(g)Does not involve alternate filling/emptying of storage facilities. It is usually observed that the low level of water at reservoir empty conditions allows for turbulence of water due to inflow jetting that causes scouring of deposited sediments at the bottom of reservoir and subsequently increase turbidity in water ,which will be either deposited in the network or accumulated at customer's flow meters, and therefore blocks the flow to their tanks.

(h)Does not require excessive working pressures. Sometimes, due to the wide gap between production and demand, operators may find it suitable to push water in to their improperly zoned networks by running the systems at high working pressures. Such acts usually leads to higher rates of losses and increase in network component's damages.

4- Impacts Of Intermittent Supply.

In water industry, intermittent supply has several impacts on water systems, operators and customers at the same time. Following are some of these impacts:

(a) Impact on Pumping Station Components.

Pumping station components involved are pumping units, electrical installations, chlorine dosing units, operational and non-return valves, pressure gauges, storage and distribution reservoirs, etc. Intermittent supply procedures may cause one or more of the following impacts on pumping stations components:

(1)Air locking inside pumping units causes:

- Corrosion of impellers and casings of pumps.
- Causes cavitation in pumps internal surface due to air locking.
- Water hammer, which damages internal parts of pumps.

(2) Alternate stop and start of pumping units which:

- Reduces life of pumps.
- Causes water hammer.
- Requires higher electrical voltage at each start.
- Requires release of air at the beginning of each start.
- Introduces risk of electrical failure.

(3) Blocking of chlorine dosing injectors. This usually occurs due to back flow of water in to chlorine dosing injector connected to outlet pumping main in post chlorinating conditions.

(4) Variation in chlorine dosing due to sudden changes in flow at the beginning of each start.

(5) Requires curious observation and continuo attention to changes in pumping programs so as to implement it on time.

(b) Impact on Transmission and Distribution Mains.

Intermittent supply may cause one or more of the following impacts on transmission and distribution mains and its constituent parts:

(1) Corrosion of the internal surfaces of pipes and fittings due to the alternate wetting and drying process.

(2) Cracking of the internal lining of pipes.

(3) Increase friction losses due to erosion of the internal lining caused by water jetting at each start.

(4) Reduces life of valves and air release valves due to excessive operations.

(5) Damages valves and non-return valves due to water hammer caused by the back Flow of water at each stop operation.

(6) Losses of energy due to the turbulent flow of water at each start operation.

(7) Requires over sized transmission and distribution lines and pumping units.

(c) Impact on Fire Fighting Systems.

Intermittent supply may cause one or more of the following impacts on fire fighting systems:

1-Intermittent supply does not facilitate continuous supply to fire fighting systems.

2-Operators of fire fighting systems have to frequently update changes in distribution programs, so as to be aware of water availability at a particular fire hydrant at the proper time. This of course looses confidence in services provided and subsequently fire hydrants becomes unreliable.

3-At the beginning and end of pumping/supply hours, pressure at fire hydrants is insufficient to run fire-fighting systems.

In Al Ain area, fire fighting systems have never been used due to loss of confidence in availability of water at fire hydrants when needed, and civil defense depends solely on their available storage facilities. Moreover, in case of critical emergencies they relay on operators of the water system to arrange supplies to their storage reservoirs or from tanker filling stations,

(d)Impact on Water Losses and Leak Detection.

Intermittent supply may have one or more of the following impacts on water losses and leak detection activities:

A- Losses due to leaky valves which does not close tightly.

B- Losses due to un-apparent small leaks.

C- Losses due to emptying and refilling of mains.

D- Reduces time margin available for carrying out leak detection activities.

E- Under estimation of quantities received by customers at the beginning and end of each Supply period due to the un-metered low flow.

F- Over-estimation of quantities pumped in to the network due to entrapped air in water.

G- Losses due to the frequent flushing of the network required for removing dirt's and Sediments entering in to the system through cracks during off supply hours.

(e)Impact on Water Quality.

Intermittent supply may cause deterioration of water quality due to one or more of the following reasons:

1-During pumping hours water seeps out through cracks, holes, or faulty joints, and during off supply hours a mixture of water and soil or sewage water enters in to the network through the same cracks or holes creating hazardous contamination of water as shown in Fig. (1) below.

2-Intermittent supply allows for back syphonage flow of water from customers vessels/ storage tanks/ irrigated land through house connections creating hazardous contamination of water.

3-The turbulent flow of water with high velocity at each start of pumping causes Scouring of sediments deposited at the bottom of the network causing contamination of water.

Fig. (1)
(Back Inflow May Cause Hazardous Contamination)

(f) Impact on Operators:

Following are some of the problems that usually arises:

1-Curiosity to keep fit distribution program and frequently modify it to suit prevailing circumstances.

2-Re-zone distribution areas to take care of bottle necks like palaces, VIPs, hospitals, Govt. offices, fire fighting systems etc, during normal and emergency conditions.

3-Handling huge number of valve operations associated with human errors in operating the system like faulty operation of valves or pumping units. The following table No. (1) shows valve operations carried out by Al Ain distribution company during year 1999 and 2000.

Table (1)
Number Of Valve Operations Carried Out during Years 1999&2000

Sr. No	Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
1	1999	6583	6736	9538	7837	8317	8613	8629	8947	8722	8689	8930	9093
2	2000	9167	8516	9125	8834	9190	8884	8382	9885	10214	10227	9951	10137

4-Failure of operational valves/ pumping units causes interruption of supply.

5- Handling complaints of week pressures.

6-More regular planned and emergency maintenance, repair or replacement of operational valves are required.

7-More frequent flushing of networks is required to remove soil/ dirt entering through cracks during off-supply hours.

8- Illegal acts by customers, like drawing water from mains using dynamos,..etc.

9-Difficult pressure management due to supplies interruptions.

10-Uneconomical investments due to the need for over sized networks and pumping units .

(g) Impact on Customers.

Intermittent supply may have one or more of the following impacts on customers:

1-The non-reliability of intermittent supply due to the several factors associated with it influence customers towards illegal acts such as drawing water from public mains, By-passing water meters, removing float valves,...etc.

2-Due to the inconvenience in supply duration or timing, many customers try to solve their problems by applying and paying for additional connection, supplement their needs by tankers, construct over sized under ground storage tanks, or lodge repetitive complaints.

3-Customers may have patiently to wait the arrival of supply.

4-Customers may have to pay for counted air entrapped in water.

5-Customers may have to lookfor an alternate source due to interruption of supply.

6-Customers may have to watch filling their tanks to prevent over flowing (it is generally noticed that they remove float valves) and to utilize supply hours to irrigate loans, wash cars and/ or fill other vessels.

(h) Impact on Network Pressure Management.

Intermittent supply programs does not facilitate full control over network pressure management, which are usually associated with:

1-Improper zoning of distribution areas.

2-Throttling of valves to develop network pressure.

3-Alternate stop/start of pumping units to control flow and pressure.

4-Loosing chances of gravity feeding in some parts of networks. due to fluctuations in pressures and flows, which alternatively requires increase in sizes of water mains or reduction in zone size. Loosing of such chances has been experienced in Zakher zone that could be conveniently supplied by gravity.

(i) Impact on Water Meters.

Wherever installed, water meters in water systems running under intermittent supply conditions are usually affected to different extents in one of the following ways:

1- Internal parts of meters deteriorates and may damage due to entrapped air bursting under network working pressure.

2-In case of mechanical flow meters, flywheels are usually damaged due to alternate water jetting and turbulent flow caused by stop/start processes.

3-Meters calibration is affected.

4-Under estimation of quantities passed through flow meters due to partial flow at the beginning and end of supply hours, thereby, increasing the estimated ratio of Unaccounted For water.

5- Cost of Intermittent Supply.

The cost estimate of valve operations during years 1999 and 2000 for AL AIN region shall be evaluated in details, while other parameters endorsing costs shall be described to the extent of understanding the concept of its impact on costs.

(a) Operational Costs (Cost of Staff and Vehicles):

Under continuous supply condition, staff and vehicles devoted solely for operation of networks are not required, where it is usually found that maintenance gangs carries the required few emergency valve operations a long with their normal daily work. However, in part time supply conditions where regular operation of valves is required, it becomes necessary to devote some staff for implementing supply programs.

The type and number of staff and vehicles engaged solely for operation of AL AIN area water networks is shown in table (2) below.

Table (2)
STAFF AND VEHICLES ENGAGED FOR OPERATION OF NETWORKS

SR NO	Description	AL AIN UNIT	ALSAAD UNIT	ALHAYAR UNIT	ALDAHIR UNIT	TOTAL
1	Engineer	1	-	1	-	2
2	Supervisor	1	1	1	1	4
3	Shift in charge	5	-	-	-	5
4	Valve operator	32	8	-	1	41
5	Pipe fitter/labor	-	4	6	1	11
6	Driver	16	1	2	1	20
	TOTAL					83
7	Car	6	2	3	2	13

Table (3) shows abstract of monthly cost estimate of operating the networks of AL AIN region during year 1999 & 2000 against the number of valves which has been operated during the same period. From this table we find that:

Cost of valve operation during 1999&2000	= 11.12 million Dirham
Number of valves operated during 1999&2000	=213157 valves
Cost of operating each valve	=52.2 DHS/valve/operation

NB- (valve operation = one opening or one closing of a valve).

(b) Replacement Cost of Valves: -

For the purpose of implementing intermittent supply programs, valves operated daily are subjected to sever operating conditions. During opening and closing, operators try to exert excessive torque on valve stem to ensure better tightness of the valve as shown in Fig. (2), which is transmitted down to the gate and seat causing its fracture. On due course, the fracturing increases and subsequently leakage through the fractured gate/seat increases.

Fig. (2)
(Excessive force on valves leads to its failure)

(Six) Tables (4) and (5) shows the number of valves replaced during 1999 and 2000 while table (6) shows number of operational valves that are operated daily.

Table No. (4)
Number of Valves replaced during year 1999

SR.NO.	Month	NO.OF VALVES					Total
		100	150	200	300	500	
1	Jan				1		1
2	Feb		1	4	3		8
3	March			1			1
4	April	1		2			3
5	May		3				3
6	June	1	2	2			5
7	July	1		2			3
8	Aug		3	1	1		5
9	Sept		1	2			3
10	Oct						
11	Nov						
12	Dec			1			
	Total	3	10	15	5		33
	Percent of total	9%	9%	15%	11%	-	11.8%

Table (5)

Number of valves replaced during year 2000

SR.NO.	Month	NO.OF VALVES					Total
		100 mm	150 mm	200 mm	300 mm	500 mm	
1	Jan	1			1		2
2	Feb.						
3	March		4		1		5
4	April	1	2				3
5	May	1		1			2
6	June						
7	July	2	1	3			6
8	Aug.		2				2
9	Sept.		4	1			5
10	Oct.			1		1	2
11	Nov.	1	1				2
12	Dec.			1			1
Total		6	15	8	2	1	32
Percent of total		18%	14%	8%	4%	25%	11%

Table (6)
Number of Operational Valves in AL AIN area

SR No.	Description	100mm	150mm	200mm	300mm	500 mm	Total
1	No of operational valves	33	105	100	48	4	290

(Including installation cost) From tables (4), (5) and (6) we found that: -

1- Total number of valve operations carried out During years 1999&2000 = 213146

2-Total number of operational valves = 290

3-Average number of operations $= \frac{213146}{2 \times 365 \times 290}$ =1.0 operation/valve/day

4-Percentage of operational valves replaced every year $= \frac{33+32}{2 \times 290} \times 100\%$ = 11.20 %

5-Average cost of replacement =0.1 million DHS/year.

(c) Cost of Deterioration in Operational Valves.

As intermittent supply is basically adopted due to deficiency in available water, Operators try to tighten operational valves in an attempt to prevent leaks through closing valves or open them fully to fulfill customer's requirements as shown in Fig. (1) above.

Due to lack of training, knowledge and awareness of these acts it may cause defects like damage to the edges of the valve gate and/ or seat, deterioration of rubber gaskets stacked on the valve gate, damage threads of the valve stem, the gate gets stuck in open or closed position, breakage of the spindle pin, twisting of the operating key or extension spindle, deterioration of the gland packing around the valve stem.

(d) Cost of Water Losses:

Intermittent supply practices participates widely in UN-accounted for water (UFW) and physical water losses which comes in terms of one or more of the following components:

1-UN-metered losses at the beginning and end of supply hours during Low flow Conditions

2-UN-detected leaks that does not appear on the surface due to short duration of Pressurizing networks.

3-Extra water required for carrying out more regular flushing of networks to remove dirt/sediments entering in to networks during off supply hours.

(e) Other Costs:

Several other factors may also influence the cost of an intermittent supply procedure, which accumulates to form a reasonable percentage of the overall operational cost like:

a) Depreciation in pumping units due to more frequent operation of pumping units to adjust for programmed flow and pressure.

b) Extra energy required for the alteration in pumping programs.

c) Impacts of water hammer and cavitation created by alternate on/off of pumps.

d) Cost of supply interruptions caused by frequent failure of operational valves.

6-Recommendation:

1-Design the most appropriate distribution program, which should comply with the requirements mentioned on page (4) of this paper and any other requirement that may sought to be reasonable.

2-Set and implement planned maintenance programs to all system Components including storage and distribution reservoirs.

3-All customers connections should be properly sized.

4-Carry out more frequent sampling and testing to ensure good quality of distributed water, as it is more liable to contamination.

5-Wherever possible domestic networks should be isolated from irrigation Systems, and kept far away from sewerage Systems.

6- All customers connections should be fitted with non return valves.

7- Pressure sustaining valves (PSV) should be fitted on distribution mains wherever feasible.

8- Chlorinating in storage/distribution reservoirs is more preferable than post chlorinating.

9- Two feeding lines of suitable size (one of which as stand by) for each sector is more preferable than several small sizes feeding lines.

10- The type of operational valves should be selected to withstand large number of valve operations.

11- All operational valves should be placed in chambers to facilitate its regular maintenance.

12- Fire fighting systems should be as far as possible connected to lines not subjected to short duration intermittent supply programs.

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Measuring Domestic Water Supply Network Performance: A Case Study of Riyadh City

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Measuring Domestic Water Supply Network Performance: A Case study of Riyadh City

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Abstract

Domestic water Supply networks (DWSN) are designed and managed to receive water from a source and distribute it among consumers to meet their domestic requirements. These systems are expected to perform efficiently in order to service their cities the best way possible. Therefore, DWSN's performance should be evaluated periodically. This study defines and applies four performance measures. They are used to indicate the degree of satisfying the objectives of adequacy, efficiency, dependability and equity of water delivery. These measures were applied on Riyadh's DWSN. Necessary data were collected for each district in the city for the year 2000/2001 (1421H). In addition, subscribers were divided into three consumption categories based on dwelling and family size, and family' socioeconomic status. Accordingly, evaluation measures were calculated for different demand levels, which finally revealed a performance level of about average.

Keywords: Water supply networks, Adequacy, Efficiency, Dependability, Equity

Introduction

Domestic water supply networks (DWSN) are constructed to meet the objectives of delivering and distributing water among users. To satisfy those objectives, proper operation and maintenance are required in order to achieve the maximum performance level possible. DWSN performance can be assessed from different points of view. Many authors have addressed the issue of DWSN performance taking into account different measures. Among those researches are the works of Karaa and Marks (1990), Xu and Powell (1991), Wu et al (1993) and Deb (1994).

In this paper, four objectives and their measures are used to assess DWSN performance: adequacy, efficiency, dependability, and equity of water delivered. Those were developed and applied for irrigation water delivery networks by Molden and Gates (1990) and Gates and Alshaikh (1993). Application of these four performance objectives and their measures are applied for Riyadh city's DWSN, in Saudi Arabia. Different possible water requirement scenarios along with the actual amounts of water delivered in the year 1421H (2000/2001) are presented herein.

DWSN Performance Objectives and Their Measures

According to Molden and Gates (1990), the four performance objectives and their measures are given below:

A) Adequacy, P_A:

$$P_A = \frac{1}{T} \sum_T \left(\frac{1}{R} \sum_R p_A \right) \quad (1)$$

$$p_A = Q_D / Q_R \quad \text{if } Q_R \geq Q_D$$

$= 1$ otherwise, so $0 \leq P_A \leq 1$

B) Efficiency, P_F:

$$P_F = \frac{1}{T} \sum_T \left(\frac{1}{R} \sum_R p_F \right) \quad (2)$$

$$p_F = Q_R / Q_D \quad \text{if } Q_D \geq Q_R$$

$= 1$ otherwise, so $0 \leq P_F \leq 1$

c) Dependability, P_D (Temporal variation):

$$P_D = \frac{1}{R} \sum_R CV_T \left(Q_D / Q_R\right) \qquad (3)$$

$0 \le P_D < \infty$

d) Equity, P_E (spatial variation):

$$P_E = \frac{1}{T} \sum_T CV_R \left(Q_D / Q_R\right) \qquad (4)$$

$0 \le P_E < \infty$

Where:

Q_R	=	required amount of water
Q_D	=	delivered amount of water
T	=	time range represented in terms of different seasons
R	=	region represented in terms of house connections, and
CV	=	coefficient of variation (ratio of standard deviation to mean)

It is clear form above that high performance level requires P_A and P_F values to approach 1 and the opposite for P_D and P_E where values approaching 0 are desirable.

Study Area/ Data Description

Riyadh water supply network is completely managed by Riyadh Region Water and Sewage Authority (RRWSA), which was established in 1963. The city, which is about 2000 Km^2 in area and 4 million in population, relies on two main water resources. These are: the desalinated water from the saline water desalination plant in Jubail contributing about 60% of the total demand and wells potable water from water well fields around the city covering the remaining 40%. The city's network is about 9404 Km in length serving more than 253000 households and distributing over 413,928,997 m^3 of quality water per year. Accordingly, the average daily water delivered in 2000/2001 is 1,165,997 m^3 offering a per capita share of 286 m^3/day. RRWSA applies the rationing concept in serving its subscribers where the city is divided into a number of zones, only part of them are served in a particular day, RRWSA (2001).

In this study all available data for 216 zones for the year 2000/2001 were collected and analyzed in terms of: 1) number of house connections per zone, 2) average quantity of water delivered per day for each season, 3) average quantity of water required per day for each season, 4) average house size in a particular zone, 5) average number of tenants per household and 6) the average socioeconomic level of people living in a particular zone. A sample of the data used is shown in Table (1). Based on this Information, the network performance was evaluated and performance indices were generated.

Table (1): Sample of data showing actual consumption vs. ideal requirement.

District Name	No. House-holds	Spring		Summer		Fall		Winter	
		Cons. m^3/d	Req. m^3/d	Cons. m^3/d	Req. m^3/d	Cons. m^3/d	Req. m^3/d	Cons. m^3/d	Req. m^3/d
Wazarat	246	1489	984	1502	1599	1337	984	1153	615
Indus. I	117	622	468	727	761	192	468	633	293
Indus. II	523	4464	2092	2348	3400	3005	2092	1973	1308
Motmarat	325	2672	1300	3070	2113	2445	1300	2521	813
Matar	1500	8272	6000	7856	9750	5453	6000	4738	3750
Warood	2546	8103	10184	8666	16549	8288	10184	8037	6365
Mazar North	289	1847	1156	1798	1879	1784	1156	1798	723
Takassi West	899	7355	3596	3656	5844	5063	3596	3202	2248
Dalla West	835	2797	3340	2887	5428	2647	3340	2667	2088
Nakheel	583	2334	2332	2318	3790	2099	2332	2034	1458

Evaluation and Results

Huge networks, such as the one described above, are often exposed to many operational problems especially under water scarcity condition. Evaluation of DWSN performance, therefore, is an important task as a step toward a better management. Accordingly, the above four explained objectives: adequacy, efficiency, dependability and equity with their measures were used to assess Riyadh DWSN.

A demographic analysis of Riyadh city has resulted in grouping its districts into three demand categories; A, B and C based on household requirements. Category A represents large household of considerable outdoor landscape, while category B represents average household with small outdoor area. Finally, category C represents small units without outdoor areas. Depending on this categorization, three different demand scenarios were assumed for each of the four seasons. Each scenario assumes a particular number of people per household and their water requirements in liters per capita per day (lpcpd).

Table (2) shows the first scenario which represents the average assumed water requirements, while Table (3) and Table (4) show 20% less than and 20% above assumed average, respectively. As an example, 400 lpcpd is the amount of water required by a household of type A for spring season. This amount reaches 500 lpcpd in summer and drops down to 300 lpcpd in winter, but it remains the same for fall season. Tenants per household for this category are assumed to be 10.

Table 2: First scenario presenting the average ideal requirements

Season	Description	A	B	C
Spring	Capita/hhold Lpcpd	10 400	7 300	5 250
Summer	Capita/hhold Lpcpd	10 500	7 400	5 300
Fall	Capita/hhold Lpcpd	10 400	10 300	5 250
Winter	Capita/hhold Lpcpd	10 300	7 250	5 200

Table 3: Second scenario presenting a 20% below average requirements

Season	Description	A	B	C
Spring	Capita/hhold Lpcpd	10 320	7 240	5 200
Summer	Capita/hhold Lpcpd	10 400	7 320	5 240
Fall	Capita/hhold Lpcpd	10 320	10 240	5 200
Winter	Capita/hhold Lpcpd	10 240	7 200	5 160

Table 4: Third scenario presenting a 20% above average requirements

Season	Description	A	B	C
Spring	Capita/hhold Lpcpd	10 480	7 360	5 300
Summer	Capita/hhold Lpcpd	10 600	7 480	5 360
Fall	Capita/hhold Lpcpd	10 480	10 360	5 300
Winter	Capita/hhold Lpcpd	10 360	7 300	5 250

As a result of districts grouping, about 70% of the districts (or consumption) lies within category B, 20% in category C and only 10% in category A. The weighted average water required per capita per day for the entire city of Riyadh could be calculated based on the first scenario as follows:

Weighted average for spring = 400 x 0.1+300 x 0.7 + 250 x 0.2
= 300 lpcpd

Weighted average for summer = 500 x 0.1 + 400 x 0.7 + 300 x 0.2
= 390 lpcpd

Weighted average for winter = 300 x 0.1 + 250 x 0.7 + 200 x 0.2
= 245 lpcpd

Weighted average for fall = 400 x 0.1+300 x 0.7 + 250 x 0.2
= 300 lpcpd

Overall weighted average = (300 + 390 + 245 + 300) / 4
= 309 lpcpd

This overall average value (309 lpcpd) looks very reasonable for a big city such as Riyadh where weather is very hot in summer and hot as well at the end of spring and beginning of fall. (In the U.S.A., the typical domestic water requirement is about 250 lpcpd, Linsley et al. 1992). On the other hand, the conservative scenario (20% below average) shows an overall weighted average of water required of about 247 lpcpd. Finally, the above average scenario (+20% from average) revealed a value of 371 lpcpd.

Results of calculating P_A, P_F, P_D and P_E are shown in Table 5 for average, above average and below average scenarios. P_A ranged between 0.83 for below average scenario to 0.95 for above average scenario. This is expected, because above average scenario assumes higher water requirements (higher Q_R) which leads to a higher P_A. On the other hand, P_A value for the average scenario was 0.90. For P_F, results revealed an opposite trend as appose to P_A. This should be the case by definition. Values of P_F ranged between 0.74 for below average scenario and 0.91 for above average scenario, with an average of 0.85.

Table 5: Results of the different scenarios

Measures	Av.	Av. + 20%	Av. – 20%
P_A	.90	.95	.83
P_F	.85	.74	.91
P_D	.23	.23	.23
P_E	.54	.54	.53

Values of P_D, which indicates temporal variation of Q_D/Q_R, have constant figure of 0.23 for all scenarios. Since values of Q_R changes with the same rate of variation (20% and 40%) from one scenario to another while Q_D remains the same, CV of Q_R/Q_D will remain the same. This means that the system is not sensitive in its dependability to any variation of amount required assuming that Q_D remains constant. But for the same scenario, P_D has a considerable value (= 0.23). The same analysis could be derived for equity, P_E, which indicates spatial variation of Q_D/Q_R, but with a much higher value of 0.54. This means that the system is worse in its equity compared to its dependability.

This shows that average scenario gives higher performance compared to conservative (below average) and non-conservative (above average) scenarios. It is clear on the other hand, that average variation in P values among scenarios is 4%, much less than the 20% variation assumed in required amounts. In other words, Riyadh DWSN performance, P, is 1: 5 sensitive to changes in water requirements. Part of this relatively small sensitivity is due to the constant values of P_D and P_E for the different requirements scenarios.

As an attempt to come up with an overall single performance index (PI), the Multi-Criteria Evaluation theory was used. This technique is concerned with how to combine the information from several criteria to form a single index of evaluation. In our study since we have continuous factors, a weighted linear combination is usually used (Voogd, 1983). With a weighted linear combination, factors are combined by applying a weight to each one followed by a summation of the results to yield a unique evaluation index.

i.e. $PI = \sum W_i P_i$

Where:

PI = Performance Index

W_i = weight of measure i

P_i = score (value) of measure i

The concern of DWSN operators is to achieve as high values of P_A and P_F as possible, and the opposite for P_D and PE, which makes the scales upon which the measures are calculated are different. Therefore, it is necessary that scales are standardized before combination, using the formulas above, and that they be transformed, if necessary, such that all of them are directly correlated with the performance index PI. A variety of procedures for standardization were reviewed, typically using the minimum and maximum values as scaling points. A simple approache is to rescale P_D and P_E as follows:

$$P'_i = 1 - P_i$$

Where:

P'_i = new measure's score (value)

P_i = measure's score (value)

And assumming Pi values grater than 1 are approximated to 1

Weights, on the other hands, could be developed by a variety of techniques. One of the most promising is that of pair-wise comparisons developed by Saaty (1977) in the context of a decision making process known as the Analytical Hierarchy Process (AHP). In this procedure, using a weighted linear combination, it is necessary that the weights sum to one. In Saaty's technique, taking the principal eigenvector of a square reciprocal matrix of pair wise comparisons between the performance measures can derive weights of this nature. The comparison concerns the relative importance of the two measures involved in determining the overall performance level for the stated objective.

In developing the weights, the authors compared every possible pairing and enter the ratings into a pair wise comparison matrix from the point view of both RRWSA and network users, (Table 6) and (Table 7). Since the matrix is symmetrical, only the lower triangular half actually needs to be filled in. The remaining cells are then simply the reciprocals of the lower triangular half. The procedure then required that the principal eigenvector of the pair wise comparison matrix be computed to produce a best-fit set of weights (Table 8) and (Table 9). In addition, the consistency ratio (CR) that indicates the probability that the matrix ratings were randomly generated was also produced and equaled .09. Saaty indicates that matrices with CR ratings less than 0.10 are acceptable.

After weights and P_i scores were determined, a weighted linear average for the four performance measures was calculated (PI). PI's were also calculated with respect to RWA and to users for the three assumed water demand strips, (Table 10). Furthermore, a single performance index was determined as the average of "RRWSA-PI" and "Users-PI" assuming that both stakeholders have the same influence.

Table 6: A pair-wise comparison matrix for assessing the comparative Importance of the four performance measures from RRWSA's viewpoint.

	P_A	P_F	P_D	P_E
P_A	1			
P_F	3	1		
P_D	3	1/3	1	
P_E	5	1/3	1/7	1

Table 7: A pair wise comparison matrix for assessing the comparative Importance of the four performance measures from user's viewpoint.

	P_A	P_F	P_D	P_E
P_A	1			
P_F	1/5	1		
P_D	1/3	3	1	
P_E	1/7	3	1/3	1

Table 8: Weights derived by calculating the principal eigenvector of the pair-wise comparison matrix for RRWSA

Performance measure	Weight
P_A	0.08
P_F	0.48
P_D	0.20
P_E	0.24

Table 9: Weights derived by calculating the principal eigenvector of the pair-wise comparison matrix for users.

Performance measures	Weight
P_A	0.58
P_F	0.07
P_D	0.23
P_E	0.12

Table 10: The overall performance Indices for all demand levels with respect to RRWSA and users.

Stakeholder	Demand Level		
	Av.-20%	Av.	Av.+20%
RRWSA	0.608	0.654	0.679
Users	0.724	0.699	0.661

Conclusion

This paper addressed the issue of DWSN performance through the use of four objectives and their measures: adequacy, efficiency, dependability and equity. Data for Riyadh city, Saudi Arabia, were gathered and analyzed considering three different possible requirements (demand) scenarios for each of the four seasons. Subscribers were categorized into three categories representing the ideal consumption for each group based on dwelling size and some other socioeconomic factors.

Results revealed that the adequacy, efficiency, dependability and equity performance measures of the city network for the average scenario were: 0.90, 0.85, 0.23 and 0.54 respectively. This indicates that the network is showing a high performance in terms of adequacy and a more then average concerning its efficiency. On the other hand, the network was rated below average with respect to dependability and poor in equity. Therefore, an effort should be made in enhancing the operational policies to achieve more dependable and equitable water distribution.

Weighted overall performance index, that compromises the four measures from the viewpoint of RRWSA and consumers as well, was considered. Results showed an average value of 0.65 and 0.7 respectively. From both viewpoints this indicates, that there is an opportunity for further improvement of the network performance by taking into consideration the four management objectives raised in this study.

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Leak Detection Control and Reduction of Distribution Losses Kingdom of Bahrain Experience

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LEAK DETECTION CONTROL AND REDUCTION OF DISTRIBUTION LOSSES KINGDOM OF BAHRAIN EXPERIENCE

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Abstract

In the past, the main source of water for the kingdom of Bahrain was totally non-renewable ground water. Desalination technology was introduced in mid- 1970s, and developed very rapidly to satisfy the growing water demand in the Kingdom. As new natural water sources have become less accessible and less acceptable environmentally, leak Detection Control and hence reduction of network losses is seen as the preferred alternative to meet increasing water demand. It can be defined as a strategy to improve efficiency and sustainable use of water resources instead of automatically investing in alternative source to satisfy future requirement. Therefore Kingdom of Bahrain adopted waste detection control and water conservation as a solution to manage the increase water demand with limited water resources. This paper explains the efforts taken by MEW over the past decade to reduce Unaccounted For Water [UFW] from 31.6% in 1993 to 23.1% in 2001. These measures include leakage control, full and accurate metering policy; proper accounting for water used. Results achieved are discussed.

Keywords: demand management, unaccounted for water, leakage control, water meter, Bahrain.

INTRODUCTION

The Kingdom of Bahrain is an archipelago of some 36 islands with a total land area of 707 km^2. Main Island Bahrain is connected to other two major islands by causeways. 70% of total area is urbanised and is supplied by water through distribution network. The island is generally flat and some urban area is situated at about 55 m above sea level.
Being a small island nation, Kingdom of Bahrain has limited natural water resources.

Bahrain falls in arid zone and experiences relatively high uniform temperature, high humidity and least rainfall. Rainfalls are scanty and are experienced only in winter season, and the annual rainfall is about 27 mm year 2002, and 39.5 mm year 2001.
Bahrain has a population of over 0.68 million. By the year 2025, the population is expected to exceeds 0.87 million.

The Water Distribution Directorate of Ministry of Electricity & Water [MEW] is responsible for the distribution of potable water supply in Bahrain, primarily to domestic, commercial & industrial consumers, and 100% of the population is supplied with potable water. MEW distributes over 70 MGD of water through a network consisting of 54 reservoirs and water towers, 145 Km of water trunk mains between blending stations, 1,050 Km of main supply network [asbestos cement and ductile iron] and 2,721 Km of service pipes [polyethylene], and 43 pumping stations. Agriculture & landscape irrigation depend almost entirely on ground water and treated sewrage effluent [TSE], and it is the responsibility of other body (Ministry of Works & Agriculture).

PROBLEM DEFINITION- LIMITED SUPPLY VS. GROWING DEMAND

Bahrain's limited water supply

Natural source of water in Kingdom of Bahrain is limited to groundwater with a very slow to none renewable water. The annual fresh water allocation is estimated to be 162 m^3/capita/year against an average international availabitity of 1000 m^3/capita/year. This is expected to further decline to 89 m^3/capita/year by year 2025 as a result of overexploitation to satisfy the excessive demand. Disalination plants were introduced to cover the water shortage. To meet the water demand at present 24 % of groundwater is blended to desalinated water.

Bahrain's growing water demand

The rapid economic and social developments in Bahrain have resulted in a sharp increase in water demand.
Bahrain water demand in 1975 was 16 mgd and in ten years the demand increased to 48 mgd [201 % increase] when the population was 385,000. By 2000 the population almost doubled but the water demand increased by more than 60% to 75.43 mgd. From 1985 to 1999, Bahrain's annual water demand growth dropped from 11.8% to 1.19% , then it increased in year 2000(refer to Table 1). Such rate of growth places a great strain on the limited water resources.

Table 1. Bahrain water Consumption statistics during (1975 - 2001)

Year	Average daily Consumption mgd	% Increase in 10 years	% Annual Increase	Population
1975	16	-	-	
1985	48.16	201%	20.10%	385,000
1995	64.38	33.7%	3.37%	557,000
1996	65.64	-	1.95%	568,000
1997	66.92	-	1.95%	580,000
1998	68.02	-	1.64%	591,000
1999	68.83	-	1.19%	604,000
*2000	75.43	-	9.59%	641,000
2001	80.46	-	6.67	680,000

$1m^3 = 4545$ gallon

* Hidd desalination plant, 30 mg/d water production capacity, started in April 2000 to cater for demand increase and further reduction in ground water abstraction.

The need for demand management to reduce network losses

To overcome the sharp increase in water demand, Ministry of Electricity and Water [MEW] looked for new and alternative source of water supply to augment the existing sources. Desalination of seawater was one of the options. Water derived from these new future sources is expensive. In the early 1980s Bahrain's Unaccounted For Water [UFW] was around 45% of total output. This high percentage of UFW was viewed with concern, and MEW began intensifying its efforts to reduce its UFW by implementing programmes like waste detection and water conservation measures.

Therefore an urgent need for demand management, through the implementation of waste detection and water conservation measures was taken up.

To begin with, several pilot studies were carried out to check the feasibility of implementation. Three zones in different areas were selected for the study. The results achieved are as indicated in Table (2) below.

Table 2: Waste Detection first pilot study test exercises results

Location Block	Property #	Initial Minimum Night Flow	Initial Consumption	Final Minimum Night Flow	Final Consumption	Daily Saving In Consumption	Costing of exercise BD.
West Riffa Ministry Of Housing **Block 910**	63	2.1 l/s 120 l/p/h	185 M^3/day	0.07 l/s 4.0 l/p/h	98 M^3/day	87 M^3/day 47%	3,600
East Riffa Ministry Of Housing **Block 929 & Block 931**	342	9.5 l/s 100 l/p/h	1,212 M^3/day	0.85 l/s 9.0 l/p/h	676 M^3/day	536 M^3/day 44%	16,670
Hamad Town Block 1204	869	11.2 l/s 46 l/p/h	1,725 M^3/day	4.2 l/s 17.4 l/p/h	1,225 M^3/day	500 M^3/day 29%	6,800

- **L/p/h : Liter per property per hour**

Based on the study that was conducted in the aforementioned areas/ zones and the results thus obtained an absolute necessity was felt to expand zoning to cover entire country and to conduct the waste detection exercise.

Waste detection exercise has a dramatic effect on overall reduction of UFW or in other terms leakage level. Because major component of UFW is leak itself.

Due to so many constraints and overall knowledge of the subject, initially establishing zones was at a low pace, and only 19 no of zones were established during 1985. Due to success of finding leaks in the established zones of the Distribution network an ever-increasing necessity was felt to zone the maximum area in a very short period. As such from year 1990 to 1995, 365 zones were established which covered 90 % of network

During the process of establishing waste zones, teams of waste detection inspectors were deployed to carry out waste detection exercises. Statistics showed a gradual steady fall in % UFW (leaks). Refer to Table3.

Table 3. Established zones & fall in UFW (1993 - 2001)

Year	No. Of Zones Established	% Saving Over Initial consumption	Demand Reduction (Saving) m^3/day	Water saving in a year	Exercise Cost BD	# of Leaks	UFW %
85-90	84						
1991	102	17.24	4209				
1992	73	11.06	3153				
1993	51	7.24	5,967	2,177,955	48,667	610	31.63
1994	59	12.56	5,427	1,980,855	29,625	358	32.32
1995	24	12.45	2,505	914,325	25,069	114	32.86
1996	14	15.52	3,903	1,424,595	30,750	155	35.71
1997	18	11.07	5,850	2,125,760	44,336	290	25.47
1998	6	9.41	3,079	1,123,835	29,254	225	18.52
1999	1	8.76	3,703	1,351,595	40,666	276	17.96
2000	2	7.50	2,666	11,098,920	33,906	430	22.88
2001	4	5.95	4,048	1,585,560	42,320	602	23.05

Waste detection exercise not only helped in locating leaks and reducing UFW, but also helped in evaluating the network and several deficiencies were found and were later corrected in:

1. Low Density Polythene [LDPE] pipes, substandard pipe materials/ sizes;
2. Jammed valve;
3. Abandoned lines;
4. Not updated Drawings.

On observing the success of the above study a broad based waste detection and water conservation programme was taken up in hand.

MEASURES IMPLEMENTED TO REDUCE UFW IN KINGDOM OF BAHRAIN AND THE APPLICABILITY OF THESE MEASURES TO OTHER ORGANIZATIONS

In the early 1980s Bahrain's UFW was around 45% of total output. This high percenrage of UFW was viewed with concern, and MEW began intensifying its effort to reduce its UFW by impleminting various programmes and water conservation measures.
These measures can be broadly categorized as follows:

- Leakage control;
- Full and accurate metering policy;
- Strict legislation on illegal draw-offs;
- Plant protection;
- Educate the consumers.

Leakage control Function

The main aim of the unit is to find waste of water in the network (distribution system) by adopting engineering techniques. The waste of water as we all know can be due to so many reasons and here we shall discuss the actual waste that is leakage in the system and the apparent waste, or we can say wasteful use of water. Both these components when put together are termed as UFW or Non Revenue Water [NRW]. Ways and methods are employed to reduce overall UFW, but utmost importance is given to detect and repair the leaks -the actual waste or loss of water .The later part, which is found during waste detection investigation/ exercise, is handed over to water conservation section for their followup and necessary remedial action.

Use of better quality pipes and fittings
Prior to 1980 mixed material pipes were being used into the water distribution network and being substandard. Through prolonged contact with water these pipes become encrusted and corroded, causing leakage and water quality problems. The first step towards reducing UFW was to minimise the occurrence of leaks in the distribution network and was done by introducing better quality corrosion-resistant materials for new pipelines, and tightening supervision on pipe-laying work to ensure high-quality workmanship.
Since 1980, the use of such pipes has been prohibited. More durable and corrosion-resistant piping materials such as ductile-iron pipes, which are internally lined with cement mortar, have been used for mains and Medium Density Polythene [MDPE] for service connection.

Initially distribution network was converted to non metalic Asbestos Cement pipe (AC) and service system to polythene pipes of low density non standard pipes (LDPE). And that was in the beginning of early 1990's, but unfortunately, due to the absence of monitoring tools to insure the suitability of Low Density Polythene [LDPE] pipes in resisting the ground condition, they fracture after a while. To understand the problem in its proper perspective the Ministry initiated a study with other consultant to study the problem and a recommendation was to use low and Medium Density Polythene pipe per British standard for service pipes.

The use of such materials has helped to decrease the number of leaks in the water distribution network.

Mains replacement and rehabilitation programmes

Priority replacement plan was set to replace all service connections with accepted polyethylene brand. Table 4, indicates the replacement scheme during 1992 - 2000 where 80% of the total network is covered, and full coverage is expected by year 2003.

Table 4. Replacement scheme during (1992 - 2000)

Activities	1992	1993	1994	1995	1996	1997	1998	1999	2000
Length of poly pipes replaced (m)	155449	57701	92050	79954	113640	152624	134751	10670	-

Note no replacement done during year 2000

The replacement programme was a dynamic one. A computer-based system is used to capture information on mains such as location, type, size and age of mains, and details of leaks and repair works. The data captured are used to plan the mains rehabilitation and replacement programme. Problem areas and potential problem areas are identified and prioritized for early replacement. One of the criteria used to determine whether the mains are due for replacement is the number of leaks occurring per km per annum at sections of the water mains.

Besides the mains replacement programme every opportunity is exploited to constantly review, upgrade and rehabilitate the distribution system through the following measures:

1. Replacing old pipeline systems with new ones in areas undergoing redevelopment. The old systems are abandoned.
2. Using better quality materials for water pipes and fittings to reduce leaks.
3. Regular maintenance and servicing programme for the distribution network.

These programmes and measures have been effective in reducing the number of leaks in the distribution system. The numbers of reports of leaks in water mains and connections have decreased from 13,795/year in 1993 to 12,303/year in 1999. Figure 1 indicates the total number of surfacing leaks and short water complaints. The majority of leaks were from old connections.

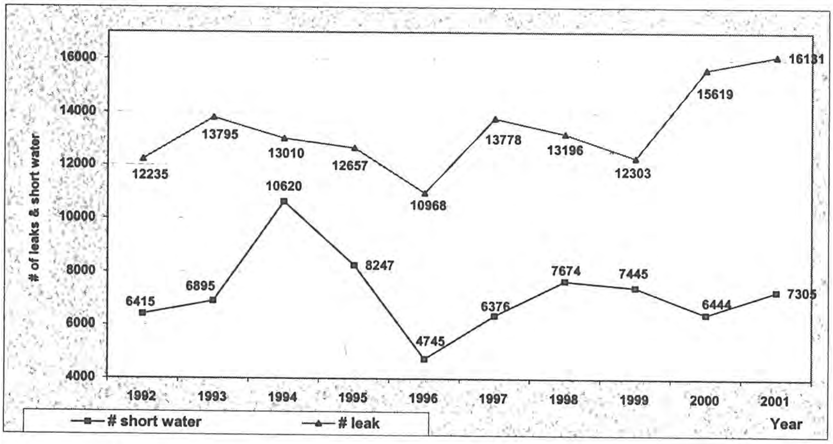

Figure 1. Total no of leaks and short water during 1992 - 2001

Note the rise in the number of surfacing leaks during year 2000 is due to the operation of Hidd Power and Water Station in 4th April 2000. Which resulted in the rise in pressure and the changes in supply duration to satisfy the rising demand, beside replacement of old non-standard service pipes did not take place during year 2000.

Leak detection programme

Leaks in any water distribution system which go undetected, especially underground leaks, constitute real loss. On the other hand, leaks and other losses, which have been detected and attended to can still contribute to UFW losses if they are not properly accounted for.

Techniques used

The distribution system in Kingdom of Bahrain comprises more than 3771 km of water mains, ranging in size from 100 mm diameter to 600 mm diameter. To curb water wastage due to leaks in the distribution system, a leak detection programme is carried out for all mains in the system throughout the year. It involves visual inspection for leaks along all distribution pipeline routes and conducting leak detection night tests for distribution mains of 200 mm diameter and below. The objective of the programme is to check the soundness of the entire network at least once a year.

To cover the invisible leak, which is otherwise very difficult to locate, step-testing procedure is adopted. This is most widely used and is quite labour extensive procedure.

This procedure involves isolating an area herein called zone and allowing the area (zone) to be supplied through a single feed which is metered the flow obtained is measured in l/s and is measured by using pulse unit. A tapping is made on line to measure pressure in the selected zone.

The leak detection programme, which was intensified in 1986, has contributed significantly to keeping underground leakage to a very low level. the number of leaks for the last ten years that were detected and the amount of water per year that would have been lost if these leaks were not detected and repaired are shown in Table 3 .

Complaint Centre

The extent of water loss from a leaking main depends on the length of time between the occurrence of the leak and the isolation of the main. Here, the public co-operation in reporting leaks is essential.

However almost on daily basis several other consumer complaints are attended, the nature of complaint varies from attending and solving low pressure problems to burst in the poly pipes/ distribution mains. In addition to the above, other jobs even though Maintenance section related, are also delt. These include location of valves, location of service connection and mains and also identifying the valve condition in the distribution network.

All the findings are recorded and analysed to take corrective actions and modify the approach.

Part of the changes in the distribution network maintenance was to computerise Complaint Centre to look after, and monitor over 24 hours, leaks and short water complaints. This Centre has helped to change direction in planning and programming by providing accurate information about the system deficiencies.

The information provided by the Complaint Centre, gave the Ministry the guidelines to set the priorities for the programme related to construction, waste detection, water conservation and pipe replacement and had significant input in updating the distribution system and reducing leakage.

Full and accurate metering policy

In the Kingdom of Bahrain, all water supplied from the distribution towers and all water consumed by the customers is 100% metered. This is done for two reasons, to account for usage and to bill customers. There were 140233 customer accounts in 2001, of which 96.8% or 135764 were domestic accounts. The remaining 3.2% or 4469 are commercial and industrial accounts.

Water meters

The accuracy of distribution towers' output meters is of utmost importance, as any error in registering the production output would grossly affect the water balance account.

Besides leaks in the water distribution system, under-registration of customers' consumption by water meters is also an important area to be studied in depth when addressing UFW.
Meter inaccuracies occur because of:

1) Deterioration of registration accuracy with age, use and the presence of sediments in the water; and
2) Inherent under-registration of even new meters caused by them being subjected to flows below their threshold of accurate registration.

Bahrain water distribution system is operated under low pressure following a strict pressure regime. Meter accuracy profile is highly affected during minimum flows [Q min] and meter tends to under register by 15% after 5 years of service [Table 5 & Figure 2]. Besides the revenue losses, leakage level indication would be misleading, based on that water meters in Bahrain are replaced after 6 years of service, as it is not economical to further maintain the meter. Accuracy studies are continued to either, further reduce the meter years of service or use different type of domestic meters to accurately evaluate the UFW percentage with more realistic trend.

Table 5. Meter accuracy Profile

No of years Installed	Average Accuracy (%)	
	QNOM [1500l/hr]	QMIN [20l/hr]
Initial	+ 0.05	- 0.24
1	- 0.58	- 1.31
2	- 0.98	- 1.63
3	- 1.68	- 6.17
4	- 3.27	- 9.05
5	- 3.71	-13.79
6	- 4.6	- 15.0
7	- 30.0	- 77.0
8	- 90.0	- 100.0
9	- 100.0	- 100.0

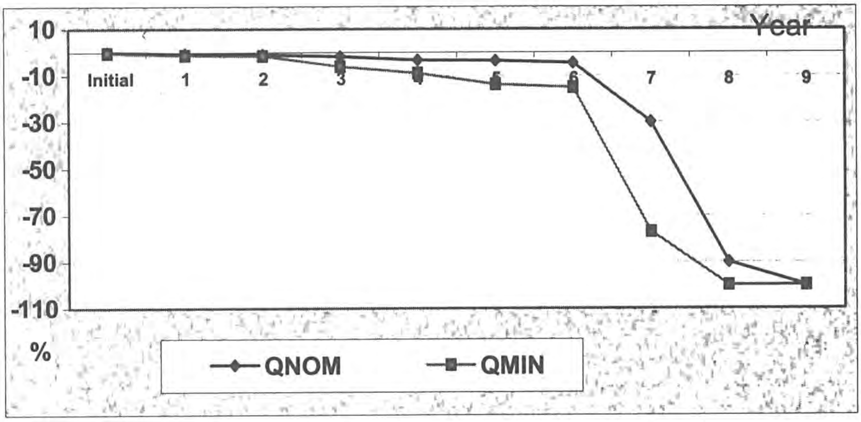

Figure 2. Average Meter Accuracy Profile

To register water consumption by customers, MEW uses water meters of sizes 15-200 mm in diameter.

Meter maintenance and replacement programmes
MEW operates a meter workshop for maintaining and testing meters. Since 1989 in-service testing of meters has been carried out periodically to check the accuracy of the various meters in service.

Reconciliation differences
Reconciliation difference in meter readings between the large work meters, which records the output from the distribution towers, and the meters at customers' premises, which measure the amount of water sold, account for the bulk of apparent water loss. MEW is unable to break-down the quantity of UFW into apparent and actual losses but it is envisaged that the apparent loss due to reconciliation of meter readings could be substantial, not with standing that accurate meters are used.

Proper accounting of water used

Significant quantities of water are used in the commissioning and filling of new mains, connections, service reservoirs and for cleaning and flushing during maintenance of the water distribution system, as well as for fire fighting. As improper accounting of the water used for such purposes will affect the UFW

Strict legislation on illegal draw-offs

There have been very few cases of illegal or unauthorized draw-offs in Bahrain .
During the routine Waste Detection Exercise and maintenance some illegal draw-offs are found. These are commonly known as By Pass connection consumers draws before the meter and thus the additional quantity is bypassed the meter. Sometimes some consumers take direct tapping and no meter at all is available for monitoring the consumption. In some cases unmetered connections in addition to metered ones are also found. Water drawn through the aforementioned also forms the part of UFW.

Plant Protection

MEW established a Damage Prevention Unit (DPU) in early 1985 to safeguard the distribution network and installation from damages by other utilities in the network vicinity through the established way-leave system [Permission to carry out excavation work]. No contractor is allowed to work in the vicinity unless the contract work is registered and way leave cleared by the damage prevention unit, stating the technical protection required. To reinforce the decision, MEW established and implemented a set of penalty charges. Table 6. Shows the penalty charges. The levy increases with the increased size of main.

Table 6. Penalty charges for damages caused by other utilities and contractors

Diameter (mm)	Penalty	Standard Cost charge	Material Cost	Labour Cost	Superv Cost	Water Cost	Total Cost BD
75	-	100	25	100	10	15	250
100	-	150	25	100	10	15	300
150	-	200	35	110	25	30	400
200	-	250	55	115	25	55	500
250	-	300	100	115	25	60	600
300	-	400	110	120	60	110	800
400	-	600	200	200	100	200	1300
500	-	800	300	300	100	300	1800
50 &>	-	100	100				200
50 & < un reported	300	100	100				500

RESULTS ACHIEVED AND COST EFFECTIVENESS OF MEASURES IMPLEMENTED

The measures taken and the various programmes implemented since the 1980s have produced desired effect of reducing UFW. The UFW for the nine year period from 1993 to 2001 is presented in Fig. 3. The reductions have been particularly significant in the first 7 years with UFW dropping from 31.6% to 17.96%. In the last 2 years the UFW was a bout 23%. The main contribution to the increase of UFW from 17.96% to 23% due to replacement did not take place, no water ceiling, and increasing the boosting supply period.

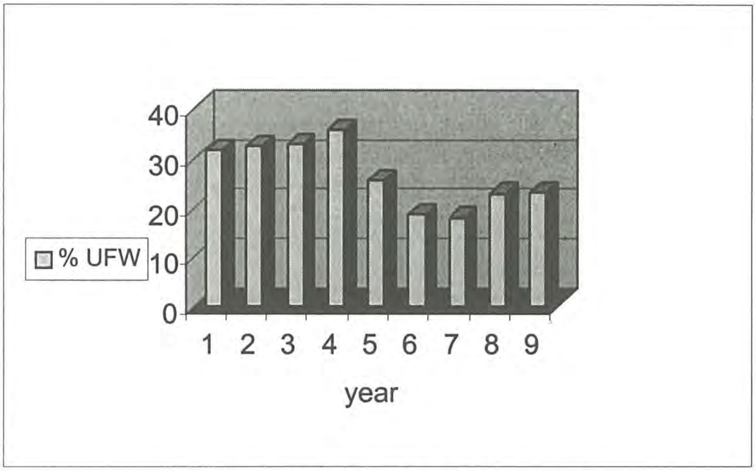

Fig.3 % UFW in the period (1993 – 2001)

CONCLUSIONS

It must be stated that there will always be leakage from the distribution systems. It is clearly not economical to ensure that pipelines will never leak. It is also clear that there is an economical limit to the loss of water that should be tolerated through leakage.

(1) Demand management is the ideal way for sustainable water resources.

(2) Groundwater extraction reduction through demand management can improve the recharge limits.

(3) Water conservation is an integral part of water demand management.

(4) Burst indicates a structural failure of the main. An assessment should be made of the cause of failure including details of the pipe material, its age, previous service history and ground conditions in order to consider the extent of deterioration of the main and need for replacement pattern.

(5) Water metering and charging for actual consumption is critical. Conservation pricing "Rising block tariffs" is second most important measure to discourage waste.

RECOMMENDATIONS

1. Improve demand management implication.

2. Introduce and enforce water legislation and Byelaws.

3. Create Public awareness and related educational program.

4. Enhance the accuracy of the billing system.

5. To promote water conservation water tariff may be restructured to identify real demand of lower income and high tariff implemented on high consumption.

6. Develop water management plan to reduce waste as one of its major demand management component.

7. The saving through various measured programs may not have significant impact over the duranal supply levels but the achievement would be significant on the overall control of the annual demand increase. Accurate evaluation of savings must be made; this would have a positive impact toward future demand augmentation.

8. In view of the increasing demand for water and its scarcity regionally, greater emphasis must be given to leakage control and UFW programs.

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