資料 1. 調査団員・氏名

Member List for Phase-1 Field Survey

Name	Position	Organization
西宮　宜昭 Mr. Noriaki NISHIMIYA	総括 Leader	国際協力機構 JICA 経済基盤開発部 審議役
松浦　信一 Mr. Shinichi MATSUURA	調達管理計画 Procurement Management Planning,	国際協力システム JICS 1)
緒方　隆二 Mr. Ryuji OGATA	計画管理 Planning Management	国際協力機構 JICA 地球環境部 水資源第 1 課
佐野　博文 Mr. Hirofumi SANO	業務主任／水道計画 Chief Consultant/Water Supply Planning 1	エヌジェーエス・コンサルタンツ（株） NJS Consultants Co., Ltd
伊澤　哲夫 Mr. Tetsuo IZAWA	施設計画・設計（プラント） 1 Facility Plan and Design (Plant) 1	
秋山　義宏 Mr. Yoshihiro AKIYAMA	施設計画・設計（プラント） 2 Facility Plan and Design (Plant) 2	
山口　岳夫 Mr. Takeo YAMAGUCHI	施設計画・設計（土木） Facility Plan and Design (Construction)	
ロナルド　J．ピーターソン Mr. Ronald J. PETERSON	運営・維持管理計画/財務分析 Operation and Maintenance Plan/Financial Analysis	
ラビ　P．ペレイラ Mr. Ravi PEREIRA	環境社会配慮 Environment and Social Considerations	
桐島　佳宏 Mr. Yoshihiro KIRISHIMA	施工計画/積算/入札図書作成/参考資料作成 Construction Schedule/Cost Estimation/Tender Document	

1) JICS: Japan International Cooperation System

資料 2. 調査工程

日順	月日	曜日	行動計画	メンバー									
				団長	松浦	緒方	佐野	伊澤	秋山	山口	ピーターソン	ペレイラ	桐島
1	9月27日	日	移動（東京～マニラ、コロンボ～セブ）	○	○	○	○	○	○	○	○	○	○
2	9月28日	月	JICA事務所、NEDA、DOF、大使館打合せ	○	○	○	○	○	○	○	○	○	○
3	9月29日	火	移動（マニラ～セブ）、NEDA、MCWD表敬	○	○	○	○	○	○	○	○	○	○
4	9月30日	水	プラント候補地、マクタン・ロック社、既存施設の視察	○	○	○	○	○	○	○	○	○	○
5	10月1日	木	MCWDとの協議、セブ州政府表敬	○	○	○	○	○	○	○	○	○	○
6	10月2日	金	MCWDとの協議	○	○	○	○	○	○	○	○	○	○
7	10月3日	土	資料収集、整理	○	○	○	○	○	○	○	○	○	○
8	10月4日	日	官団員(マニラに移動）、休み	○	○	○	○	○	○	○	○	○	○
9	10月5日	月	官団員(NEDA、JICA、大使館打合せ）、MCWDと候補地選定の協議	○	○	○	○	○	○	○	○	○	○
10	10月6日	火	官団員（日本着）、MCWDと候補地の視察	○	○	○	○	○	○	○	○	○	○
11	10月7日	水	候補地の比較検討				○	○	○	○	○	○	○
12	10月8日	木	候補地の比較検討				○	○	○	○	○	○	○
13	10月9日	金	MCWDと候補地について協議				○	○	○	○	○	○	○
14	10月10日	土	団内打合せ、資料分析				○	○	○	○	○	○	○
15	10月11日	日	休み				○	○	○	○	○	○	○
16	10月12日	月	資料収集・分析、候補地の検討				○	○	○	○	○	○	○
17	10月13日	火	資料収集・分析、候補地の検討				○	○	○	○	○	○	○
18	10月14日	水	インペリアルホテルの海淡施設視察及び協議				○	○	○	○	○	○	○
19	10月15日	木	資料収集・分析、候補地の検討				○	○	○	○	○	○	○
20	10月16日	金	事業内容の検討、移動（セブ～東京）				○	○	○	○	○	○	○
21	10月17日	土	団内打合せ				○	○	○		○	○	○
22	10月18日	日	休日、マクタン島の海岸線の水質状況視察				○	○	○		○	○	○
23	10月19日	月	事業内容の検討				○	○	○		○	○	○
24	10月20日	火	事業内容の検討				○	○	○		○	○	○
25	10月21日	水	事業内容の検討				○	○	○		○	○	○
26	10月22日	木	事業内容の検討				○	○	○		○	○	○
27	10月23日	金	事業内容の検討				○	○	○		○	○	○
28	10月24日	土	団内打合せ				○	○	○		○	○	○
29	10月25日	日	休み				○	○	○		○	○	○
30	10月26日	月	移動（セブ～東京、セブ～コロンボ）、候補地周辺の視察				○	○	○		○	○	○
31	10月27日	火	MCWDと理事会結果について協議				○						
32	10月28日	水	候補地の土地情報収集				○						
33	10月29日	木	移動（セブ～マニラ）、JICAマニラ事務所で協議				○						
34	10月30日	金	移動（マニラ～東京）				○						

資料 3. 関係者（面会者）リスト

Organization	Name (nickname)	Status
MCWD Metro Cebu Water District	Mr. Armando Paredes (Mandy)	General Manager
	Mr. Lasaro P. Salvacion (Boboy)	Manager, Water Resources Department
	Mr. Michael M. Balazo (Mike)	Assistant General Manager, Technical Services
	Ms. Rowan E. Tenedo (Wawa)	Manager, Corporate Planning Department
	Mr. Edgar H. Donoso (Edgar)	Assistant General Manager, Finance
	Mr. Noel R. Dalena (Noel)	Assistant General Manager, Pipeline Maintenance
	Mr. Angelo H. Cabije (Gelo)	Manager, Service Connection & Installation Dep.
	Mr. Jose Eugenio B. Singson (Eugene)	Officer in Charge, Project Management Office
	Mr. Roel A. Panebio (Roel)	Division Manager, Environment Division, WRKC
DOF Department of Finance	Mr. Rommel Herrera	International Finance Group
NEDA Manila (National Economic & Development Authority)	Ms. Pia Reyes	Infrastructure Staff
	Mr. Reno Cantre	Infrastructure Staff
	Ms. Joyse Ann	Infrastructure Staff
NEDA Reagion7 (Cebu Office)	Ms. Mariene	Resional Director
	Mr. Rafael Tagalog	Division Chief
	Mr. Engr. Margarito Cabadsan	Senior Economic Specialist
Province of Cebu (Cebu State Government)	Mr.Adolfo V. Quiroga	Provincial Planning & Development Coordinator
JICA Philippines Office	Mr. Norio Matsuda	Chief Representative
	Mr. Masafumi Nagaishi	Senior Representative
	Mr. Naoto Kuwae	Representative, Poverty Reduction Section
	Mr. Makoto Iwase	Representative

資料 4. 討議議事録（M/D）

以下のミニッツは 2009 年 10 月 13 日に調査団及びフィルピン側の合意の下に署名された。

資料 5. 参考資料／入手資料リスト

Name of Materials	Month/ Year	Publication
Feasibility Study of Seawater Desalination Facility for Water Supply in Metro Cebu　Final Report	Sep. 2005	JBIC: Japan Bank for International Cooperation TEPSCO: Tokyo Electric Power Service Co., Ltd.
Provincial Water Supply, Sewerage and Sanitation Sector Plan (PW4SP)　CEBU Main Report	Dec. 2003	GTZ: German Technical Cooperation Provincial Government of Cebu
Provincial Water Supply, Sewerage and Sanitation Sector Plan (PW4SP)　CEBU Appendix		
Imperial Palace Hotel RO System Design Materials & System Flow Diagram	2009	Imperial Palace Hotel Internal Document
The Study for Improvement of Water Supply and Sanitation in Metro Cebu in the Republic of the Philippines　Progress Report	Apr. 2009	NJS: NJS CONSULTANTS CO., LTD. NK: NIPPON KOEI CO., LTD.
Revised Procedural Manual (RPM) for DENR Administrative Order No. 30 of 2003 (DAO 03-30) Implementing Rules and Regulations of PD. No. 1586 establishing PEISS	August 2007	DENR: Department of Environment and Natural Resources EMB: Environmental Management Bureau
Environmental Laws in the Philippines	1999 – 2nd Ed	Central Book Supply Inc. Editorial Staff
A Legal Arsenal for the Philippine Environment The Philippine Islands: Batas Kalikasan	2002	Antonio A. Oposa Jr.
Geological Map of Cebu Quadrangle (Sheet 3750 I)	First Ed. 1985	Philippine Bureau of Mines and Geosciences

資料 6. その他資料・情報

海水淡水化資料

【1】 沖縄県企業局海水淡水化 Q&A 編集委員会、1994 年 11 月

- 沖縄の例(40,000m^3/day)では、O/M 費は約 170 円/m^{3}となっているが、そのうち動力費、資本費、薬品費、膜交換費はそれぞれ、33、28、12、11%となっている。
- 海水淡水化施設で生産された水は、pH が低く、ランゲリア指数が大きい負の値であるのでスケールなどの析出は起きないが、腐食性があり、このまま水道施設に送水すると施設の配管、設備及び水道器具内で赤水の発生が起こりやすい。そのため、苛性ソーダを注入し、pH 調整を行なっている。また、硬度も低いため通常はカルシウム等硬度成分の添加を行なう後処理必要。
- しかし、当海淡施設の場合、隣接している北谷浄水場の陸水系の処理水が硬水となっており、この浄水場の処理水とブレンドすることにより、適度な硬度及びアルカリ度をもったおいしい水になり、特別な後処理は必要ないと考えている。
-

海水淡水化施設概要：

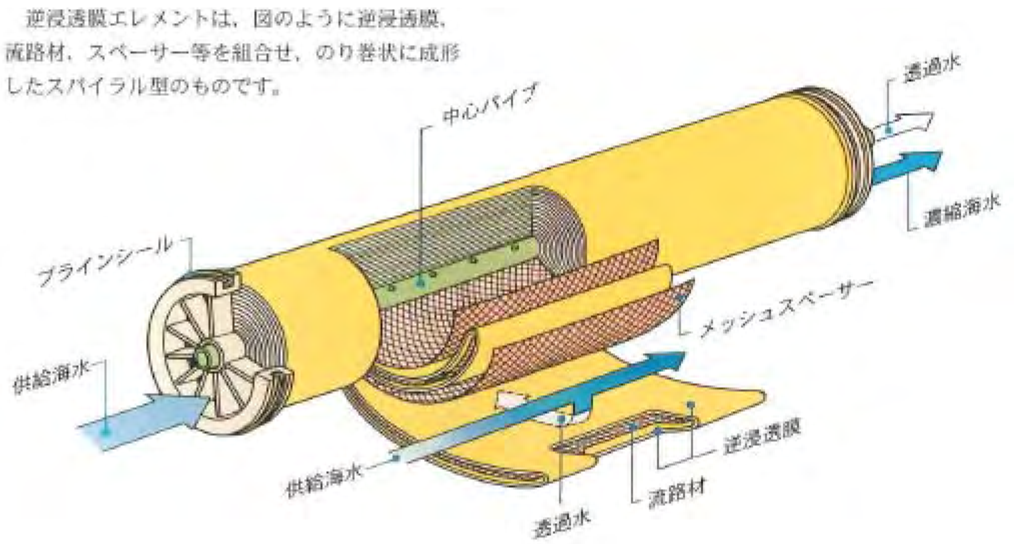
- 場所　沖縄県北谷町宮城
- 敷地面積　約 12,000m^2 （0.3 m^2/m^3-capacity）
- 建築面積　約 9,900m^2（延床面積 約 17,600m^2）
- 建屋　RC 及び PC 造り（地下 1 階、地上 4 階）
- 施設規模（生産水量）　40,000m^3/日
- 淡水化方式　逆浸透法（RO 法）
- 回収率　約 40%
- 膜の種類　スパイラル型芳香族ポリアミド複合膜（逆浸透膜）
- 受変電施設　約 8,000kW、沖縄電力（株）の供給規定により特別高圧（66kV）受電となる。
- 取水方式　海底取水管方式
- 放流方式　水中拡散方式
- 総事業費　約 347 億円（国庫補助率 85%）（86,750 円/m^3/日）

水質比較：2005 Water quality

	原海水	RO 膜生産水	除去率(%)
TDS (mg/L)	34,800	278	99.20
Cl^- (mg/L)	19,800	119	99.40
SO_4^{2-} (mg/L)	2,490	5.9	99.76
Na (mg/L)	11,400	96.1	99.16
T-hardness (mg/L)	6,360	10	99.84
Conductivity (µS/cm)	50,800	456	99.10

逆浸透膜ユニット：

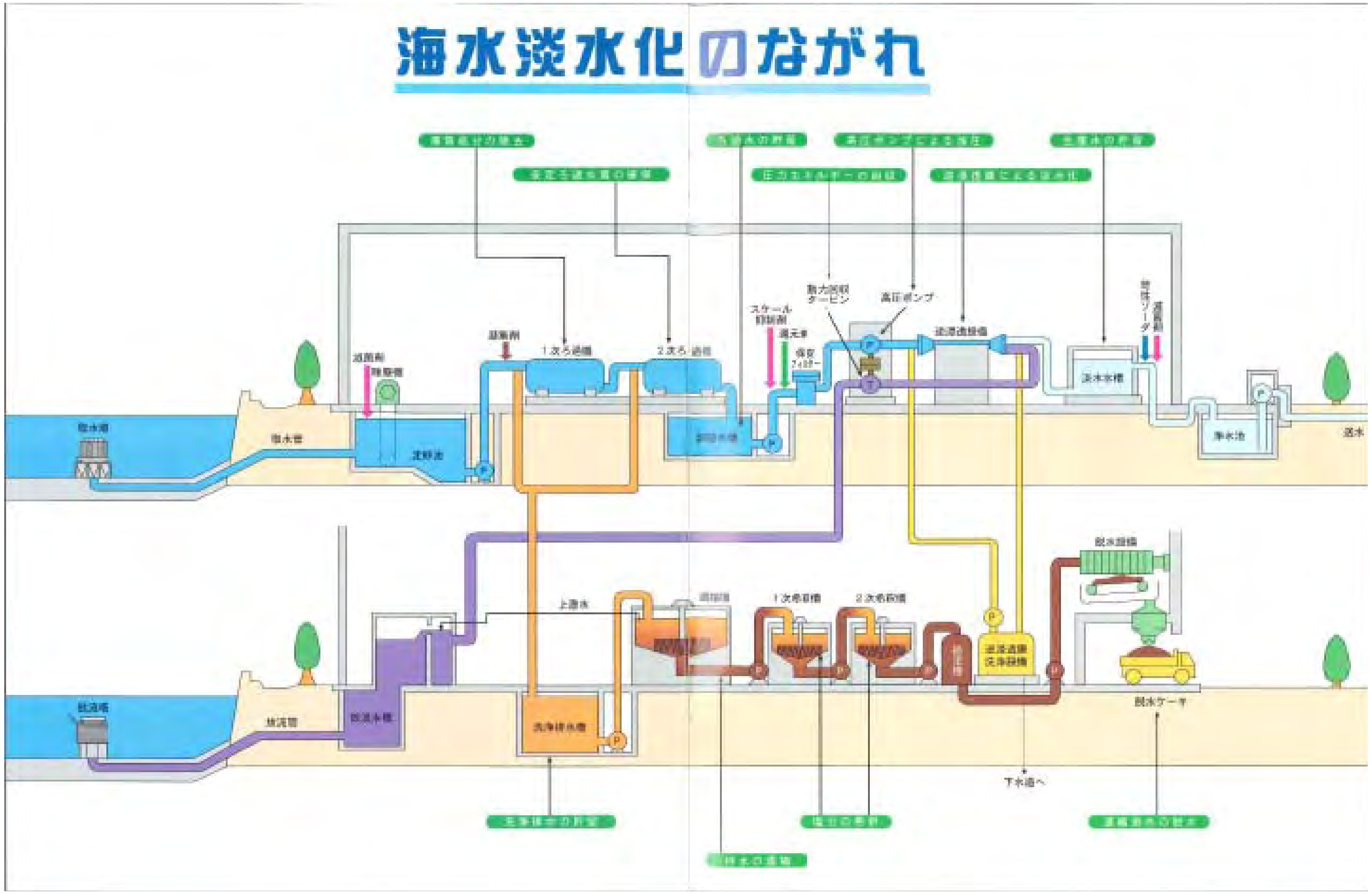
- 1 基当り約 5,000 m^3-生産水/日
- 1 ﾕﾆｯﾄ:　63 RO ﾓｼﾞｭｰﾙ
- 1 ﾓｼﾞｭｰﾙ:　6 ｴﾚﾒﾝﾄ



海水淡水化施設概要

設備		仕様（40,000 m3/日）、取水（10,000 m^3/日）	備考
1) 海水取水設備	取水管	Φ1,200 x 220 m x 1条 (海底取水方式)	速度 = 1.0 m/秒
	取水ﾋﾟｯﾄ	$4.5m^W$ x $10.5m^W$ x $5.3m^H$ (有効) x 2	容積 =500 m^3
	(沈砂池)	(自動除塵機)	滞留時間: 7.2 分
	取水ﾎﾟﾝﾌﾟ	19.4 m^3/分 x 48mH x (4+1) 基	取水量 = 112,000 m^3/日
2) 前処理	ろ過器	直接凝集ろ過 (直列2段ろ過)	
		第1段ろ過器: 32m^2/ﾀﾝｸ x (12+1) 基	断面積= 384 m^2, ろ過速度= 10 m/時
		第2段ろ過器 : 33.6m^2* (8+1) 基	断面積= 270 m^2, ろ過速度= 15 m/H
	ろ過水槽	容量= 1,000 m^3 x 2	容量 =2,000 m^3 , 滞留時間 = 30 分
3) RO設備	供給ﾎﾟﾝﾌﾟ	8.9m^3/分 x 45mH x (8+1) 基	供給量 = 102,500 m^3/日
	保安ﾌｨﾙﾀｰ	537m^3/時 x (8+1) 基	
	高圧ﾎﾟﾝﾌﾟ	8.91m^3/分 x 650mH x 8 基	供給量 = 102,500 m^3/日
	RO 膜 ﾕﾆｯﾄ	5,131 m^3/日 x 8 基	生産水量 = 41,000 m^3/日
		63 ﾍﾞｯｾﾙ/ﾕﾆｯﾄ (7 列 x 9 段), 6 ｴﾚﾒﾝﾄ/ﾍﾞｯｾﾙ	13.6 m^3/ｴﾚﾒﾝﾄ
	昇圧ﾎﾟﾝﾌﾟ	4m^3/分 x 40mH x (2+1) 基	供給量 = 11,500 m^3/日
	生産水貯槽	容量 = 200 m^3 x 2 (ｻｯｸﾊﾞｯｸ水槽)	滞留時間: 14 分
4) 放流設備	放流管	Φ700 x 230 m x 1条 (海底放流方式)	容量 = 1.8 m/秒
	放流水槽	容量 = 2,100 m^3 x 1 基	滞留時間: 50 分
(廃水処理設備)	逆洗排水槽	容量 = 330 m^2 x 2 基	
	濃縮槽送りﾎﾟﾝﾌﾟ	1.63 m^3/分 x 20mH x (3+1) 基	
脱水設備	濃縮槽	容量 = 380 m^3 x 3 基, A=94 m^2, H=4.0 mH (有効)	水面積負荷: 25 m^3/m^2/day
	希釈槽	容量 = 260 m^3 x 3 基i , A=64 m^2, H=4.0 mH (有効)	水面積負荷: 36 m^3/m^2/day
	脱水機	運転時間: 4 -5 時間/日	
		脱水面積: 100 m^2 x 2 基	
		脱水汚泥: 約 2.5 m^3/日 (水分 65 % 以下)	
5) 薬品注入設備		塩化第二鉄注入設備	
		次亜塩素酸ﾅﾄﾘｳﾑ注入設備	
		重亜硫酸ｿｰﾀﾞ注入設備	
		苛性ｿｰﾀﾞ注入設備	
6) 受変電設備		受電, 変電、配電設備	
7) 制御設備		電源供給, 非常用電源, 制御盤, 監視盤, 制御ｼｽﾃﾑ	

Note: Remarks are estimated by the specifications



海水淡水化のながれ
凝集剤
1次ろ過機
2次ろ過
スケール
抑制剤
還元剤
保安
フィルター
動力回収
タービン
高圧ポンプ
逆浸透設備
淡水水槽
浄水池
送水
上澄水
1次希釈槽
2次希釈槽
逆浸透膜
洗浄設備
脱水設備
洗浄排水槽
脱水ケーキ
下水道へ

逆浸透（RO）法海水淡水化技術の上水道分野への適用、三菱重工技報

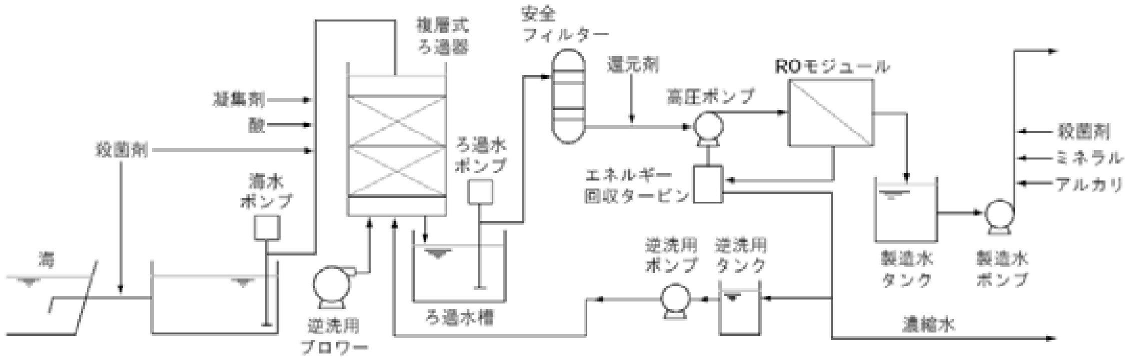


図１　RO海水淡水化プロセスフロー　　代表的なRO海水淡水化プロセスフローを示す．前処理にはDMF（複層式ろ過器）を用いている．

1.　処理フロー

- 海水は殺菌後，砂ろ過に代表される前処理設備で海水中の汚れを除去する。
- 微生物が RO 膜モジュール内で繁殖したり，濁質の多い海水が RO 膜モジュールに供給されたりすると膜面に生物や濁質が蓄積し性能が低下する．したがって，プラントの安定運転には前処理設備の性能が大きな影響を与える。
- 前処理により清澄になった海水は高圧ポンプで圧力を 5〜8 MPa まで昇圧し RO 膜に供給され，供給海水の 30 〜 60 %が淡水として取り出される。
- 残りは濃縮水として膜モジュールから排出されるが，圧力を有しており回収タービン等によりエネルギーを回収した後，放流される．

2.　RO 法の特徴

海水淡水化技術において RO 法は蒸発法と比べて，

- 使用エネルギーが少ない。
- 生産水中に適度のミネラル分を含む。
- 運転維持管理が容易。
- 装置がコンパクト

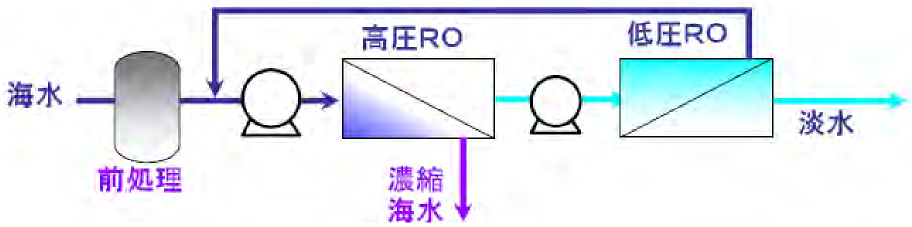
のような特徴を有する。

これまで日本では RO 海水淡水化の造水コストは高いとされていた。

これは回収率 40 %，エネルギー回収無しの場合，エネルギー原単位が 7〜8 kWh/m^3 程度であり，電気代が大きな割合を占めていたからである．しかし現在では，回収率の増加（50 〜 60 %），エネルギー回収システムの適用により 3 kWh/m^3 台の数値が得られており，国内でも最新の造水コストは 170 円／m^3 以下と予想される．海外では，プラント立地条件や設備仕様にもよるが，既に 65 〜 130 円／m^3 に到達している．

3. 現時点の RO 海水淡水化の課題と対応策

RO 法の課題	対応策
造水コストの一層の低減	♦ 設備費及び運転費の低減による低コスト化 - 前処理ろ過装置のろ過速度の増加, - RO システム回収率増加 - エネルギー回収システムの適用, - プラント運転方法の適正化によるエネルギー原単位の低減
汚染の進んだ原海水への対応	高濁質（SS10mg/L～），有機物汚染の進んだ海域での前処理として ♦ 砂ろ過システムの改善, - 無機系凝集剤＋高分子凝集助剤によるろ過水質の改善 - 薬品無添加除濁装置＋通常ろ過の組合せで直接ろ過への負荷低減 ♦ 膜ろ過の導入 - RO 膜の化学洗浄間隔を延伸するとともにより良好な水質を得るため限外ろ過（UF： Ultrafiltration）膜，精密ろ過（MF： Microfiltration）膜の適用。現状では設備費が砂ろ過に比べ 2~3 倍要するが，ろ過膜の大容量化や高フラックス化のほか，運転条件の適正化により低減可能
生産淡水の高品質化，具体的には，トリハロメタン等塩素系有機化合物，ホウ素等水質基準の規定物質の除去	♦ 水質高度化に対応する 2 段 RO システムの適正化 1 段目透過水を再度 RO で処理する 2 段法によりトリハロメタン，ホウ素の高除去率を得る。 たとえばホウ素は，海水中に 4.5 ppm 程度含まれ，中性付近では分子状で存在するため，現状の海水淡水化用 RO 膜の運転条件（pH 6.5 ～ 7.5）ではこの分子状ホウ素の除去率が低く， 1 段 RO では水質基準 1 ppm 達成が困難である。[1]この場合，2 段目として低圧 RO で処理し水質基準を達成する。 また，膜材質によってはトリハロメタンの除去率が悪いものがあるが，この場合も 2 段目にポリアミド系膜を使用すれば水質基準の達成が可能。



4. 造水コスト

[1]フィリピンの水道基準ではホウ素は 0.5mg/L 以下。現在の WHO 指針も 0.5mg/L 以下であるが、WHO はより緩やかな値に変更する予定。（1mg/L 或いはこれ以上）

試算条件		試算結果			
項　目	使用数値	項　目		コスト (円/m^3)	割　合 (%)
生産水量	50 000 m^3/日	運転費	電気代	60.0	41.5
回収率	50 %		膜　代	4.6	3.2
稼働率	95 %		薬品代	8.8	6.1
原単位	5 kWh/m^3		補修費	5.8	4.0
電気代	12 円/kWh		労務費	9.8	6.8
膜交換率	年 10 %		小　計	89.0	61.6
建設単価	20万円/(m^3/日)	設備償却費		55.6	38.4
耐用年数	15 年	合計		144.6	100
利子率	5 %				

<u>海水淡水化施設整備事業のあらまし、福岡地区水道企業団</u>

1. 事業スケジュール：

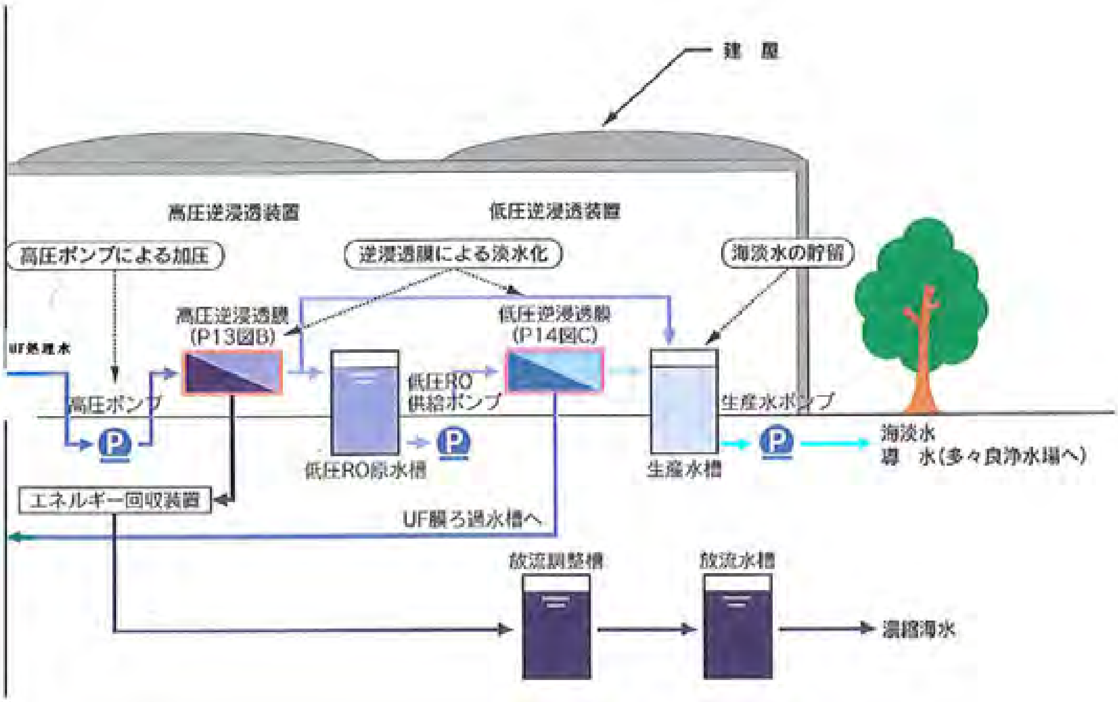
- 工事期間：導水工事 5.5 年（海水淡水化施設：4.5 年）

2. 事業概要

- 敷地面積： 約 46,000 m^2（0.92 m^2/m^3/日）建築面積約 16,000m^2（延床面積約 21,000m^2）海水淡水化本体：0.42 m^2/m^3/day
- 生産水量： Max. 50,000 m^3/日
- 取水方式： 浸透取水方式
- 淡水化方式： 逆浸透法（淡水回収率 60%）
- 放流方式： 水処理センター処理水と混合して博多湾内へ放流
- 導水施設： 導水管 φ800 x approximately 20 km
  プラント施設~浄水場、延長=約 12 km
  浄水場～配水池 延長=約 8 km
- 事業費： 約 440 億円 （88,000 円/m^3/日）

3. 事業の特徴

- 浸透式取水方式：清涼な海水を安定的に取水
- 前処理：UF 膜（ポリスルホン系スパイラル型）で微生物や極細微粒子まで除去
- 逆浸透膜方式：2 段式（高圧（三酢酸セルロース中空糸型）一段処理に部分低圧方式（ポリアミド系スパイラル型）により、より良質な水の生産
- 低コスト：淡水回収率 60%



4.　特記事項

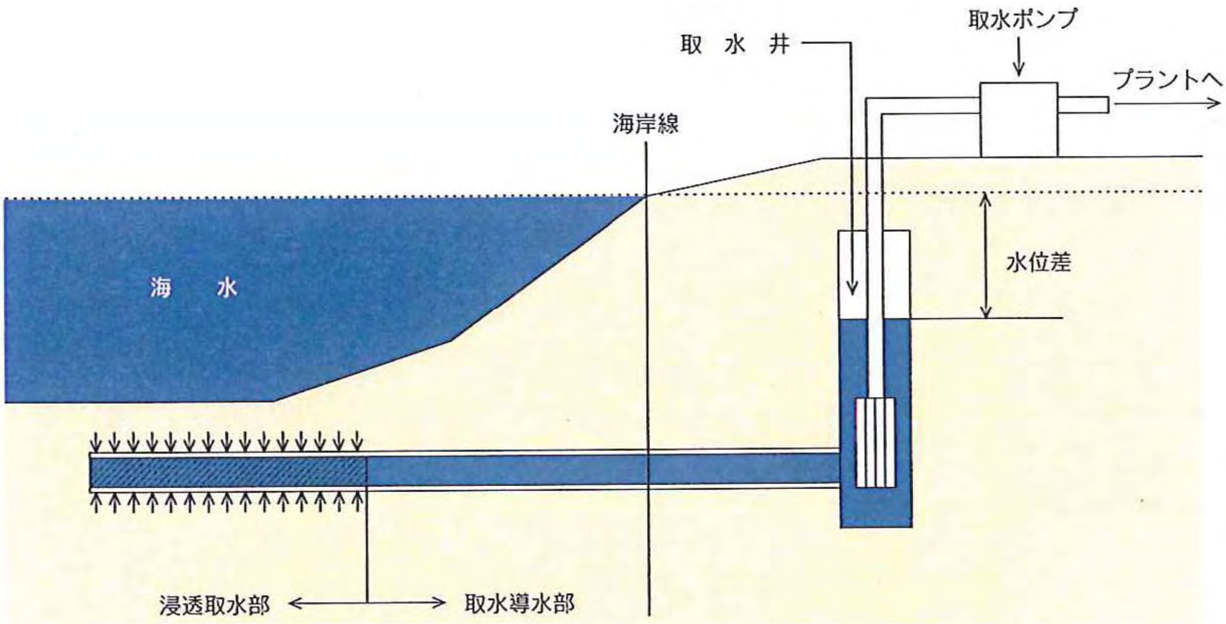
(1)　取水方法：浸透取水方式

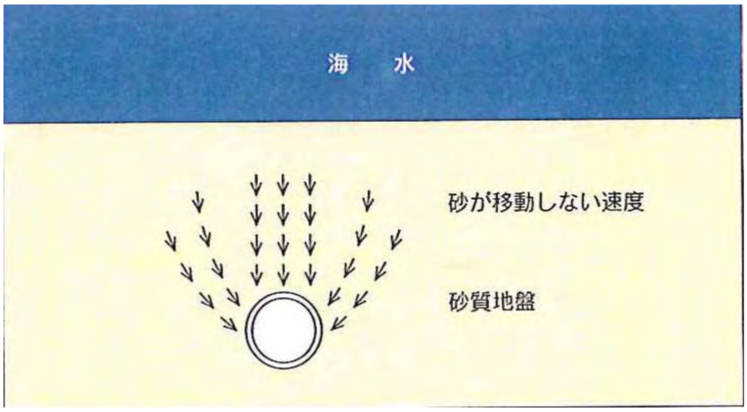
(2)　浸透取水の基本的考え方

- 浸透取水方式は、構造物設置に伴う周辺海域への影響を少なくすること、また、砂のろ過作用によりきれいな海水を取水できる。
- 浸透取水方式では、取水ポンプによって取水井の水位を海面より下げ、その水位差を利用して、砂が移動しない非常に遅い速度（限界流速以下）で取水する。

(3)　RO 膜寿命：5 年以上

RO 膜への供給水の汚れが極めて少なく、膜が機械的、化学的な損傷（劣化）を受けない理想的な運転ができた場合には、膜は長期間安定した性能が得られる。





(4)　エネルギー回収装置

放流濃縮海水のもつ圧力エネルギーをエネルギー回収タービンによって回転エネルギーに変換し、これを高圧ポンプ駆動の補助エネルギーとして使用する装置。約 20%のエネルギーを回収する。

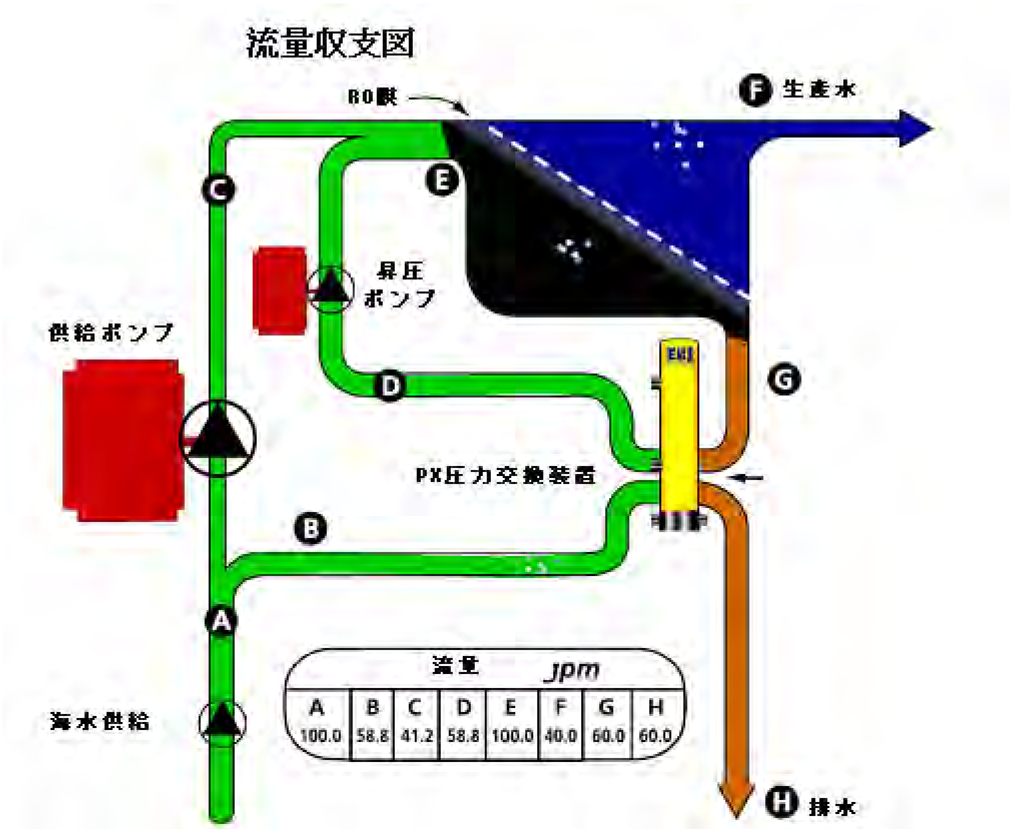
（参考）最近では以下のような、より効率の良いエネルギー回収装置が使用されている。

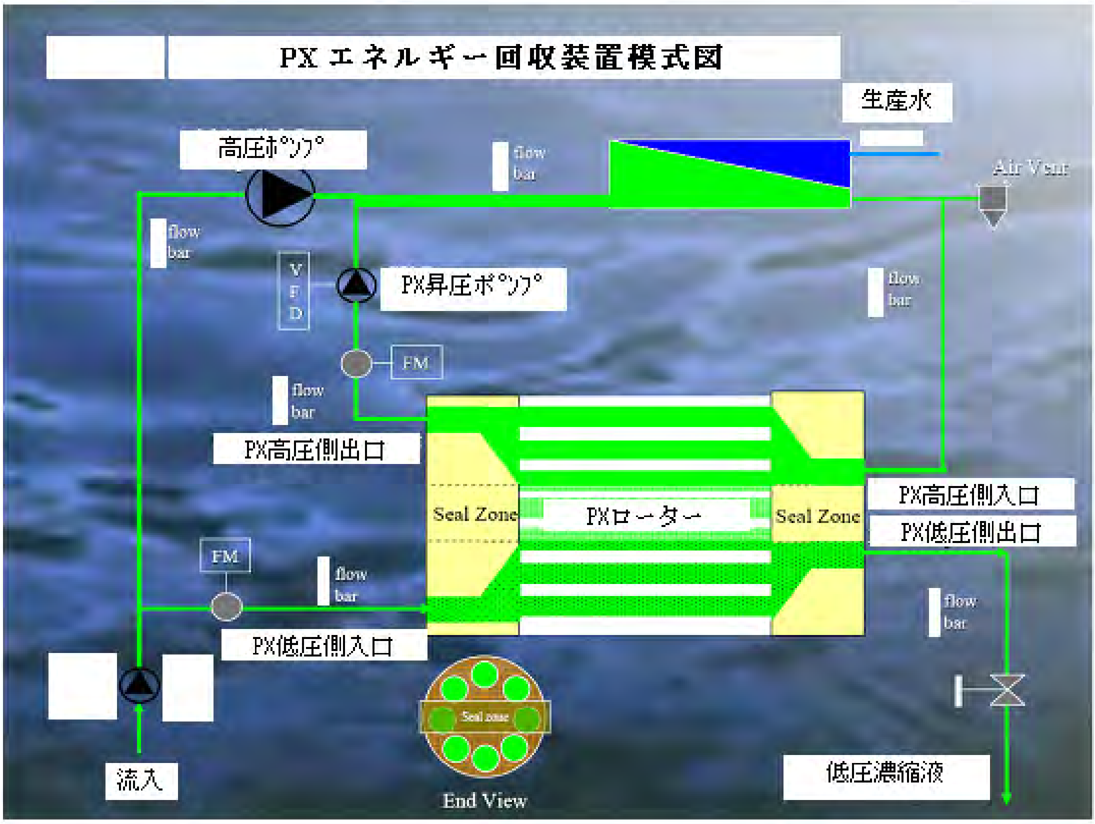
Energy Recovery 社の PX 圧力交換装置® (PX®)はたった一つの駆動部分のみをもつ回転式エネルギー回収装置で RO システム（SWRO）濃縮液からエネルギーを 98%程度回収する。

装置中心部分に耐食性に優れたセラミックローターがあり、低振動、維持管理不要し

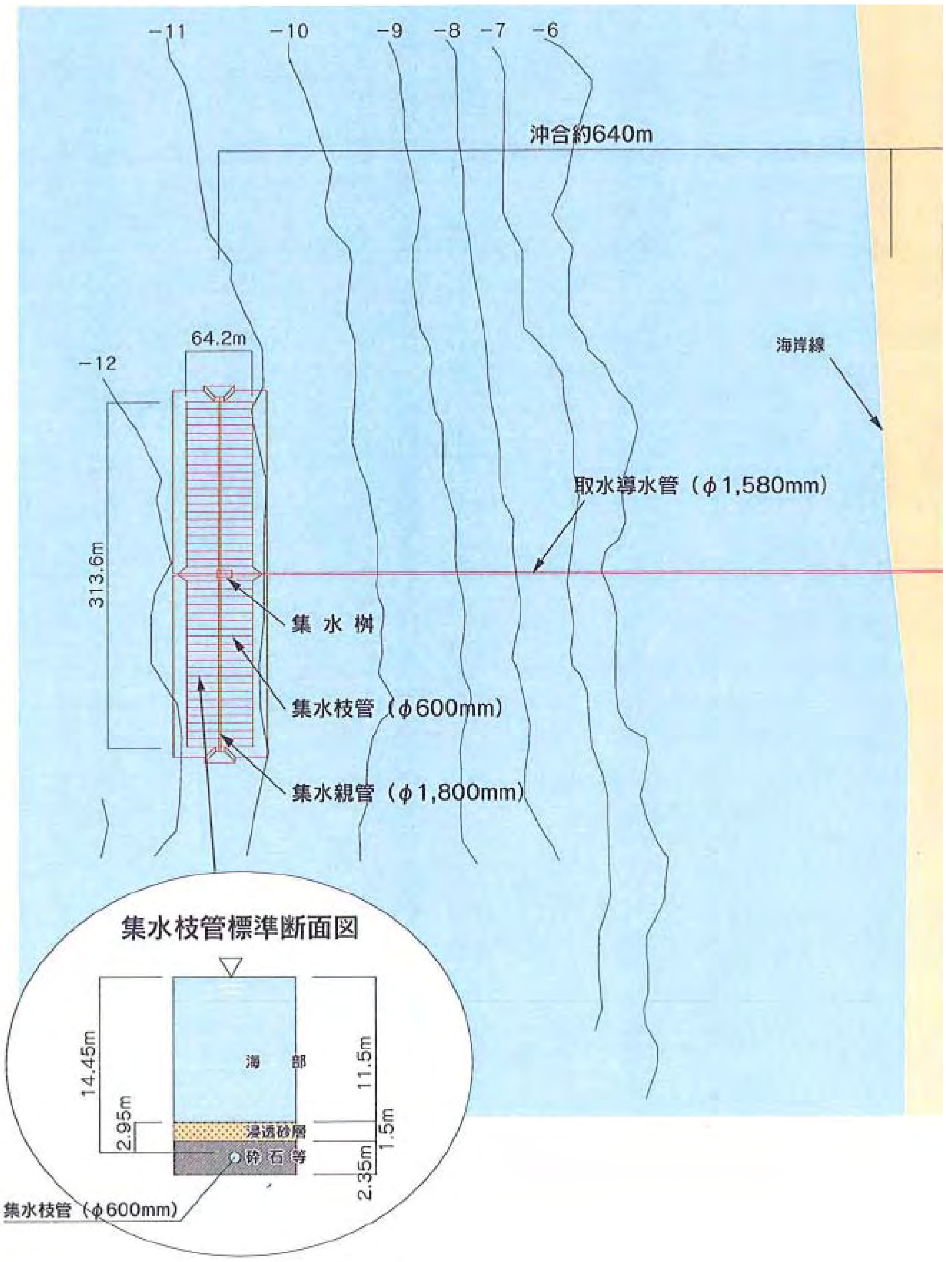
かも故障しにくい。PX は SWRO 淡水化プロセスのエネルギーに起因するコストを劇的に減少する。エネルギー回収装置なしの場合に比較して約 60%コストを減少できる。約 30 ケ国で採用されている。

PX エネルギー回収装置は正極移動と等圧室原理を利用し、RO 濃縮液のような高圧排液から低圧供給原液に非常に効率よく（約 98%）エネルギーを移動させる。移動時にエネルギーは殆ど失われない。

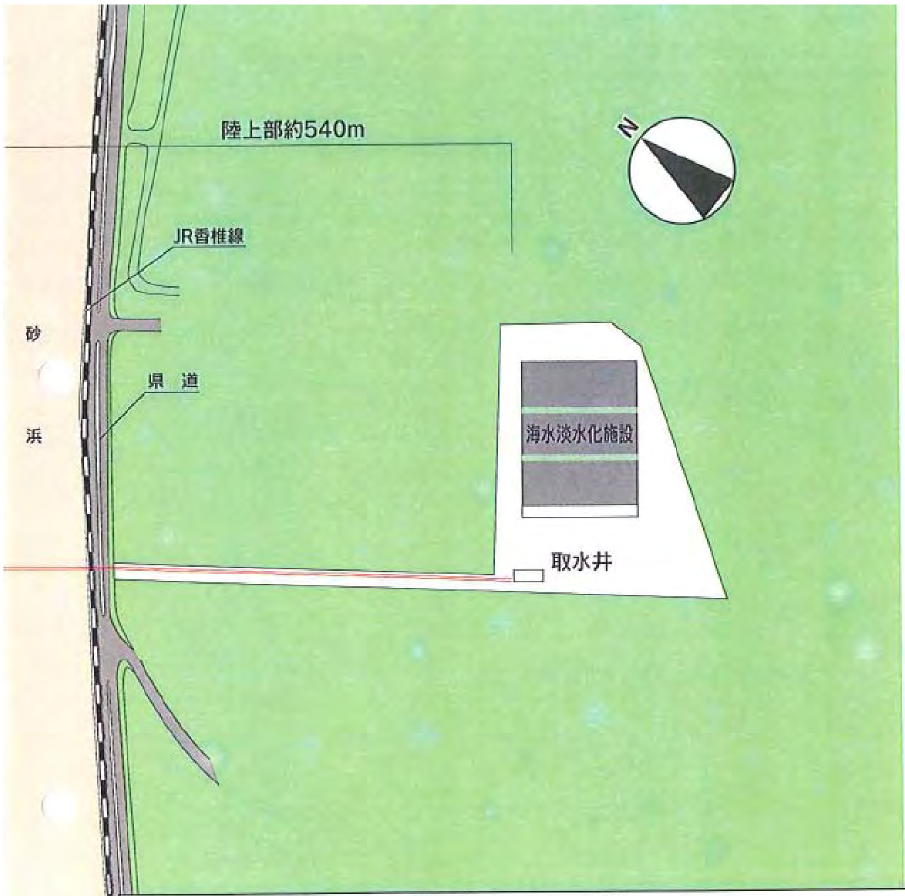



PX エネルギー回収装置模式図
生産水
高圧ﾎﾟﾝﾌﾟ
flow
bar
Air Vent
V
F
D
PX昇圧ﾎﾟﾝﾌﾟ
FM
PX高圧側出口
Seal Zone
PXローター
Seal Zone
PX高圧側入口
PX低圧側出口
PX低圧側入口
End View
流入
低圧濃縮液

取水施設概要図



−11
−10
−9
−8
−7
−6
沖合約640m
64.2m
−12
海岸線
取水導水管（φ1,580mm）
313.6m
集 水 桝
集水枝管（φ600mm）
集水親管（φ1,800mm）
集水枝管標準断面図
14.45m
海 部
11.5m
浸透砂層
1.5m
2.95m
砕 石 等
2.35m
集水枝管（φ600mm）



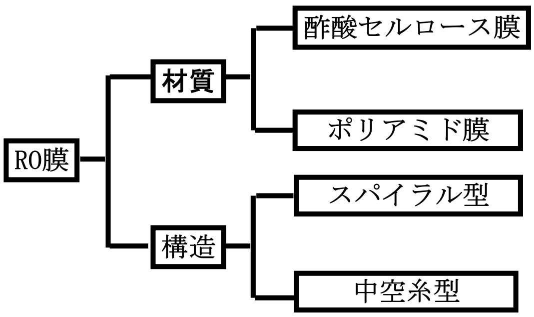
構造	
浸透集水部	浸透流速 6m／日 集水親管 φ1,800mm L＝約314m 集水枝管 φ 600mm L＝約 30m 5mピッチ（総延長 3,600m）
取水導水部	φ1,580mm L＝1,178m
集水桝	幅 長さ 高さ 集水桝内空寸法 5.0m×8.0m×4.9m
取水井	幅 長さ 高さ 内空寸法 5.0m×13.0m×10.7m×2

海水淡水化 **Q&A**、沖縄県企業局海水淡水化 **Q&A** 編集委員会**, 1994**

1.　海水淡水化方式の原理及び特徴（透過気化法：参考）

方式	原理	特徴
透過気化法	水蒸気は通すが液体の水は通さない透過気化膜で容器を仕切り、その片側に海水を入れ、水蒸気のみを透過」させて淡水を得る方法	省ｴﾈﾙｷﾞｰ化が充分進んでおり、排熱の有効利用が可能であり、太陽熱等利用し得る排熱が充分に存在する地域に最適

2.　RO 膜種類と特徴



中空糸型膜には酢酸セルロース膜とポリアミド膜が用いられ、スパイラル型（平膜をのり巻き条にしたもの）にはポリアミド系複合膜が用いられている。また、ポリアミド系複合膜には架橋全芳香族ポリアミド膜と線状全芳香族ポリアミド膜がある。

ポリアミド系複合膜は

- 酢酸セルロース膜では除去できないﾄﾘﾊﾛﾒﾀﾝ類が除去できる。
- また、一般的にスパイラル型の方が膜の目詰まりが起こりにくい構造になっている。
- スパイラル型は複数の膜製造メーカーがあり、各メーカーにより外観の違いはあっても寸法は共通になっている。即ち、どのメーカーの RO 膜エレメントも同じ圧力容器に装填できる。
- ポリアミド系膜の場合、膜流入前に SBS にて脱塩素することが必要。脱塩素を完全に行うため、
  - ①　SBS を常時 2 台で注入：1 台の故障に対応
  - ②　SBS 注入ラインに流量センサー設置。ORP 設置：塩素リークが検出された場合は 3 台目の SBS ポンプが作動、過剰添加する。
- スパイラル型 RO 膜は給水側にメッシュスペーサ（許容孔径：約 30μm）使用：給水側の流速を速め、撹拌効果を上げる。

（参考）

- 非対称膜：膜分離機能を有する脱塩機能層とこれを支える支持層がともに同一材質であり、代表的には酢酸セルロースの非対称膜がある。
- 複合膜：　脱塩機能層（架橋型全芳香族ﾎﾟﾘｱﾐﾄﾞ膜等）と支持層（ﾎﾟﾘｽﾙﾎﾝ等）が異質の材質で構成されていて、それぞれの構成素材を機能的に最適なものから選択できる。代表的にはポリアミド系複合膜がある。

<u>市販 RO 膜の化学構造による分類</u>

膜素材/会社名	商品名	モジュール形式
架橋全芳香族ポリアミド		
Film Tec	TW/BW/SW/HR-30*	Spiral
(DOS)	HR-95*, HR-99*	Plate & frame
(PCII)	ZF-99*	Tubular
東レ	SU-700*, SU-800*, SU-900*	Spiral
日東電工	NTR-759*	Spiral
線状全芳香族ポリアミド		
Du Pont	Permasep B-9, B-10	Hollow fine fiber
Du Pont	Permasep B-15	Spiral
ｱﾘﾙｰｱﾙｷﾙﾎﾟﾘｱﾐﾄﾞ/ﾎﾟﾘｳﾚｱ		
UOP	RC-100 (and PA-300)*	Spriral
Hydranautics	CPA*	Spriral
日東電工	NTR-7197*, NTR-739HF*	Spriral
Du Pont	Permasep A-15*	Spriral
ﾎﾟﾘﾋﾟﾍﾟﾗｼﾞﾝｱﾐﾄﾞ		
Film Tec	NF-40*, NF-40HF*	Spiral
日東電工	NTR-7250*, NTR-729*	Spiral
東レ	SU-200*, SU-600*, SU-500*	Spiral
ｾﾙﾛｰｽｱｾﾃｰﾄ		
東レ	SC-1000, 3000	Spiral
UOP	ROGA-4160	Spiral
Hydranautics	4007-1620CA	Spiral
DSI	8054-98	Spiral
Du Pont	C-1	Spiral
ｾﾙﾛｰｽﾄﾘｱｾﾃｰﾄ		
東洋紡	Hollosep	Hollow Fiber
架橋ﾎﾟﾘｱｽﾃﾙ		
東レ	PEC-1000*	Spiral
ﾎﾟﾘｱｸﾘﾛﾆﾄﾘﾙ		
住友化学	Solrox	Tubular, Spriral
ﾎﾟﾘﾍﾞﾝｽﾞｲﾐﾀﾞｿﾞﾛﾝ		
帝人	PBIL	Tubular, Sriral
ｽﾙﾎﾝ化ﾎﾟﾘｽﾙﾎﾝ		
DSI	DesalPlus*	Spiral
Millipore	PSRO*	Spiral
日東電工	NTR-6410,7450*	Spiral

*: 複合膜

（参考文献）栗原 優、青木 孝夫、表面、29(10)、837(1991)

3.　取水施設：

(1)　取水地点

取水地点は、台風等荒天時における海藻、砂などの異物混入を防止できる位置、また、滞留が生じない位置に設置するものとし、取水地点を沖合い約 200m、水深約 9m とし

た。

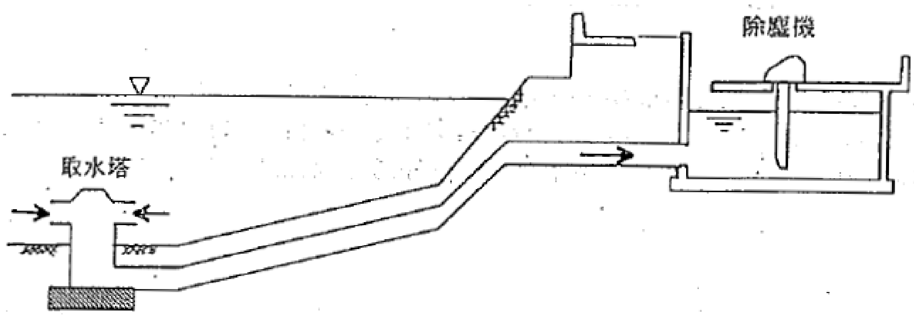
(2) 取水管

取水管口径は管内流速を 1.32 m/sec とすれば、φ1,100 mm となるが、それに貝類の付着を見込んでφ1,200 mm とする。塩素注入管の破損や腐食による塩素の海中への遺漏を防ぐため塩素注入をやめた。

管の材質は海底配管として一般的な鋼管（STPY400）を採用し、内面エポキシ樹脂、外面コールタールエナメルの塗装を施す。さらに 20 年耐用の電気防食を施す。

(3) 取水ピット

取水ピット水位は、界面水位を那覇港検潮所の観測データより推定し、取水管損失水頭、自動除塵機の損失水頭から設定した。スクリーン最大通過流速 0.13 m/sec



4. 前処理施設(ろ過機)：

- 原水濁度：1〜2 度(SS 2 mg/L)
- 設置面積が小さく 1 次ろ過機と 2 次ろ過機の形式が同一可能で、建設費が安価な圧力式（横型）ろ過機を選定。
- ろ過機洗浄直後は濁質がろ層を通り抜けてしまうことから、その処理水が一時的に悪化することがある。そのため、ろ過機洗浄直後にリークした濁質分の補足を行い、常に安定したろ過水質を確保するため、ポリッシングろ過機（2 次ろ過機）を選定した。
- 製作及び輸送限界からろ過機の寸法を計画した。

(1) 一次ろ過機仕様

形式：　横型圧力式ろ過器（複層ろ過方式）

寸法：　φ3,200 x 11,000^{L}

材質：　SS/内面ｺﾞﾑﾗｲﾆﾝｸﾞ

ろ材及びろ過厚：　ｱﾝｽﾗｻｲﾄ 400 mm、砂 400 mm、砂利 200 mm

ろ過速度：　300 m/日

基数：　（12 +1）

(2) 二次ろ過機

形式：	横型圧力式ろ過器（単層ろ過方式）
寸法：	φ3,200 x 11,500L
材質：	SS/内面ｺﾞﾑﾗｲﾆﾝｸﾞ
ろ材及びろ過厚：	砂 700 mm、砂利 200 mm
ろ過速度：	400 m/日
基数：	（9 +1）

5. <u>前処理に使用する薬品</u>

薬品	目的
次亜塩素酸ナトリウム	殺菌。微生物繁殖による配管等の詰り防止
塩化第２鉄	凝集・砂ろ過による濁度成分の除去
硫酸	pH を下げてスケール防止
重亜硫酸ナトリウム	塩素除去。塩素による膜の劣化を防ぐ。

<u>薬品添加量：</u>

Chemicals	Dosing Rate (mg/L)
NaOCl	０.5 to 2.5
$FeCl_3$	2 to 8
H_2SO_4	40 to 50
$NAHSO_3$	5 x 2 台

(1) RO 膜供給水質指標：SDI 値 or FI 値、ｐH、ORP 等

(2) SDI 値：4 以下

- 塩素殺菌した海水→凝集・ろ過（二層ろ過、ポリッシング砂ろ過）

(3) pH

- 海水の pH は 8.3 程度、海水中炭酸カルシウム析出防止のため pH 7 以下とする。

(4) ORP：重亜硫酸ソーダによる塩素除去確認

6. 保安フィルター：

処理海水量：537 m^3/h x (8+1)

ｴﾚﾒﾝﾄ許容孔径：20 μm 95 % 以上除去

7. 高圧ポンプ：水平分割多段渦巻ポンプ

8. エネルギー回収装置：

- 海水淡水化逆浸透設備では、設備供給水量の 40%程度が淡水となり、残りの約 60%は運転圧力とほぼ同じくらいの高圧力を持ったまま濃縮排水として排出される。
- 一方、海水淡水化施設全体の運転に要する電力のうち、高圧ポンプが占める割合は 75%以上になり、その電力費が生産コストに与える影響は大きい。

- したがって、濃縮排水のもつ圧力エネルギーをエネルギー回収タービンとして使用することにより、省エネルギーを図る。
- エネルギー回収タービンによってエネルギーの回収はタービンの効率によって異なり、一般にタービン規模が大きいほど効率が良くなり、エネルギー回収率も高くなる。
- 1 ユニットの規模が 5,000 m^3/日であり、タービン吸い込み流量は 320 m^3/時（濃縮排水 3,000 m^3/日＋5,000 m^3/日＝8,000 m^3/日＝333 m^3/時）でエネルギー回収率は 30%と予想される。
- 次の 4 点を考慮し、エネルギー回収タービン形式として逆転ポンプ型（フランシス型）タービンを選定した。

  1) 効率及び経済性
     効率はベルトン型タービンより劣るが、設備費は安価
  2) 補修・維持管理が容易
  3) 設置面積及び土木基礎
     施設の用地面積が狭いこと、支持基盤が弱いことなどの制約があり、据付の土木基礎が比較的容易で地上設置に適する。
  4) 実績

9. 膜エレメントと膜ベッセル仕様：

(1) 膜エレメント

形式：	スパイラル型	
材質：	芳香族ポリアミド系複合膜	
寸法：	ϕ 201 x $1,016^L$	
性能：	透過水	平均 15 m^3/日以上
	塩除去率	平均 99.75%以上（35,000 mg/L 海水）
		平均 99.60%以上（35,000 mg/L NaCl 溶液）
エレメント数：	1 ユニット当り（約 5,000 m^3/日）378 エレメント、13 m^3/element	
	8 ユニット当り（約 40,000 m^3/日）3,024 エレメント	

(2) 膜ベッセル

型式：	円筒横型（膜エレメント 6 本用）
数量：	1 ユニット当り 63 組（7 列 9 段）
設計圧力：	7.5 MPa
材質：	FRP

10. RO 膜運転圧力

- 海水の浸透圧力：約 2.5MPa
- RO 膜運転圧力：5.6 ~ 6.5 MPa （RO 装置を運転するときには膜の浸透圧の 2 倍以上の圧力を必要とする。

RO 膜運転のエネルギー

分離方式（回収率、あるいは単位セルへの付加電圧）	**必要動力(kWh/m³)**
RO 方式（回収率 40%）	3.5
エネルギー回収 80%付	1.8
RO 方式（回収率 30%）	4.7
エネルギー回収 80%付	2.0
電気透析法 (付加電圧：0.15V)	2.4
電気透析法 (付加電圧：5V)	8.0
多段ﾌﾗｯｼｭ法	10.9*
浸透気化法　(5%)	14.9

*：100℃、35℃、造水比 10、エクセルギー値

(参考文献)「分離膜のおはなし」大谷晴彦　日本規格協会

11. RO 洗浄薬品

- 微生物汚染：重亜硫酸ソーダまたはクロラミン
- 鉄・炭酸カルシウム等無機汚染：クエン酸(pH2~4)
- 有機汚染：DSS のようなアニオン系界面活性剤 0.1~1%

12. スライム防止

- 取水・前処理：塩素。
- RO 膜：ポリアミド膜には塩素不可。重亜硫酸ソーダ又はクロラミンを間欠的に添加（SBS を 500 mg/L, 30～60 分添加、又はクロラミン 1 mg/L、約 60 分）
- 架橋構造芳香族ポリアミド系膜に塩素が接触すると、初期の段階で短時間に水質向上、水量低下が起こる。塩素リークがしばらく継続すると膜の酸化分解により膜劣化が起こり水質が悪化し、水量が増加する。

13. 運転時注意事項

運転時間経過とともに生産水量の低下と水質悪化が起こる。対策としては、

- 膜性能に応じた運転
  - 膜運転圧力を上げすぎない。（定量運転時注意
  - 膜供給水量の適正化
- 非対称膜（酢酸セルロース中空糸型膜）では圧密化が起こりやすく、定圧運転をしていると透過水量が減少する。架橋芳香族アミド系膜では起こりにくい。

14. RO 膜の保管：SBS 0.05～0.1% 溶液中

15. 膜性能に与える影響

主要な運転条件としては、

- 圧力
- 温度
- 濃度
- 供給水流量
- 回収率

条件	酢酸セルロース膜	複合膜
温度高		• 透過水量：大 • 透過水中塩濃度：大 水の透過量より塩の透過量の増加程度が大きいため
圧力高	• 透過水量：小 圧密化	• 透過水量：大 • 透過水塩濃度：小 水の透過量の増加が塩の透過量程度より大きいため
圧力低		• 透過水量：小 • 透過水中塩濃度：大
化学反応（塩素）	• 高温では耐塩素性の減少	• 劣化

条件	影響
回収率一定、温度：高	• 供給水量：大 • 透過水量、塩濃度共に大
供給水量一定、温度：高	• 回収率：大 透過水量が増加するため

ここで回収率が増加することは濃縮海水の濃度が増加することであり、膜で処理される海水の平均原水濃度、言い換えると浸透圧が増加することになる。

16. 排水処理

(1) 放流海水

- 濃縮水はスケール防止のため硫酸を加えるため pH が低いため、pH 調整を行い、また、ポリアミド系モジュールの場合は残留塩素を除去するため加えた重亜硫酸ソーダの影響で COD が高くなっているため、曝気処理により COD を低減する。

(2) 膜保管廃液処理

- 膜モジュールは重亜硫酸ソーダ溶液で保管する。廃水量は膜の種類により異なるがスパイラル型モジュールの場合約 180 m^3/回。(60 L/element x 3,204 elements)
- 膜保管廃液は一時貯槽に貯え、曝気処理により COD を低減し、苛性ソーダにより pH 調整処理を行い放流。

(3) 膜洗浄廃液処理

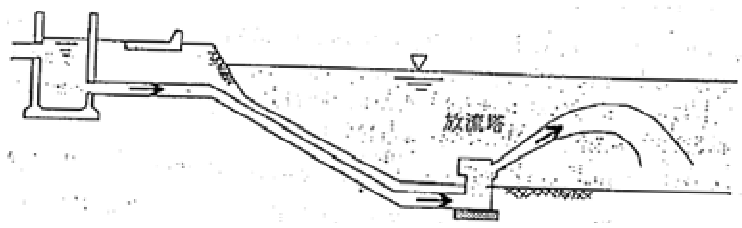
- 膜モジュールの洗浄は、クエン酸 1%を使用するが、廃液 COD は約 5,200 mg/L。SS は 100～500 mg/L, pH 4 の有機廃水。
- 膜洗浄は年数回行なわれ、スパイラル型モジュールでは約 40 m^3/unit（約 5,000 m^3/回）
- 洗浄廃液は苛性ソーダで pH 調整を行なう。

(4) ろ過器逆洗廃液

- 1 回程度/日/器 *(SSinlet= 2mg/L の場合の逆洗間隔としては多すぎる。)*
- 総廃水量：約 5,900 m^3/日 *(3.8 times/total V-media)*
- 排水は色度及び濁度が高い。
- 凝集・沈殿処理必要。

17. 放流設備

- 放流は沖合いの放流地点まで放流管を設置放流する水中放流方式（マルチノズルタイプ）を採用。



(1) 放流地点

放流地点は取水設備の場合と同様の理由により、沖合い約 200m、水深約 13m（放流ノズルは水深約 10m）

(2) 放流管

- 放流管口径：φ700 x 1（流速 2.0 m/sec）
- 材質：鋼管（STPY400）と同じく内面エポキシ樹脂、外面コールタールエナメルの塗装を施す。さらに 20 年耐用の電気防食を施す。

(3) 放流槽：V=210 m^3 x 1

(4) 給水ノズル

陸と反対側の面に 16 個（φ100）最大流速 6.4 m/sec

<u>取水・放流口の位置考慮点</u>

- 干潮時に露出してしまう珊瑚礁を避ける。
- 台風や高潮等の荒天時における低層部の藻類や塵芥の巻上げによる異物混入を防止する位置。
- 潮流により清涼な海水の入れ替えが期待でき滞留の生じない位置。
- 放流口は比重の重い放流海水の影響を取水口に与えない位置（約 3m 以上取水口から下げるなど）

18. 主要機器材質

主要機器材質

機器名称		材質
ろ過器	本体	SS 400/ｺﾞﾑﾗｲﾆﾝｸﾞ
	内部装置	SS 400/ｺﾞﾑﾗｲﾆﾝｸﾞ、SUS-316L
保安ﾌｨﾙﾀｰ	本体	SUS-316L
	内部装置	ﾎﾟﾘﾌﾟﾛﾋﾟﾚﾝ、SUS-316L
高圧ﾎﾟﾝﾌﾟ	本体及び羽根車	二相ｽﾃﾝﾚｽ
	主軸	二相ｽﾃﾝﾚｽ
ｴﾈﾙｷﾞｰ回収ﾀｰﾋﾞﾝ	本体及び羽根車	二相ｽﾃﾝﾚｽ
	主軸	二相ｽﾃﾝﾚｽ
海水ﾎﾟﾝﾌﾟ	本体	二相ｽﾃﾝﾚｽ
	羽根車	SCS14
	主軸	SUS-316L
配管、弁類	高圧系配管	SUS-316L
	高圧系弁類	SCS14
	低圧系配管	SGP/ﾎﾟﾘｴﾁﾚﾝﾗｲﾆﾝｸﾞ、SUS-316L
	低圧系弁類	FCD/ｺﾞﾑﾗｲﾆﾝｸﾞ、SCS-14
硫酸貯槽	貯槽	SS400/PTFE
	注入ﾎﾟﾝﾌﾟ	SCS14/PTFE
塩化第二鉄貯槽	貯槽	FRP
	注入ﾎﾟﾝﾌﾟ	PVC/PTFE
調整水槽		鉄筋ｺﾝｸﾘｰﾄ内面ｴﾎﾟｷｼ塗装
淡水槽		SUS444

（注）PTFE：ﾃﾌﾛﾝ

19. 建屋、設置条件

(1) RO プラントは建屋に入れるのがいい。

- RO ヴエッセル中 RO エレメントは直射日光や温度上昇や予期しない気候条件によるで劣化する。

(2) 固い地盤に設置

(3) 発電機必要

(4) RO プラント内は 35 度以下に保つこと。

(5) 水蒸気が凝結しない条件とすること。

Public Health and the Environment World Health Organization Geneva 2007, Desalination for Safe Water Supply Guidance for the Health and Environmental Aspects Applicable to Desalination

1. Intake facilities

- Intake facility occupies 10 -30 % of the capital cost of entire facility.
- Seawater intake wells are either vertical or horizontal source water collectors, which are typically located in close vicinity to the sea. In the case of aquifers of high porosity and transmissivity, which easily facilitate underground seawater transport such as the limestone formations, seawater of high quality and large quantity may be collected using intake wells located in-land rather than at the shore. (well: less than 20,000 m^3/day)
- Raw sea water collected using wells is usually of better quality in terms of solids, silt, oil & grease, natural organic contamination and aquatic microorganisms, as compared to open seawater intakes. Well intakes may also yield source water of lower salinity than open intakes.

2. Pretreatment

- Generally most membranes require feed water with an SDI of less than 5 (favorably 4) in order to maintain steady and predictable performance.
- Chemicals used for pretreatment prior to membrane desalination

3. Product Water Disinfection

- Usually chlorine dosage used for disinfection is 1.5 to 2.5 mg/litre.
- Usually, sodium hypochlorite solutions decay rapidly over time and loose 10 to 20 % of their strength over a period of 10 to 15 days, especially in warm climates.

4. Concentrates management

- The TDS level of concentrate from seawater desalination plants usually is in a range of 65,000 to 85,000 mg/litre;
- The amount of particles, total suspended solids (TSS) and biological oxidation demand (BOD) in the concentrate is usually below 5 mg/litre because these constituents are removed by the plant's pretreatment system.
- Often scale inhibitors contain phosphates or organic polymers. The concentration of scale inhibitors in the concentrate may reach 20 to 30 mg/litre.
- The elevated salt content of the concentrate samples could interfere with the standard analytical procedures and could often produce erroneous results. Therefore, concentrate

analysis has to be completed by an analytical laboratory experienced with and properly equipped for seawater analysis.

- Many crops and plants cannot tolerate irrigation water that contains over 1000 mg/litre of TDS. However, TDS is not the only parameter of concern in terms of irrigation water quality.
- Boron/borate levels in the effluent could also limit agricultural reuse because borates are herbicides. Chlorides and sodium may also have measurable effects on the irrigated plants. Most plants cannot tolerate chloride levels above 250 mg/litre.

Pretreatment chemicals used in membrane desalination systems

Chemical Type	Purpose of Use	Dose	Application
Scale inhibitors (polyelectrolyte polymer blends).	Increase of solubility of sparingly soluble salts such as calcium and magnesium carbonates and sulfates. Additional chemicals may be used to target specific species, such as silica.	<2-5 mg/litre	Primarily in brackish water desalination and water reclamation using RO and ED/EDR operating at high recoveries.
Acid (usually sulfuric acid).	Reduction of pH for inhibition of scaling and for improved coagulation.	40-50mg/litre as required to reduce pH to ≈6-7	Primarily in seawater RO applications. Not used in all applications.
Coagulant (usually ferric chloride or ferric sulphate).	Improvement of suspended solids removal.	5 -15 mg/litre	Primarily in open intake seawater RO and surface water RO systems.
Flocculant Aid (usually cationic polymer).	Improvement of suspended solids removal.	1-5 mg/litre	Primarily in open intake seawater RO and surface water RO. May only be used intermittently when feed SDI is unusually high.
Oxidizing Agent; most often a form of chlorine. However biocides have found some use, particularly in smaller systems.	To control bio-fouling and aquatic organism growth in the intake and pre-treatment facilities. Chloramines may be used for pre-treatment in reclamation systems and their use should be avoided in seawater desalination systems.	Site specific but may be 3.7mg/litre for 30-120 minutes every 1-5 days	Used for large surface and sea water intakes. Small systems and those using wells, especially those in which source water is anaerobic may not require oxidation.
Reducing agent (usually a form of bisulfite); function of chlorine dosage	To eliminate oxidizing impacts on the RO membrane.	Generally 2 to 3 times higher than oxidizing agent dose	In all membrane processes using polyamide RO membranes (Less common cellulose acetate membranes have greater tolerance of oxidants).
Membrane preservation and sterilization	Off line membranes must be sterilized and preserved. Sterilization may utilize hydrogen peroxide. In some cases acetic acid is also used to create peracetic acid. Preservation most commonly utilizes sodium bisulfite.		

- Chemicals used for pretreatment should be of high-quality ("food-grade")

Residuals from membrane desalination processes

Residual	Source or cause	Application
Backwash Solids/Sludge	Suspended solids in the feed water	Open intake seawater, brackish surface water
Backwash water	From removal of suspended	Open intake seawater, brackish solids in the feed water surface water
Cleaning Solutions	Cleaning of filtration membranes (MF/UF) and process membranes (RO, NF)	Open intake seawater, brackish surface water
Concentrate or blow down (if cross flow)	Filtration membranes operating in a cross flow mode	Open intake seawater, brackish surface water
Spent media (sand, anthracite and/or garnet)	From the removal of suspended solids in the feed water	Open intake seawater, brackish surface water
Cartridge Filters – polypropylene	Final fine filtration prior to RO, periodic replacement	Most membrane desalination processes, except those using MF/UF filtration membranes
MF/UF membranes – polymeric material (polypropylene, polysulphone, polyvinylidene-fluroide (PVDF), cellulose acetate	Membrane replacement for MF/UF systems	Open intake seawater, brackish surface water
RO membranes (polyamide thin film composite, cellulose acetate)	Membrane replacements.	Open intake seawater, brackish surface water

- In general, the membrane pretreatment systems produce 1.5 to 2 times larger volume of spent filter backwash water than the granular media filters. However, contrary to the MF or UF membrane pretreatment filters, the granular media filters require their feed water to be preconditioned with coagulant (usually iron salt) prior to filtration. This typically adds 60 to 80 percent of additional solids load to the spent filter discharge, and therefore its disposal typically results in higher solids handling costs.
- Filter backwash sedimentation tanks are often designed for a retention time of 3 to 4 hours and allow removing more than 90 percent of the backwash solids.

5. Small desalination systems

- Less than 4.000 m^3/day
- Sea based mobile applications that are configured in one skid and often referred to as package plants.
- For small skid mounted systems, it is common to have the pretreatment chemical injection points, cartridge filter, feed pump, and membranes and pressure vessels on the skid.
- Small membrane desalination units may be deigned to operate with smaller size (2-inch ~5 cm or 4-inch ~10 cm) membranes.

6. Chemical Aspects of Desalinated Water

(1) Boron and bromide

In terms of key contaminants of direct interest for health and environment, the most important is probably boron, which can be of significance in reverse osmosis plants since the rejection ratio of boron (probably mostly as borate) is less than that for most other inorganics.

The current WHO guideline value for boron (borate) in drinking water is 0.5 mg/litre, however, this is due to be reconsidered under the rolling revision of the Guidelines (WHO, 2004). Although a health based guideline might possibly be 1 mg/litre or higher, there are plants that are sensitive at 0.5 mg/litre.

The latter might become the principal issue for residual boron i.e. its effect as an herbicide if present in sufficient amount in irrigation water, particularly in areas where rainfall is so low as to not cause leaching of salts from soils.

7. Quality control

Quality control of chemicals, maintenance of monitoring equipment, review of laboratory performance and selection of test methods are important components of monitoring programs.

(1) Additives and chemicals

- to use only chemicals certified for use in the production of drinking water.
- Documented procedures for the control of chemicals, including purchasing, certification, delivery, handling, storage and maintenance should be established and adherence to these procedures should be monitored.

(2) Monitoring equipment, sampling, laboratories and methods of analysis

Monitoring can be undertaken using on-line instruments, field kits and laboratory-based analyses depending upon the application of the data and the precision and accuracy requirements.

- Maintenance and regular calibration of on-line instruments and field kits. Chemicals used in these instruments and kits should be stored under appropriate conditions and results obtained should be periodically checked by comparison with laboratory based analyses.
- Assurance of the accuracy and representative nature of water samples. Guidance on sample collection is provided in International Organization for Standardization (ISO) Standard 5667.
- Regular assessment of the competence and accuracy of testing laboratories. General guidance on quality assurance for analytical laboratories is provided in Water Quality Monitoring (Bartram, 1996).
- An important issue for desalination facilities is the selection of appropriate testing
- Equipment and testing methods. Equipment and methods used to monitor freshwater sources of drinking water may not be suitable or provide accurate results when used with

high salinity water

- Suggested monitoring parameters and frequencies for desalination plants (Small plant)

Component Control measures	**Control measures**	**Operational Parameters**	**Monitoring frequency**
Source	Detect and prevent contamination by sewage (Pathogenic protozoa, viruses, bacteria) (Likelihood of presence based on sanitary inspection)	Enterococci and/or E.coli	Weekly
	Detect and prevent impacts of storm events	Turbidity (used as on-line measurement for process control)	Preferably on-line
	Detect and prevent impacts of microalgae/cyanobacteria	Algal species, including cyanobacteria, dinoflagellates, or chlorophyll as a surrogate	Monthly
	Detect and prevent impacts by industrial discharges (based on an assessment of local conditions)	TOC (if concentrations change investigate sources)	Monthly
		Petroleum oil hydrocarbons/grease including volatile compounds	Yearly
		Industrial chemicals	Monthly
		Radioactivity	Yearly
	Monitoring associated with downstream control measures (pre-treatment and treatment)	Salinity	Daily
		Chloride	Daily
		Sodium	Weekly
		Boron	Yearly
		Bromide	Yearly
		Silica	Daily
		Iron	Weekly
		Manganese	Yearly
		Turbidity	On-line
		Alkalinity	Daily
		pH	On-line
		Temperature	On-line
		Heavy metals	Monthly
		Low solubility chemicals e.g. Ca, , F, Ba, Sr, Mg, ,fluoride, sulfate	Monthly
		Hydrogen sulphide and metal sulphides	Monthly
		Ammonia	Monthly
		Total dissolved solids (TDS)	Daily
Pre-treatment	Detection and prevention of biofouling/scaling/precipitation	SDI	On-line
		Flow rates	On-line
		Conductivity	On-line
		Conductivity/TDS ratios	Daily
		Turbidity after pre-treatment, particle counts	Daily
		pH (if acidification or alkalinisation)	On-line
	Use of additives e.g. antiscalant	Flow and dose rate monitoring	On-line
	Quality control on additives and materials	Test additives and materials; check records	Daily
	Prevention of microbial fouling	Disinfectant residual or ORP	On-line
Process Management	Membranes	Recovery ratio (calculated from flow rates)	Daily

Component Control measures	Control measures	Operational Parameters	Monitoring frequency
Process Management	Membranes	Chemical balance from conductivities and flow rates (calculated)	Monthly
		Trans-membrane pressure	On-line
		Flow meters on permeate and brine	On-line
		Conductivity in permeate and brine	On-line
		TOC (particularly where source water contains elevated microbial contamination)	On-line
Disinfection	Removal of microbial contaminants	Disinfectant dose monitoring	On-line
		Calculate Ct (Values for Inactivation of Viruses (mg-minutes/L) (Concentration x time)	Weekly
		HPC (heterotrophic plate counts)	Yearly
		Disinfection byproducts (including brominated compounds) relevant to the method of disinfection	Monthly
Corrosion inhibition	Reduction of corrosion in distribution systems using inhibitors such as phosphates and silicates	Flow and dose rate monitoring	On-line
	Quality control on additives and materials	Test additives and materials; check records	Daily
Storage Distribution	Preventing microbial and chemical contamination by controlling intrusion through cross connections/backflow or faults in mains or other infrastructure	E.coli	Weekly
		HPC	Monthly
		Turbidity	Daily
		Inspect for system integrity, monitor burst main frequency and repairs	Monthly
		Monitor system leakage	Yearly
	Control of free living microorganisms	HPC	Weekly
		Disinfectant residual (consider persistent disinfectant where Legionella/Naegleria potential considered unacceptable)	Daily
	Prevention of corrosion in storage tanks, long pipes, domestic plumbing	pH	Daily
		Iron	Monthly
		Zinc	Yearly
		Nickel	Yearly
		Copper	Yearly
		Lead (if problem)	Monthly
		Zinc and phosphate (if corrosion inhibitors are used)	Weelky
	Maintain chemical stability after mixing different sources (desalinated/non-desalinated water) or after disinfection	Post mixing or post disinfection monitoring for LSI (Langlier Saturation Index) /CCPP (Calcium Carbonate Precipitation Potential) where mortar linings used or Larson Index where steel or carbon/steel used	Daily
	Disinfection	Disinfection by-products (including brominated compounds)	Monthly

Component Control measures	Control measures	Operational Parameters	Monitoring frequency
Concentrate discharges	In marine or brackish lake environments select discharge points to minimise impacts. Discharge into areas with high levels of mixing or use diffusers to promote mixing	Temperature and DO (thermal processes)	On-line
		pH	On-line
		Salinity	On-line
		Heavy metals/salts	Quarterly
		Additives	Quarterly
		Phosphates and nitrates	Quarterly
Wastewater effluents from pre-treatment facilities or from membrane cleaning	Collect discharges and treat or discharge in accord with requirements set by environment protection agencies	pH	On-line
		Turbidity	On-line
		Suspended solids(SS)	Daily
		Residual disinfectants	Daily
		Iron or aluminum – based on the type of coagulant used	Monthly
		Membrane cleaning agents	On discharge

8. EIA (Standard Approach)

- "Mandatory' or 'positive' lists which include projects always requiring EIA (e.g. major projects, possibly large co-generation plants for electricity and water);
- Project lists which define thresholds and criteria above which EIA is required (e.g. a desalination plant with more than 20,000 m3/day of production capacity);
- 'Exclusion' or 'negative' lists which specify thresholds and criteria below which EIA is never required or below which a simplified EIA procedure applies (e.g. a desalination unit with less than **4,000 m^3/day** of production capacity).

<u>Jørgen Wagner, B. Sc. Chem. Eng, Membrane Filtration Handbook Practical Tips and Hints, Second Edition, Revision 2, November 2001</u>

1. Replacement spiral wound element price.

- Thin-film RO sells for US$ 15 - 25 per m^2 membrane area

(Note) the price varies from country to country. It also depends on the number of elements and element construction.

2. DESIGNING A SYSTEM

1	Select, guess or measure flux in lmh.
2	Calculate the number of m2 membrane area by dividing permeate volume by flux. (15 to 25 lmh)
3	Select a membrane element and find the m2 membrane area per element.
4	Calculate the number of membrane elements: (membrane area) / (membrane area per module)
5	Is the number of modules reasonable? If NO : go back to # 4 If YES : continue to # 6
6	Is there more than one membrane element per housing, e.g. spiral wound elements? If YES : select the number of modules per housing and calculate number of housings. If NO : continue to #7
7	Calculating the number of recirculation loops is a bit tricky, because several parameters are involved in making a decision. If the flux curve is steep, select relatively many loops. If the flux curve flat, select relatively few loops. Select a number of loops and distribute the membrane elements evenly. Are the number of housings/modules big enough to justify the number of loops chosen? (The more expensive a system is, the more loops can be justified in order to increase efficiency and decrease membrane costs.)
8	Find the specified feed flow and typical pressure drop per module. Since all modules/housings in a loop are in parallel, the type of recirculation pump can be chosen. Knowing the volume to be treated and (hopefully) the operating pressure, a feed pump can be chosen.
9	Having selected flow, pressure and pumps, the kW consumed can be calculated.
10	With respect to the cost of a membrane system, only a broad guideline can be provided. For industrial applications: Most spiral wound element systems will cost between US$ 400 and US$ 600 per m^2 installed. These numbers can be doubled for more expensive tubular or fiber systems. For water desalination: Somewhat less expensive than industrial systems.
11	The internal volume is typically 1.5 liters per m^2 membrane area. This figure is important in order to calculate the amount of water used for flushing.
12	Water for flushing is three times the internal volume per flush.
13	Variable costs are mostly US$ 0.4 - 1.0 per m3 permeate. Interest and amortization is the same number as the variable costs. US$ 1 per m3 permeate in total is a good figure.
14	There are no good rules of thumb for floor space. A lab system will usually take 2 -3 m^2. A production system with 1,000 m^2 membrane as spiral wound elements needs 30 square meters of floor space. Compared to most other processes, membrane filtration equipment does not take up much floor space.
15	Membranes are a consumable item. All users want to know how long membranes last, but it varies widely

	from application to application. The following is typical for polymer membranes, but even small variations in product composition can have a big impact on the life time, and so can the plant operator. Water RO, NF 3 to 6 years Water UF 2 to 4 years
16	Typical investment in a complete system, Prices based on incl. pumps, tubes, membranes and controls exchange rates January 2000. US$ per m^2 Spiral wound element water 150 Spiral wound element industrial 350 Tubular 1400 Plate and frame >1700 Fiber system >1700 Ceramic >3000

3. Comparison Between Spiral and Hollow Fiber Membrane Modules

	Spiral wound element	**Hollow Fiber (wider)**	**Hollow Fiber (fine)***
Membrane density (m^2/m^3)	High	Average	Very high
Plant investment	Low	Very high	Medium
Tendency to fouling	Average	Low	Very high
Cleanability	Good	Low	None
Variable costs	Low	Average	Low
Change of membrane (see note 1)	No	No	No
Flow demand	Medium	High	Low
Pre-filter, Other demands	≦50 µm, no fibers	≦100 µm, few fibers	≦5 µm, extreme pre-treatment

Note 1) Membrane systems can be designed in such a way that a change of membrane means a complete change of a major part of the hardware. Most tubular and flat sheet designs are made in such a way that only the membrane is changed, leaving the bulk of the system unchanged.

4. Glass Fiber and Stainless Steel Vessel

	(FRP)	**Stainless Steel**
Pressure	20 mPa	rarely above 8.0 mPa
Temperature	<70°C	<100°C
Side port entry	difficult / rare	easy / standard
End cap entry	standard	non-standard
Sanitary	no	yes (possible)
Price	100%	150 - 200%
2.5", 4.0", 8.0"	water standard	difficult
3.8", 5.8", 6.3"	not available	dairy standard
6.0"	military standard	not used
4.3", 8.3"	not available	Koch dairy standard

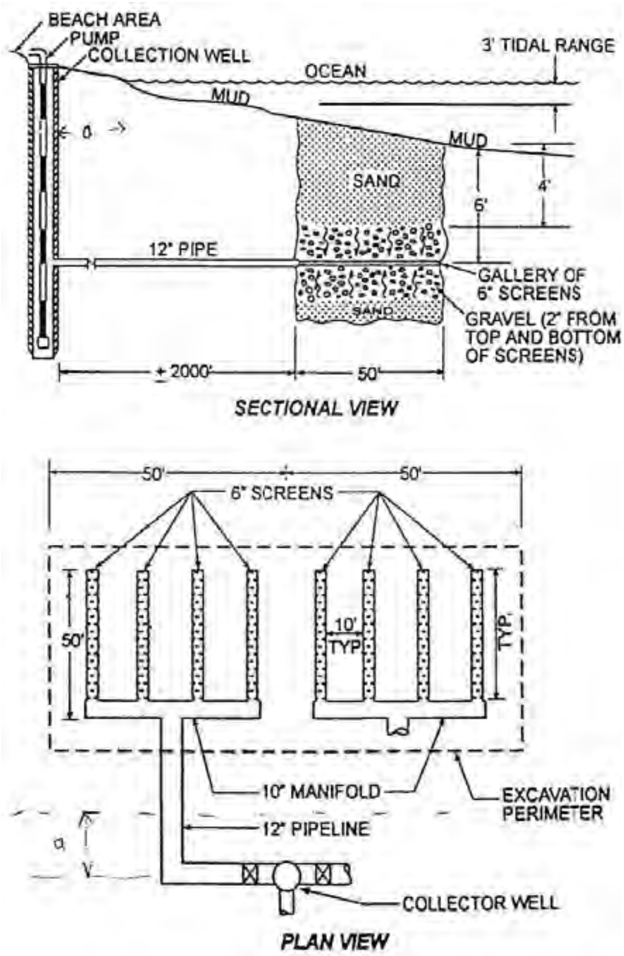
Desalination: A National Perspective Committee on Advancing Desalination Technology, National Research Council ISBN: 0-309-11924-3, 316 pages, 6 x 9, (2008)

1. Average Seawater Quality (mg/L)

TDS	35,000
Chloride	19,000
Sodium	10,500
Sulfate	2,700
Magnesium	1,350
Calcium	410
Potassium	390
Bicarbonate	142
Bromide	67
Strontium	8
Silica	6.4
Boron	4.5
Fluoride	1.3
Nitrate	3.0
Arsenic	0.003
Uranium	0.003
Selenium	0.00009

2. Intake facility

- Design engineering, equipment procurement, and construction spending on intakes and outfalls are estimated to total 5 to 7 percent of capital costs for RO
- Coastal subsurface intakes include beach wells, radial wells, horizontal directionally drilled (also called slant-drilled) wells, and infiltration galleries. By taking advantage of the natural filtration provided by sediments, subsurface seawater intakes can reduce the amount of total organic carbon and total suspended solids, thereby reducing the pretreatment required for membrane-based desalination systems and lowering the associated operations and maintenance costs. Pumping from subsurface intakes may also under some conditions dilute the seawater with less saline groundwater, thereby reducing the total dissolved solids (TDS) in the intake water.
- Vertically drilled beach wells are typically used for small (<19,000 m^3/day; 5 MGD) systems where the local hydrogeology (e.g., aquifer transmissivity) will permit it.
- One of the potential disadvantages of beach wells is that deep wells may result in lower water temperature and thus higher viscosity; hence, higher pressure (and increased energy) will be required to pump the water through the RO



Seabed filtration system.

3. Pre-treatment

- Proper pretreatment of feed water is the most important factor in the successful operation of an RO plant, and pilot testing of the pretreatment process is a critical part of plant design.
- Subsurface seawater intakes, aquatic filter barriers, and deep ocean water intakes can greatly reduce the need for pretreatment.

4. RO membrane

- For seawater RO, the specific energy usage is typically about 3-7 kwh/m^3 with energy recovery devices
- For brackish water RO, energy usage is comparatively lower, about 0.5-3 kwh/m^3
- Predominant Seawater RO Processes

Operating temperature (°C)	<45
Pretreatment requirement [d)]	High
Electrical energy use (kWh/m^3)	2.5-7
Current, typical single train capacity (m^3/d) [a)]	< 20,000
Product water quality (TDS mg/L)	200-500 [b)]

Typical water recovery	35-50%
Reliability [c)]	Moderate

a) For the purpose of this table, a train is considered a process subsystem which includes the high pressure pump, the membrane array(s), energy recovery devices, and associated instrumentation/control.

However, larger facilities may group pumps, membranes, and energy recovery into process or pressure centers to lower capital costs and improve operating costs.

b) Product water quality for RO is a design variable. Each pass through an RO plant typically removes 99 to 99.5 percent of dissolves salts in the feed water. Successive passes using additional membranes can be added along with other design optimizations to achieve permeate with the TDS required for a target water use. Potable water requirements can readily be met with 200-500 mg/L TDS water, which can be achieved from seawater with a single RO pass.

c) and d) : Compared to electro-dialysis or vapor process

5. Energy Recovery Devices.

- Typically 40 to 60 percent of the applied energy in the process can be lost if the concentrate is discharged to atmosphere without any attempt to recover that energy.
- In general, energy recovery devices can recover from 75 to 96 percent of the input energy in the concentrate stream of a seawater RO plant
- Existing energy recovery systems can be divided into two categories.
- The first are devices that transfer the concentrate pressure directly to the feed-stream (e.g., pressure exchanger, work exchanger), which have energy recovery efficiencies of about 95 percent.
- The second category includes devices that transfer concentrate pressure to mechanical power, which is then converted back to feed pressure (e.g., Pelton turbine, Francis turbine, reverse-running pumps). The overall efficiency of energy recovery here is about 74 percent (assuming a Pelton turbine efficiency of around 87 percent coupled with a pump efficiency of 85 percent).

6. Typical NF and RO cleaning formulations.

Foulant	Type Cleaning Solutions
Inorganic saltsa	0.2% HCl
	0.5% H_3PO_4
	2% citric acid
Metal oxides	2% citric acid
	1% $Na_2S_2O_4$
Inorganic colloids (silt)	0.1% NaOH, 0.05% Na dodecyl benzene sulfonate, pH 12
Silica (and metal silicates)	Ammonium bifluoride

	0.1% NaOH, 0.05% Na dodecyl bezene sulfonate, pH 12
Biofilms and organics	Hypochlorite, hydrogen peroxide, 0.1% NaOH, 0.05% Na dodecyl bezene sulfonate, pH 12
	1% sodium tripolyphosphate, 1% trisodium phosphate, 1% sodium EDTA

Source: Dow Chemical

7. Climate Change and Desalination

There seems to be no question that climate change will significantly impact the water resources sector and, as such, will indirectly impact desalinization. A rise in sea level over tens of years may have adverse impacts on coastal aquifers from increased seawater intrusion. Direct impacts of rising ocean levels may over the lifetime of the project have some minor effect on desalination structures built adjacent to coastlines because current sea-level rise is approximately 2 mm/year (United Nations Intergovernmental Panel on Climate Change, 2007). Furthermore, storms associated with climate warming may be of either higher frequency or higher intensity.

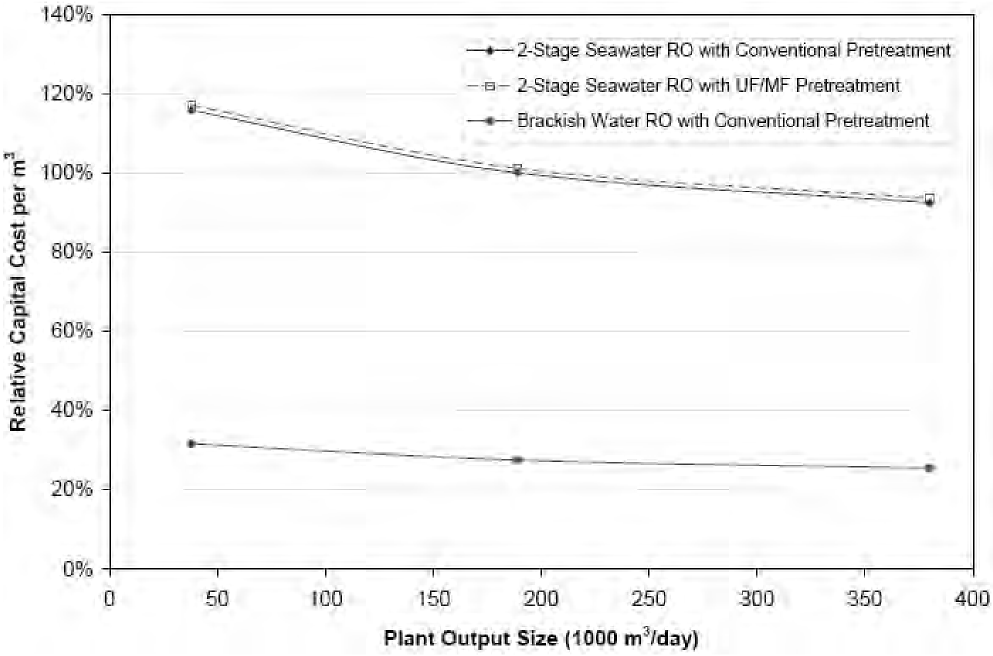
Depending on the location of the intake, the temperature of the water may increase slightly, requiring small changes to the desalination process. Although these direct impacts to desalination structures and processes appear to be small, they should be clearly understood prior to the design of a major desalination facility.

8. The Costs and Benefits of Desalination

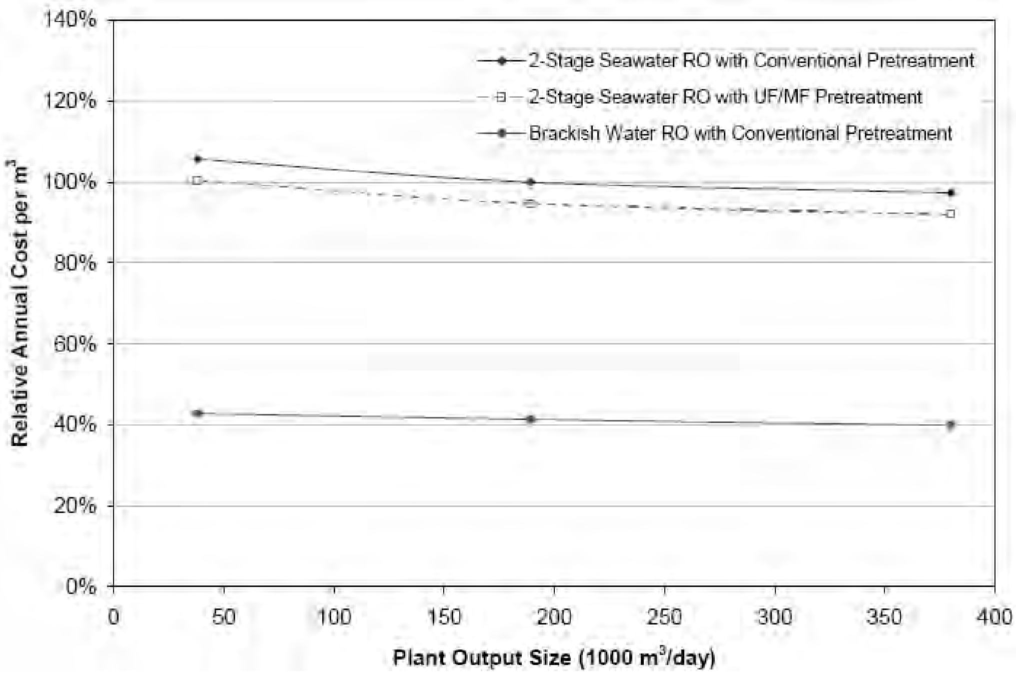
- The costs for the seawater desalination process by RO to be $0.61/m^3. The cost is based on a system of 100,000 m3/day; a normal interest rate of 6 percent; $450 element cost; $0.05/kWh energy cost; assumed electricity use of 4.5 kWh/m^3; and 20-year capital invest period.

Annualized capital costs	0.15
Parts/maintenance	0.03
Chemicals	0.07
Labor	0.10
Membranes (life not specified)	0.03
Electrical energy ($0.05 k/Wh)	0.23
Total ($/m3)	**0.61**

- Bid construction cost for a 3,000 m^3/day (0.8 million gallons per day [MGD]) RO facility was about $26 million, of which approximately $7 million was accounted for by the costs of a brine concentrator
- Impact of Water Source, Scale, and Process Design on Capital Costs (38,000 to 380,000 m^3/day)
- Membrane Life. Membrane costs are now quite modest, ranging from only 3 to 5 percent of annual costs. Extending membrane life is likely to have a very small impact on desalination costs.



Relative capital costs per cubic meter for seawater and brackish water RO desalination according to facility size. Brackish water is 1,000 mg/L TDS(38,000 to 380,000 m^3/day)**.** below 38,000 m^3/day where the costs rise even more dramatically (USBR, 2003)



Effect of facility size, water source, and pretreatment process on relative annual costs per cubic meter for RO plants. The baseline assumptions for this scenario are as follows: energy costs are constant at $0.07/kWh; membrane life is assumed to be 5 years; nominal interest rate is 5 percent; depreciation period is 25 years.

9. Research to Lower the Costs of Desalination

(1) Improve pretreatment for membrane desalination

Pretreatment is necessary to remove potential foulants from the source water, thereby ensuring sustainable operation of the RO membranes at high product water flux and salt rejection. Research to improve the pretreatment process is needed that would develop alternative, cost-effective approaches.

- **Develop more robust, cost-effective pretreatment processes.**

  Membrane fouling is one of the most problematic issues facing seawater desalination. Forms of fouling common with RO membranes are organic fouling, scaling, colloidal fouling, and bio-fouling. All forms of fouling are caused by interactions between the foulant and the membrane surface. Improved pretreatment that minimizes these interactions will reduce irreversible membrane fouling.

  Alteration of solution characteristics can improve the solubility of the foulants, preventing their precipitation or interaction with the membrane surface. Such alteration could be chemical, electrochemical, or physical in nature.

Membranes such as microfiltration (MF) and ultrafiltration (UF) have several advantages over traditional pretreatment (e.g., conventional sand filtration) because they have a smaller footprint, are more efficient in removing smaller foulants, and provide a more stable influent to the RO membranes. Additional potential benefits of MF or UF pretreatment are increased flux, increased recovery, longer membrane life, and decreased cleaning frequency. More research is necessary in order to optimize the pretreatment membranes for more effective removal of foulants to the RO system, to reduce the fouling of the pretreatment membranes, and to improve configuration of the pretreatment membranes to maximize cost reduction.

- **Reduce chemical requirements for pretreatment**.

  Antiscalants, coagulants, and oxidants (such as chlorine) are common chemicals applied in the pretreatment steps for RO membranes. Although these chemicals are added to reduce fouling, they add to the operational costs, can reduce the operating life of membranes, and have to be disposed of properly or they can adversely impact aquatic life. Antiscalants may also enhance bio-fouling, so alternative formulations or approaches should be examined. Research is needed on alternative formulations or approaches (including membrane pretreatment) to reduce the chemical requirements of the pretreatment process, both to reduce overall cost and to decrease the environmental impacts of desalination.

(2) Improve membrane system performance

Sustainable operation of the RO membranes at the designed product water flux and salt rejection is a key to the reduction of desalination process costs. In addition to effective pretreatment, research to optimize the sustained performance of the RO membrane system is needed.

- Develop high-permeability, fouling-resistant, high-rejection, oxidant-resistant membranes. New membrane designs could reduce the treatment costs of desalination by improving membrane permeability and salt rejection while increasing resistance to fouling and membrane oxidation. Current membrane research to reduce fouling includes altering the surface charge, increasing hydrophilicity, adding polymers as a barrier to fouling, and decreasing surface roughness.

  Oxidant-resistant membranes enable feedwater to maintain an oxidant residual that will reduce membrane fouling due to biological growth. Current state-of-the-art thin-film composite desalination membranes are polyamide based and therefore are vulnerable to damage by chlorine or other oxidants. Thus, when an oxiant such as chlorine is added to reduce bio-fouling, dechlorination is necessary to prevent structural damage. Additionally, trace concentrations of chlorine may be present in some feed waters. Cellulose-derivative RO membranes have much higher chlorine tolerance; however, these membranes have a much lower permeability than thinfilm composite membranes and operate under a narrower pH range. Therefore, there is a need to increase the oxidant tolerance of the higher-permeability membranes. Lower risk of premature membrane replacement equates to overall lower operating costs.

  Past efforts to synthesize RO membranes with high permeability often resulted in reduced rejection and selectivity. There is a need to develop RO membranes with high permeability without sacrificing selectivity or rejection efficiency. Recent research on utilizing nanomaterials, such as carbon nanotubes, as a separation barrier suggest the possibility of obtaining water fluxes much higher than that of traditional polymeric membranes.

  The development of membranes that are more resistant to degradation from exposure to cleaning chemicals will extend the useful life of a membrane module. The ability to clean membranes more frequently can also decrease energy usage because membrane fouling results in higher differential pressure loss through the modules. By extending the life of membrane modules, the operating and maintenance cost will be reduced by the associated reduction in membrane replacements required.

- **Optimize membrane system design.**

  With the development of high-flux membranes and larger-diameter membrane modules, new approaches for optimal RO system design are needed to avoid operation under thermodynamic restriction and to ensure equal distribution of flux between the leading and tail elements of the RO system. The key variables for the system design will involve the choice of optimal pressure, the number of stages, and number and size of membrane elements at each stage. An optimal system configuration may also involve hybrid designs where one type of membrane (e.g., intermediate flux, highly foulingresistant) is used in the leading elements followed by high-flux membranes in the subsequent elements. Fouling can be mitigated by maintaining high crossflow velocity; thus, foulingresistant membranes may be better served in the downstream positions where lower crossflow velocity is incurred. Thus, additional engineering research on membrane system design is needed to optimize performance with the objective of reducing costs.

- **Develop lower-cost, corrosion-resistant materials of construction**.
  The duration of equipment life in a desalination plant directly relates to the total costs of the project. Saline and brackish water plants are considered to be a corrosive environment due to the high levels of salts in the raw water. The development and utilization of corrosion-resistant materials will minimize the frequency of equipment or appurtenance replacement, which can significantly reduce the total project costs.

- **Develop ion-selective processes for brackish water**.
  Some slightly brackish waters could be made potable simply though specific removal of certain contaminants, such as nitrate or arsenite, while removing other ions such as sodium, chloride, and bicarbonate at a lower rate.
  High removal rates of all salts are not necessary for such waters. Ion-specific separation processes, such as an ion-selective membrane or a selective ion-exchange resin, should be able to produce potable water at much lower energy costs than those processes that fully desalinate the source water. Ion-selective removal would also create fewer waste materials requiring disposal.
  Ion-selective processes would be useful for mildly brackish groundwater sources with high levels of nitrate, uranium, radium, or arsenic. Such an ion-selective process could also be used to optimize boron removal following RO desalination of seawater.

- **Develop hybrid desalination processes to increase recovery**.
  Overall product water recovery in a desalination plant can be increased through the serial application of more than one desalination process. For example, an RO process could be preceded by a “tight” nanofiltration process, allowing the RO to operate at a higher recovery than it could with less aggressive pretreatment. Other options could be devised, including

hybrid thermal and membrane processes to increase the overall recovery of the process.

The possible hybrid combinations of desalination processes are limited only by ingenuity and identification of economically viable applications. Hybridization also offers opportunities for reducing desalination production costs and expanding the flexibility of operations, especially when collocated with power plants, but hybridization also increases plant complexity and raises challenges in operation and automation.

(3) Improve existing desalination approaches to reduce primary energy use

Energy is one of the largest annual costs in the desalination process. Thus, research to improve the energy efficiency of desalination technologies could make a significant contribution to reducing costs.

- **Develop improved energy recovery technologies and techniques for desalination**.
  Membrane desalination is an energy-intensive process compared to treatment of freshwater sources. Modern energy recovery devices operate at up to 96 percent energy recovery, although these efficiencies are lower at average operating conditions. The energy recovery method in most common use today is the energy recovery (or Pelton) turbine, which achieves about 87 percent efficiency. Many modern plants still use Pelton wheels because of the higher capital cost of isobaric devices. Thus, opportunities exist to improve recovery of energy from the desalination concentrate over a wide operating range and reduce overall energy costs.

- **Research configurations and applications for desalination to utilize low-grade or waste heat**.
  Industrial processes that produce waste or low-grade heat may offer opportunities to lower the operating cost of the desalination process if these heat sources are co-located with desalination facilities. Low-grade heat can be used as an energy source for desalination via commercially available thermal desalination processes. Hybrid membrane-thermal desalination approaches offer additional operational flexibility and opportunities for water production cost savings. Research is needed to examine configurations and applications of current technologies to utilize low-grade or waste heat for desalination.

- **Understand the impact of energy pricing on existing desalination technology over time**.
  Energy is one of the largest components of cost for desalination, and future changes in energy pricing could significantly affect the affordability of desalination. Research is needed to examine to what extent the economic and financial feasibility of desalination may be threatened by the uncertain prospect of energy price increases in the future for typical

desalination plants in the United States. This research should also examine the costs and benefits of capital investments in renewable energy sources.

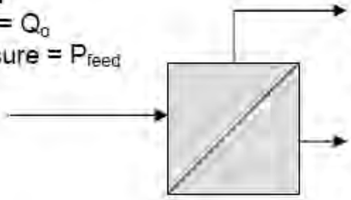
- **Investigate approaches for integrating renewable energy with desalination.**
  Renewable energy sources could help mitigate future increases in energy costs by providing a means to stabilize energy costs for desalination facilities while also reducing the environmental impacts of water production. Research is needed to optimize the potential for coupling various renewable energy applications with desalination.

(4) Develop novel approaches or processes to desalinate water in a way that reduces primary energy use

Because the energy of RO is only twice the minimum energy of desalination, even novel technologies are unlikely to create step change (>25 percent) reductions in absolute energy consumption compared to the best current technology. Instead, substantial reductions in the energy costs of desalination are more likely to come through the development of novel approaches or processes that optimize the use of low-grade heat. Several innovative desalination technologies that are the focus of ongoing research, such as forward osmosis, dewvaporation, and membrane distillation, have the capacity to use low-grade heat as an energy source. Research into the specific incorporation of waste or low-grade heat into these or other innovative processes could greatly reduce the amount of primary energy required for desalination and, thus, overall desalination costs.

Mass and Energy Balance on Reverse Osmosis System:

Feed:
Flow = Q_o
Pressure = P_{feed}



Concentrate:
Flow (@ 40% Recovery) = $0.6Q_o$
Pressure = P_R
Energy ~ $0.6Q_o(P_{feed}+P_R)/2$ x (1-fraction of Energy Recovered)

Permeate:
Flow (@ 40% Recovery) = $0.4Q_o$
Pressure = P_P
Energy ~ $0.4Q_o((P_{feed}+P_R)/2 - P_P)$

Following is an approximation of the energy used in a typical RO process operating at 40% recovery and an energy recovery device operating at an efficiency of η_{eff}

$$\text{Energy Used} \cong 0.6Q_O \frac{(P_O + P_R)}{2}(1-\eta_{eff}) + 0.4Q_O(\frac{P_O + P_R}{2} - P_P).$$

Making the assumption that P_p is significantly less than the applied average operating pressure,

(i.e., that $P_P = 14.7$ at atmospheric pressure and

because this term is << $\frac{P_0 + P_R}{2}$ this term is presumed to be negligible and $\cong 0$)

and taking a ratio of a future, new energy balance based on a new membrane with new properties relative to a baseline energy balance we get the following equation:

$$\frac{\text{Energy}_{\text{New}}}{\text{Energy}_{\text{Baseline}}} = \frac{0.6Q_O \frac{(P_{ON} + P_{RN})}{2}(1-\eta_{eff}) + 0.4Q_O \frac{(P_{ON} + P_{RN})}{2}}{0.6Q_O \frac{(P_O + P_R)}{2}(1-\eta_{eff}) + 0.4Q_O \frac{(P_O + P_R)}{2}}$$

This equation can be factored as follows,

$$\frac{\text{Energy}_{\text{New}}}{\text{Energy}_{\text{Baseline}}} = \frac{\frac{(P_{ON} + P_{RN})}{2}(0.6Q_O(1-\eta_{eff}) + 0.4Q_O)}{\frac{(P_O + P_R)}{2}(0.6Q_O(1-\eta_{eff}) + 0.4Q_O)}$$

and further simplified to the following equation:

$$\frac{\text{Energy}_{\text{New}}}{\text{Energy}_{\text{Baseline}}} = \frac{\dfrac{(P_{ON} + P_{RN})}{2}}{\dfrac{(P_O + P_R)}{2}} = \frac{P_{\text{Avg. Applied New}}}{P_{\text{Avg. Applied Baseline}}} = \frac{P_{\text{Avg Driving New}} + P_{\text{Osmotic}}}{P_{\text{Avg. Applied Baseline}} + P_{\text{Osmotic}}}$$

As shown above, the average applied pressure can be broken down into two components: (1) the osmotic pressure required to overcome the osmotic energy barrier and (2) the net driving pressure required to overcome the native resistance of the membrane permeability.

For the purposes of illustrating the sensitivity of membrane permeability on potential future energy reductions, the following system operating data is taken from "The Guidebook to Membrane Desalination Technology," p. 472, Balaban Desalination Publications, 2007:

Average Total Dissolved Solids (TDS): 59,921 ppm

Temperature: 26 °C

$P_{\text{Avg Osmotic}}$ = 656 psi (at the average TDS of 59,053 ppm and Temperature of 28 °C; calculated by using the Van't Hoff equation)

$P_{\text{Avg Applied Baseline}}$ = 936 psi (P_{feed} = 947 psi; $P_{\text{concentrate}}$ = 924 psi)

$P_{\text{Avg Driving Baseline}}$ = (936 – 656) = 280 psi

$P_{\text{Avg Driving New}}$ = 0.5 x 280 = 140 psi (Reflecting a doubling of membrane permeability)

Assuming that the membrane permeability can be doubled without sacrificing salt rejection, the average driving pressure for the new membrane can be reduced by 50 percent (shown above).

Substituting these values into the equation above,

$$\frac{\text{Energy}_{\text{New}}}{\text{Energy}_{\text{Baseline}}} = \frac{P_{\text{Avg. Driving New}} + P_{\text{Osmotic}}}{P_{\text{Avg Applied Baseline}} + P_{\text{Osmotic}}} = \frac{140 + 656}{280 + 656} = 0.85$$

results in an energy ratio of new to baseline of 0.85. This translates into a net reduction of energy equal to 15 percent from today's baseline

海水淡水化技術評価委員会；海水淡水化技術開発
（逆浸透法海水淡水化技術開発調査）中間報告書；1998 年 10 月

1. 海水汚染対策

- 汚染が進んだ海水(最大濁度 12、SDI 値 6.5 程度、油分最大 10 ppm) でも凝集剤無注入で SDI4 以下を達成するには膜ろ過前処理を使用する。
- 海水中油分が 1mg/L 以下では油分による RO 膜の急激な劣化、性能低下は見られない。
  - ➢ 0.1mg/L 以下の油分は蛍光光度法使用

2. 高回収 RO 膜システム

- NF によるスケール防止と高圧 RO 膜による高回収率を達成し、トータルコスト 25%削減を目指す。

<u>NF（低圧 RO）膜</u>

- ➢ 1 価イオン（Na, Cl 等）の除去率は小さいが、多価イオン（Ca, Mg, SO_4^{2} 等：スケール成分）の除去率は高く、微粒子・細菌のほか有機物除去も可能
- ➢ 透過水量は低圧（1.5MPa 以下）で透過水量も大きく、ホウ素除去にも有効。

3. ホウ素除去

- 水道水水質監視項目指針値（1mg/L 以下）にするのは、ﾎﾟﾘｱﾐﾄﾞ系合成複合膜低圧 RO 膜 2 段脱塩で可能。pH7～8 及び 10 以上では処理水ホウ素はそれぞれ 0.2、0.6mg/L 以下となる。

4. 前処理で膜処理を使用する際の留意事項

- 約 1,000～2,000 時間の連続運転ができる実用的ろ過速度
  MF 膜(0.1～0.2μ,)：　　0.5～1.0m/day（SDI 値：4 以下）
  UF 膜：　　0.6～0.6m/day（SDI 値：2 以下）
- ろ過抵抗 100kPa 以下で化学洗浄を行なう。

<u>**RO Desalination Plant for Imperial Palce Hotel by Asian Industry Inc.**</u>

2 x 500 m^3/day sea water desalination, consisting of ;

1. Specifications

(1) Wells pumps (2+1)

- For transferring the sea water into the feed water tank
- Type: Grundfos SP-R, submergible centrifugal pumps
- Material: Stainless steel
- Specification: 5 -60 m^3/hr x 150 – 400 kPa x 9 kW x 3 phase x 380 V x 60 Hz
- Quantity: (2+1)
- Connection Outlet: Rp 4 inch

(2) Feed water tank 1

- For storage of well water
- Volume: 200 m^3
- All measurement devices are included in scope of supply
- Civil works to be supplied locally

(3) Feed pumps

- For providing flow and pressure from the feed water tank to the downstream equipment
- Type: KSB Etanorm, centrifugal pumps, bronze alloy
- Specification: 5 -60 m^3/hr x 350-550 kPa x 11 kW x 3 phase x 380 V x 60 Hz
- Quantity: (2+1)
- Connection inlet/outlet: DN65/DN40

(4) Prominent Media Filters

- For the removal of turbidity from the feed water
- Type: KF-4882 SIA
- Specification

Dimension	Dia 1,300 x 2,500H
Filter media	Support: gravel 3 -5 mm x 130 mmH
	Filter: sand 1 -2 mm x 820 mmH
Flow rate	13.9 m^3/hr (LV 10 m/hr).
Operating pressure	300 kPa (Min.), 800 kPa (Max.)
Operating temperature	35 ℃ max.

Air temperature	40 ℃ max.
Backwash	19 m^3/hr (LV 14 m/hr)
Backwash pressure loss	80 kPa
Backwash period	5- 20 minuets
Backwash volume	1.6 – 6.4 m^3

- Materials

Pressure vessel x 1	Fiber glass
Control valves x 1	ABS + fiber glass type SIATA
Pressure gauges x 2	Stainless steel (316 or similar)

- Quantity 2 (parallel)
- Notes
  - Including distributer for raw water, ascending pipe and sieve for filtered water, support gravel and filter sand (both to be filled into pressure vessel at site
  - Electronic controller for programming of backwash cycles as well as backwash periods
  - Limit switch for switching off the RO-unit during backwashing
  - Unit pre assembled and ready for connection
  - Space for installation for one filter is 2,500H x 1,600x 1,600
  - Gross weight on filter 1,700 kg

(5) Prominent dosing system

- For injection of AntiScalant to prevent membrane scaling
- Type Bt4a
- Specifications

Capacity	0.74 l/hr
Back pressure	max.1 MPa
Volume of dosing tank	60 l
Suction lance	6 x 4 mm
Dosing hose	6 x 4 mm
Motor	0.02 kW x 230 V x 60 Hz

- Materials

Dosing tank x 1	PE
Suction launce x 1	PP with 2 stages float switch fault indicator
Injection valve x 1	PVC
Meter dosing hose x 5	PE

- Quantity 1

(6) Prominent Inline mixer

- For optimizing of chemical reactions in the feed water
- Type PE-DN 100
- Specifications

  Total capacity mixture 50 m^3/hr

  Pressure loss 10 kPa

  Connection DN 100

  Dimension ϕ 110 x 500 mm

  Material construction PVC
- Quantity 1

(7) Prominent ORP-controlling "OPR"-measurement of raw water"

- For control and monitoring of the final ORP value of the raw water
- Type D1Ca OPR

  Redox controller Type D1CA x 1

  DGM in –line probe housing x 1

  Redox recorder x 1
- Specifications

  Power supply 230 v x 60Hz

  Measure range 1,000 to + 1,000 (mV)

  Relay control alarm relay

  Ambient temperature 0.5 -50 ℃

  Dimensions 125^W x 75^D x 135^H
- Quantity 1

(8) Prominent pH-controlling "pH"-measurement of raw water"

- For control and monitoring of the pH value of the raw water
- Type D1Ca pH

  pH controller Type D1CA x 1

  DGM in line probe hosing x 1

  pH sensor x 1
- Specifications

  Power supply 230 v x 60Hz

  Measure range 1 to 12

  Relay control alarm relay

  Ambient temperature 0.5 -50 ℃

  Dimensions 125^W x 75^D x 135^H
- Quantity 1

- Quantity 1

(9) Prominent conductivity-controller ”Cond-measurement of raw water”

- For control and monitoring of the conductivity of the raw water
- Type D1Ca Cond

  Conductivity controller Type D1CA

  DGM in –line probe housing x 1

  Inductive conductivity sensor x 1
- Specifications

  Power supply 230 v x 60Hz

  Measure range 0.2 to 1,000 mS/cm

  Relay control alarm relay

  Ambient temperature 0.5 -50 ℃

  Dimensions 125^W x 75^D x 135^H
- Quantity 1

(10) Prominent RO unit (20 m^3/hr/unit) incl. AC for control cabinet

- For desalination of sea water
- Type Pro 1700SW ERI
- Quantity 1

(11) Prominent Dosing Station

- For injection of NaOCl
- Type Bt4a
- Specifications

  Capacity approx. 0.74 l/hr

  Back pressure max. 1 MPa

  Volume of dosing tank 60 l

  Suction lance 6 x 4 mm

  Dosing hose 6 x 4 mm

  Motor 0.02 kW x 230 V x 60 Hz
- Materials

  Dosing tank x 1 PE

  Suction launce x 1 PP with 2 stages float switch fault indicator

  Injection valve x 1 PVC

  Meter dosing hose x 5 PE
- Quantity 1

(12) Prominent Dosing Station

- For injection of Na_2CO_3

- Type Bt4a
- Specifications

Capacity	approx. 12.3 l/hr
Back pressure	max. 0.4 MPa
Volume of dosing tank	1,000 l
Suction lance	8 x 5 mm
Dosing hose	8 x 5 mm
Motor	0.02 kW x 230 V x 60 Hz

- Materials

Dosing tank x 1	PE
Suction launce x 1	PP with 2 stages float switch fault indicator
Injection valve x 1	PVC
Meter dosing hose x 5	PE

- Quantity 1

(13) Prominent Dosing Station

- For injection of $CaCl_2$
- Type Bt4a
- Specifications

Capacity	approx. 12.3 l/hr
Back pressure	max. 0.4 MPa
Volume of dosing tank	1,000 l
Suction lance	8 x 5 mm
Dosing hose	8 x 5 mm
Motor	0.02 kW x 230 V x 60 Hz

- Materials

Dosing tank x 1	PE
Suction launce x 1	PP with 2 stages float switch fault indicator
Injection valve x 1	PVC
Meter dosing hose x 5	PE

- Quantity 1

(14) Prominent Inline mixer

- For optimizing of chemical reactions in the permeate line
- Type PE-DN 65
- Specifications

Total capacity mixture	20 m^3/hr
Pressure loss	11 kPa

Connection	DN 65
Dimension	ϕ 75 x 500 mm

- Material construction — PVC
- Quantity — 1

(15) Prominent pH- controller

- For control and monitoring of the pH values of the permeate
- Type — D1Ca pH incl. Accessories

pH controller Type D1CA	x 1
DGM in line probe hosing	x 1
pH sensor	x 1

- Specifications

Power supply	230 v x 60Hz
Measure range	1 to 12
Relay control	alarm relay
Ambient temperature	0.5 -50 ℃

- Dimensions — 125^{W} x 75^{D} x 135^{H}
- Quantity — 1

(16) Prominent conductivity -controller

- For control and monitoring of the conductivity value of the permeate
- Type — D1Ca cond. incl. Accessories

Conductivity controller Type D1CA	x 1
DGM in line probe hosing	x 1
Conductive conductivity sensor	x 1

- Specifications

Power supply	230 v x 60Hz
Measure range	0.01 to 20 (mS/cm)
Relay control	alarm relay
Ambient temperature	0.5 -50 ℃

- Dimensions — 125^{W} x 75^{D} x 135^{H}
- Quantity — 1

(17) Permeate storage tank

- For storage of product water
- Volume (min.) — 800 m^3
- Quantity — 1
- Civil works construction to be supplied locally
- All necessary level measurements, scope of supply

(18) Prominent central control panel (each line independent)

- For control and monitoring of the positions 1-18
- Type PM CCP17
- Quantity 1

(19) Product pumps

- For transferring the product water into the hotel distribution
- Type Grundfos CR
- Specifications

Flow	5-15 m^3/hr
Pressure	320-570 kPa
Power supply	5.5 kW x 380 V x 3 phases x 60 Hz
Connection (Inlet/Outlet)	DN 65/DN65

- Material Stainless steel DIN 1.4401
- Quantity (3+1)

2. Price 780,000 US $

- Deliver on site, CIF Cebu
- Including transport, installation and start up service
- Exclusions;
  - Raw water tank
  - Product water storage tank
  - Building permits, DENR license
  - Main power supply to the plant room
  - Construction of civil works and drainage

3. Delivery time Approx. 12- 14 weeks after clarification of all technical and commercial issues

Notes:

1. The sea water RO design is based on a theoretically feed water analysis with a TDS of 35,000 mg/l and a temperature of 25 ℃. The feed water entering the RO-unit s beach well sea water or sea water coming from an open intake which is suitably pre-treated.

In general the feed water entering the Ro-unit should be filtered, chemically conditioned, have a COD<5 mg/l, fouling index≦3.0, max turbidity 0.5 NTU, and it is to be free of oil, chlorine, H_2S and colloidal SiO_2. Further parameters such as Ba, Sr, Fe, Mn Al are to be in acceptance non-scaling concentrations.

2. If the sea water comes from a good maintained well, the following pre- and post treatment are recommended;

- Homogenous distribution of the injected chemicals via inline mixer
- Filtration over 25 μm or a sand filter for removal of SS (in addition to 5 μm filter on RO)
- Injection of anti-scalant (e.g. Permatreat) to prevent precipitation of sparingly soluble salt in the sea water
- Monitoring of the redox potential, pH and conductivity of the sea water via suitable controllers
- Injection of NaOCl or $Ca(OCl)_2$ to disinfect the permeate of RO
- Injection of (Na_2CO_3 + $CaCl_2$) to adjust the pH and hardness of the permeate according to WHO
- Monitoring of the pH and conductivity of the final drinking water via suitable controllers

3. The daily consumption of anto-scalant (e.g. Permatreat 100 for sea water) can be calculated after provision of a detailed feed water analysis.

4. The salt rejection of the proposed RO is approximately 99 % for the sea water desalination unit, perfect drinking water quality will be produced having salinities well under 500 mg/l. However, due to the low permeate pH and low hardness it is necessary and recommended to adjust the pH and the hardness of the final drinking water, eg. by injection of Na_2CO_3 and $CaCl_2$, or by filtration over dolomite. Finally, a disinfection e.g. by NaOCl or chlorine dioxide should be done before it is distributed into the hotel.

5. Proposed RO units are supposed to run at a recovery of 40 % (sea water desalination unit). This might be able to be optimized after provision of a detailed feed water nalysis.

6. The estimated energy consumption of the above sea water desalination RO-Unit is to be expected around 2.6 to 3 kWh/m3 of permeate only, because the state of the energy recovery by pressure exchanger is applied.

7. Control cabinet for the power distribution and control of the complete for each version as offered above.

8. At least 300 kPa is required directly before the RO plants.

9. Prominent Sea Water Desalination RO-Unit Type PRO SW ERI

For desalination of filtered and chemically conditioned sea water according to theoretically created sea water analysis with a max. feed water salinity (TDS) of 35,000 mg/l at a temperature of 25 ℃ (to be free of residual Chlorine, colloidal SiO2, and H2S, COD < 5 mg/l, fouling index ≦3.0 and max. turbidity 0.5 NTU. Further parameters such as Ba, Sr, Fe, Mn, Al are to be in accordance to WHO guidelines), consiting of;

- Compact frame made of stainless steel x 1
- Front table for control instruments mad of PP x 1
- Pre-filter made of PP incl. filter bag 5 μm x 1
- Set of glycerol filled pressure gauges made of stainless steel x 1
- Motor valve for raw water made of PES x 1
- Set of check valves made of PVC + stainless steel x 1
- Pressure switch for raw water x 1
- Thermometer made of stainless steel x 1
- High pressure axial piston pumps in parallel operation brand new Danfoss made of duplex and super duplex stainless steel x1
- **Set (5 pieces) of pressure vessels mad of glass fiber**
- **Set (30 pieces) of membrane elements made of composite membrane (PE, PS, PA*) x 1**
- **Pressure exchanger incl. booster pump and incl. variable frequency drive for energy recovery from brine stream x 1**
- Magnetic inductive flow meters made of neoprene coated mild steel for flow on pressure exchanger low and high pressure side x 2

- Variable area type flow meter for permeate and concentrate flow made of polyamide x 2
- Set of sampling valves made of PVC and stainless steel x 1
- **CIP system** for chemical cleaning, disinfecting or stand still conservation of modules and piping incl. pump made of stainless steel, cartridge filters made of PP, tank made of PE, 2 –way valves and drain valve x 1
- **System for automatic filling of cleaning tank and rinsing of membranes by permeate at every unit shut off** x 1
- Interconnecting piping made of PVC, stainless steel DIN 1.4539 or equal at high-pressure side x 1
- **Air conditioned micro-processor control panel** according to EN 60204, DIN VDE 0113 standard-protection class IP 54 incl.
  - backlit graphical display with real text messages, digital conductivity meter, adjustable limit values,
  - operation and malfunction real text messages and LEDs,
    - main switch,
    - menue for activation of automatic operation and cleaning or disinfecting,
    - 1 potential-free contact for remote alarm,
    - terminals for pre-treatment units as softner, dosing pumps, hardness control as well as level control for permeate tank

Note:
* PE = Polyester, PS=Polysulfon, PA=Polyamide; PP=Polypropylene

10. Technical Data of Prominent Sea Water Desalination RO-Unit Pro SW ERI per unit

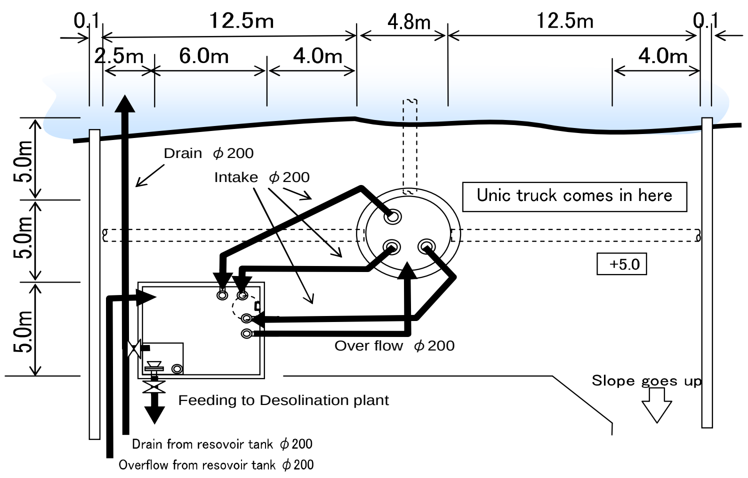
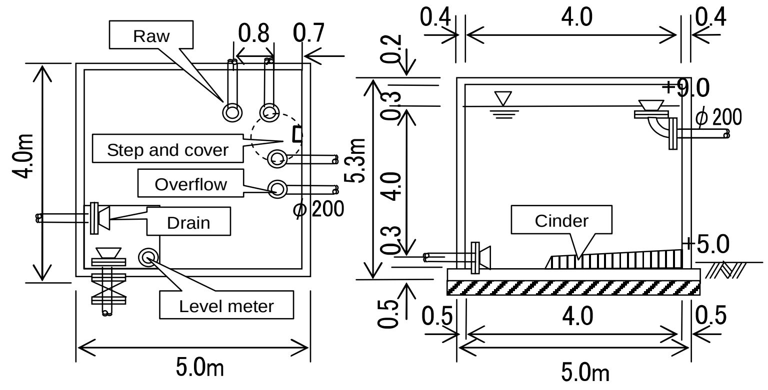
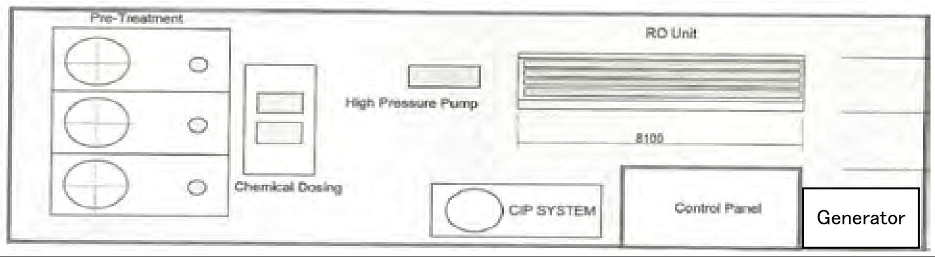
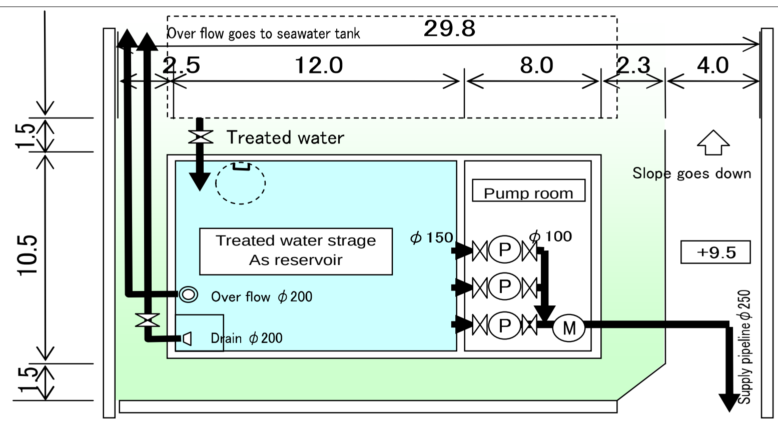
• Permeate flow rate at 25 ℃	Approx. 20.8 m^3/hr (16.7 m^3/day/element)
• Operating pressure	Approx. 6.3 MPa
• Recovery*	Max. 40 (%)
• Raw water consumption	Approx. 50 (m^3/hr)
• Required raw water pressure (min./max.)	0.3/0.6 MPa
• Rejection rate	99 %
• Main supply	380 v x 60 Hz
• Power installed	55 + 7.5 kW
• R.O power/m^3	2.2 kWh
• Connections: Raw water, permeate, concentrate	DN 100, 65, 80

- Dimensions of RO frame $7{,}000^{W} \times 1{,}400^{D} \times 2{,}200^{H}$
- Dimensions filter frame $2{,}500^{W} \times 2{,}500_{D} \times 1{,}800^{H}$
- Dimensions cleaning tank $\phi\ 1{,}100 \times 1{,}720^{H}$

Note:

- Prominent RO units are produced according to EC (European Community) standards and will be delivered incl. EC conformity declaration as well as CE (Certificate European) plate.
- The max. recovery can only be adjusted in case of best water quality, fouling index $\leqq$ 3.0 problem free operation, and according to the needed permeate quality.

Cost Estimation and Project Components

No.	Facilities	Specifications	Image
1	Well	ϕ 3,000 to 4,000 diameter well Seawater Pump ϕ 200 x 3 Porus concrete pipe	
2	Intake Pipe	Intake: PVC ϕ 200 x 3, L=30m x3 Overflow: PVC φ200 x 1, L=30m Flexible connecter, Air valve, Butterfly valve	
3	Raw Seawater Tank	L4.0m x B5.0m x H5.3m Waterproofing painting Butterfly valve, Flexible Connecter, Drain pipe ϕ 200,L=20m	
4	RO Desalination Facility	**$3,000m^3$/day RO unit** Pre-treatment unit Chemical dosing unit High pressure pump CIP system	See plan for details 
5	Electricity and Generator Facility	Electricity panels (No.1 LV, No.2 LV, Static capacitor, Intake pump, Distribution pump, Chemical dosing) Backup generator	
6	Building	RO desalination plant building Electricity and generator room Control room or adminstration room	See plan for details
7	Treated Water Tank and Pump Room	L12.0m x B10.5m x H5.3m Waterproofing painting Pump room L8.0m x B10.5m x H5.3m Flexible connecter, Drain pipe ϕ 200,L=100m Overflow pipeφ200,L=80m	
8	Distribution Pipe and Pump	PVC pipe ϕ 250, L=200m Distribution pump, 1.83～0.85m3/min, h=27～48m Flow meter for ϕ 250	
9	Waste water tank	L4.0m x B5.0m x H5.3m Waterproofing painting Butterfly valve, Flexible connecter, Drain pipe ϕ 200,L=20m	Almost same as 3. Influent tank
10	Discharge Pipe	PVC pipe ϕ 300, L=700m Distribution outlet, Butterfly valve, Flexible connecter	See plan for details
11	Pavement etc.	Administration road Gravel and asphalt pavement	See plan for details
Others	Chemicals and Analysis Machinery	FI (SDI), pH, Turbidity, Residual chlorine, Electric conductivity, ORP meter, Anthracite, Sand, NaClO, etc.	-
	Design and management	Construction management, Operation test and training, Soft componet	-
Total			
Contingency 8%			
VAT 12%			**MCWD responsibility**
Grand Total			
O&M Cost (per year)		Including RO exchange, Chemicals, Electricity, Manning, Sand and Anthracite exchange, Cartridge filter exchange and Repair cost 5% Initial	**MCWD responsiblity,** Unit cost $50Php/m^3$ Note: RO excnage will be every 5 years (20% per year)

項　　目			備考
土木建築関係建設費			
内訳	1	井戸	
	2	導水管	
	3	原水貯留槽	
	6	建屋	
	7	浄水貯留槽	
	8	配水管	
	9	排水貯留槽	
	10	排水管	
	11	場内整備工	
①	直接工事費計		
②	共通仮設費		①×0.20
③	現場管理費		①×0.20
④	一般管理費		①×0.10
合計（①＋②＋③＋④）			
機械電気関係建設費			
内訳	4	RO施設	
	5	受変電、自家発施設	
⑤	直接工事費計		
⑥	共通仮設費		⑤×0.10
⑦	現場管理費		⑤×0.10
⑧	一般管理費		⑤×0.10
合計（⑤＋⑥＋⑦＋⑧）			
建設費合計			
機材調達費			
⑨	消耗品、薬品等		
⑩	機材費（水質分析機器等）		
合計（⑨＋⑩）			
設計管理費			
⑪	施工管理費		
⑫	試運転費、運転指導費		
⑬	ソフトコンポーネント費		
合計(⑪＋⑫＋⑬)			
本工事費			
予備費、本工事費の8%			
概算事業費(VATなし)			
VAT、上記の12%			
概算事業費(VAT込)			

Well

Exchange rate
1.995

No.	Item	Q-ty	Cost
1	Drilling Works		
	ϕ 3,000-4,000		
	15m x 1	15 m	
2	Well Logging & Casing Installation		
		1 set	
3	Gravel Packing & Seal	1 set	
4	Surface Sealing with cement	1 set	
	Sub-total		
5	Sea water Pump (submarged type)		
		3 set	
6	Pump Installation		
	Footstool, etc.		
		3 set	
7	Well Development ＆ Pumping Test		
		1 set	
8	Transportation (to and return)		
		1 set	
9	Porous concrete pipe		
	ϕ 300mm x 10m x 2 pipes	20 m	
Subtotal		1 set	
10	Others (Level meter, Cover, Step、10% of above)		
	Total		

Intake pipe, ϕ 200 x 3

Exchange rate
1.995

No.	Item		Q-ty	Cost
1	PVC Pipe			
		L=30m		
		ϕ 200 x 3	90 m	
2	Overflow Pipe	L=30m		
		ϕ 200 x 1	30 m	
3	Flexible Connecter	ϕ 200		
		Twin sphere	8 set	
4	Air Valve complete set			
		Assembly		
		1set stand-by	4 set	
5	Butterfly valve			
		ϕ 200, Assembly		
		1set stand-by	4 set	
Subtotal				
6	Others	10% of above		
	(PVC pipe coating for sun protect, etc.)		1 set	
	Total			

Raw Seawater Tank

Exchange rate
1.995

No.	Item		Q-ty	Cost
1	Earthwork			
		Back-hoe	50 m^3	
		Backfilling Manpower	20 m^3	
2	Gravel Base		9 m^3	
	Mortar		5 m^3	
			1 set	
3	Rainforced Concrete			
		4.0m x 5.0m x 5.3m		
			50 m^3	
4	Form work			
		Assembly	200 m^2	
5	Waterproofing painting			
			100 m^2	
6	Pipe work			
	Enveded pipe	ϕ 200 x 5set		
		ϕ 300 x 1 set	6 set	
7	Butterfly valve			
		Assembly		
		ϕ 300 x 1 set	1 set	
8	Flexible Connecter	ϕ 200		
		Twin sphere	3 set	
9	Pipe work	Drain pipe		
		L=20m		
		ϕ 300 x 2 set	40 m	
Subtotal				
10	Others (Manhole, Water level meter, etc.)			
		10% of Above	1 set	
		Total		

RO desalination plant

Exchange rate
1.995

No.	Item	Q-ty	Cost
1			
	1000m3/day x 3 unit	3 unit	
	Total		

Electricity, Generation facility

Exchange rate
1.995

No.	Item	Q-ty	Cost
1	Backup Generator		
	1,000kVA, Mafler	1 set	
2	Electricity Panels		
	No.1 LV, No.2 LV, Static Capacitor, Intake Pump,		
	Distribution Pump, Chemical dosing	1 set	
Subtotal			
3	The establishment costs		
	35% of above subtotal		
	Total		

RO, Electricity and Generator Building

Exchange rate
1.995

No.	Item	Q-ty	Cost
1	Earthwork		
	Back-hoe	3,000 m^3	
	Backfilling Manpower	500 m^3	
2	RO desalination plant		
		750 m^2	
3	Electricity and Generator Room		
		50 m^2	
4	Control room or Adminstration room		
		50 m^2	
5	Administration room etc.		
		100 m^2	
	Total		

Treated Water Tank

Exchange rate
1.995

No.	Item		Q-ty	Cost
1	Earthwork			
		Back-hoe	170 m^3	
		Backfilling Manpower	60 m^3	
2	Rainforced Concrete			
	Tank	12 x 10.5 x 5.3m		
	Pump room	8 x 10.5 x 5.3m	290 m^3	
3	Form work			
		Assembly	550 m^2	
4	Flexible Connecter	ϕ 250	1	
		ϕ 200	2	
		Assembly		
5	Pipe work			
	Enveded pipe	ϕ 150		
		ϕ 200		
		Assembly	6 set	
6	Waterproofing painting			
			400 m^2	
7	Drain from Resovoir tank			
		ϕ 200		
			100 m	
8	Overflow from Resovoir tank			
		ϕ 200		
			80 m	
Subtotal				
9	Others (Manhole, Water level meter, etc.)			
		10% of Above	1 set	
		Total		

Distribution pipe ϕ 250 x 1, Distribution Pump

Exchange rate
1.995

No.	Item		Q-ty	Cost
1	PVC Pipe			
		L=200m		
		ϕ 250 x 1	200 m	
2	Flexible Pipe	ϕ 250		
		Assembly	1 set	
3	Air valve	for ϕ 250		
		Assembly	2 set	
4	Butterfly valve	φ100 x 3	3 set	
		φ150 x 3	3 set	
		φ250 x 1	1 set	
		Assembly		
5	Distribution pump	1.83～0.85m3/min		
		h=27～48m		
			3 set	
6	Flow Meter			
		for φ250		
		Assembly	1 set	
Subtotal				
7	Others			
		10% of Above	1 set	
		Total		

Waste Water Tank

Exchange rate
1.995

No.	Item		Q-ty	Cost
1	Earthwork			
		Back-hoe	50 m^3	
		Backfilling Manpower	20 m^3	
2	Gravel Base		8 m^3	
	Mortar		4 m^3	
			1 set	
3	Rainforced Concrete			
		4.0m x 5.0m x 5.3m		
			50 m^3	
4	Form work			
		Assembly	200 m^2	
5	Pipe work			
		L=10m		
		φ200 x 3 set	30 m	
6	Waterproofing painting			
			600 m^2	
	Gravity flow			
Subtotal				
7	Others (Manhole, Water level meter, etc.)			
		10% of Above	1 set	
		Total		

Discharge pipe, ϕ 300 x 1

Exchange rate
1.995

No.	Item		Q-ty	Cost
1	PVC Pipe	Submarine		
		L=700m		
		ϕ 300 x 1	300 m	
2	Flexible Pipe			
		Assembly	2 set	
3	Distribution outlet			
		Assembly	1 set	
Subtotal				
4	Others			
		10% of Above	1 set	
		Total		

Pavement etc.

Exchange rate
1.995

No.	Item	Q-ty	Cost
1	Gravel Pavement	550 m^2	
	Asphalt Pavement	550 m^2	
	Subtotal		
2	Excavation		
		180 m^3	
3	Back filling with compaction		
		180 m^3	
	Total		

Consumablles, Chemicals

Exchange rate
1.995

No.	Item		Q-ty	Cost
1	Anthracite			
			13 ton	
2	Sand	for water purification		
			20 ton	
3	NaClO	10% liquid		
		Dose: 0.5 to 2.5 mg/L		
			1 ton	
5	Anti-scalant	63% or 75% liquid		
		Dose: 40 to 50 mg/L		
			1.35 m3	
6	SBS ($NaHSO_3$)			
			3.8 m3	
7	NaOH	20% liquid		
	Post treatment for pH control			
			0.54 m3	
8	**RO unit stock for one(1) year**			
		Total		

Instruments

Exchange rate
1.995

No.	Item	Q-ty	Cost
1	FI (SDI) measurement tools		
		1 set	
2	pH meter with temperature meter		
		1 set	
3	Turbidity meter		
		1 set	
4	Residual chlorine analyzer		
		1 set	
5	Electric conductivity meter		
		1 set	
6	ORP meter		
		1 set	
	Total		

Fence & Gate

Exchange rate 1.995

No.	Item		Q-ty	Cost
1	Net Fence			
		30m x 2		
			60 m	
2	Gate	Road access	4 m	
		Seashore access	2 m	
		Total		

Land Price

Exchange rate
1.995

No.	Item	Q-ty	Cost
1	Land Acquisition		
	90m x 30m		
		2,700 m²	
	Total		

Cost Caluculation for Electrical Equipment

MANE	Parts	Q'ty		Cost
N0.1 LV Feeder Panel	panel	1	1000W	
	MCCB3P 1000A	2	motor operated	
	MCCB3P 150A	1	with ZCT	
	tie transformer 50kVA	1	440V/220-110V	
	MCCB3P 100A	2		
	MCCB3P 50A	1		
	PT	6		
	CT	6		
	V meter	2		
	A meter	2		
	F meter	1		
	Power Factor meter	1		
	WHM	1		
	AS, VS	4		
	Total			
N0.2 LV Feeder Panel	panel	1	1000W	
	MCCB3P 300A	3	with ZCT	
	MCCB3P 100A	3	with ZCT	
	MCCB3P 100A	2		
	Total			
Static Capacitor Panel	panel	1		
	MCCB3P 50A	5		
	Static Capacitor	3	20kVA with SR	
	Total			
Intake Pump Panel	panel	1		
	PT	1		
	CT	1		
	V meter	1		
	A meter	1		
	MCCB 100A	1		
	MCCB 50A	7		
	MCCB 30A	1	with ZCT	
	Direct on-line stater	3	15kW	
	Reverse starter	3	0.4kW	
	tie transformer 5kVA	1		
	MCCB 10A	3		
	COS 2p	3		
	CS 2p	3		
	CS 3p	3		
	Lamp	15		
	Total			
Distribution Pump Panel	panel	1		
	PT	1		
	CT	1		
	V meter	1		
	A meter	1		
	MCCB 100A	1		
	MCCB 50A	7		
	MCCB 30A	1	with ZCT	
	Direct on-line stater	3	30kW	
	Reverse starter	3	0.4kW	
	tie transformer 5kVA	1		
	MCCB 10A	3		
	COS 2p	3		
	CS 2p	3		
	CS 3p	3		
	Lamp	15		
	Indicating Controller	1	pH controll	

MANE	Parts	Q'ty		Cost
	Indicator	1	Flow	
	Totarizer	1	Flow	
	pH meter	1		
	Flow meter	1	150mmDIA	
	Total			
Chemical Dosing Panel	panel	1		
	PT	1		
	CT	1		
	V meter	1		
	A meter	1		
	MCCB 100A	1		
	MCCB 50A	7		
	MCCB 30A	1	with ZCT	
	Direct on-line stater	6	0.2kW	
	tie transformer 5kVA	1		
	MCCB 10A	3		
	COS 2p	6		
	CS 2p	6		
	Lamp	12		
	Total			
Diezel Engine Generator	750kVA	1	Pacage type	
	Mafler	1	65dB	
	Total			
Equipment Total				
Marerial and Installation			35%	
Grand total				

A6-3. Site Photos

Meeting with MCWD

Candidate Site Overview

Desalination Plant of Mactan Rock Company (1)

Desalination Plant of Mactan Rock Company (2)

Desalination Plant of Mactan Rock Company (3)

Desalination Plant of Mactan Rock Company (4)

Tisa Water Treatment Plant (1)

Tisa Water Treatment Plant (2)

Tisa Water Treatment Plant (3)

Tisa Water Treatment Plant (4)

Dam Site for Tisa Water Treatment Plant

Dam Site for Tisa Water Treatment Plant

Candidate Site (1) Opposite site

Candidate Site (2)

Candidate Site (3)

Candidate Site (4)

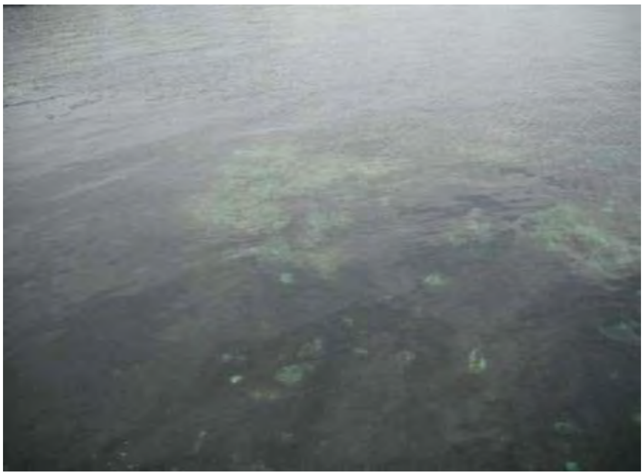
Candidate Site (5)

Candidate Site (6) Seashore Side

Candidate Site (7) Seashore Side

Candidate Site (8) Seashore Side

Candidate Site (9) Seashore Side



Candidate Site (10) Seawater Condition

Electricity Receiving Facility Image

Meeting with NEDA Reagion7 (Cebu)

資料 7. 公式レター