CHAPTER 5

WATER DEMAND AND SUPPLY FORECAST, AND DESALINATION PLANT DEVELOPMENT PROGRAM

CHAPTER 5 WATER DEMAND AND SUPPLY FORECAST, AND DESALINATION PLANT DEVELOPMENT PROGRAM

5.1 CURRENT STATUS OF WATER DEMAND AND SUPPLY

5.1.1 Existing water supply system

The planned water supply district as covered by this Project is the Batina coastal area of 70 km from Muscat to Barka. The water supply district of the Capital Area is shown in Fig. 5.1.

Up to the year 1976, the water supply to the Capital Area had been dependent on pumping up of underground water only. To meet the rapid growth of water demand, in 1977 the first desalination plant was constructed in Ghubrah and entered into service. In 1983, the No.2 plant was put into a parallel operation with the above No.1 plant. The present water production capacity of the desalination plants is 54,560 - 40,910 m^3/day (the average 47,730 m^3/day), as shown in Table 5.1.

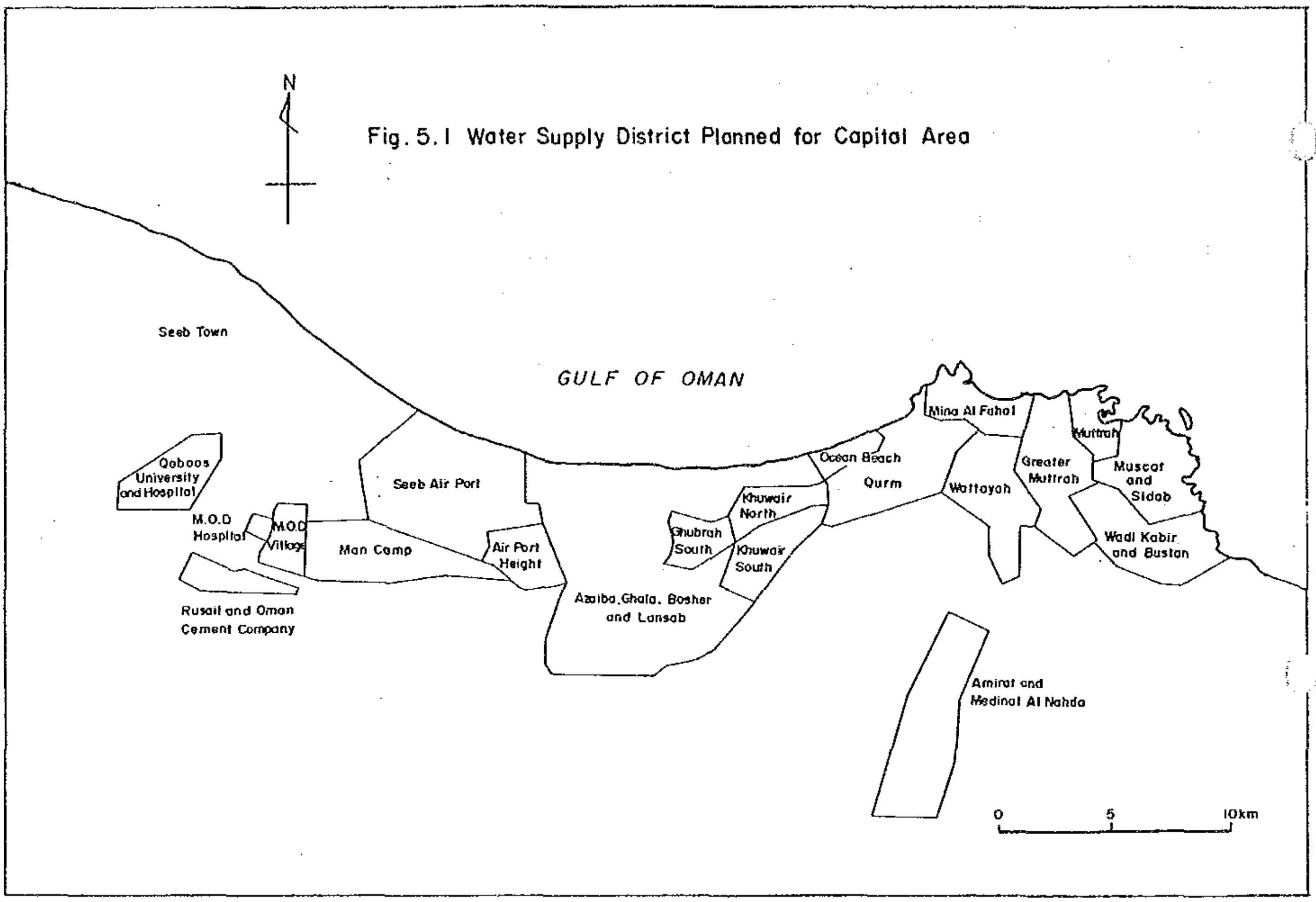

N
Fig. 5.1 Water Supply District Planned for Capital Area
Seeb Town
GULF OF OMAN
Qaboos University and Hospital
Seeb Air Port
M.O.D Hospital
M.O.D Village
Man Camp
Air Port Height
Rusail and Oman Cement Company
Azaiba, Ghala, Bosher and Lansab
Ghubrah South
Khuwair North
Khuwair South
Ocean Beach
Qurm
Mina Al Fahal
Wattayah
Greater Muttrah
Muttrah
Muscat and Sidab
Wadi Kabir and Bustan
Amirat and Medinat Al Nahda
0
5
10km

Table 5.1 Outline of Ghubrah Desalination Plant

Name of Plant	Water Production Capacity: High Temperature Operation	Low Temperature Operation	Average	Commission
	MIGPD m³/d	MIGPD m³/d	MIGPD m³/d	
No.1 MSF Plant	6 (27,280)	4(18,180)	5 (22,730)	1977
No.2 MSF Plant	6 (27,280)	5(22,730)	5.5(25,000)	1983
Sub-total	12 (54,560)	9(40,910)	10.5(47,730)	
No.3 MSF Plant	6 (27,280)	5(22,730)	5.5(25,000)	1986
No.4 MSF Plant	6 (27,280)	5(22,730)	5.5(25,000)	1986
Sub-Total	12 (54,560)	10(45,460)	11 (50,000)	
Total	24(109,120)	19(86,370)	21.5(97,750)	

Note) MIGPD = Million Imperial Gallon/day
1 Imperial gallon = 0.004546 m^3

At present, two more plants of No.3 and No.4, each with the same capacity (27,280 - 22,730 m^3/day), are being constructed in Ghubrah and scheduled to be put into commercial operation in March 1986. Consequently, by March 1986, the total production capacity of all desalination plants will reach 109,120 - 86,370 m^3/day (the average 97,750 m^3/day), as shown in Table 5.1.

Most of wells in the Capital Area are located at five ground water regions of Wadi Adey, Wadi Hatat, Seeb, Mawallaa, and Al Khawd. The ground water pumping quantity has been increased rapidly since 1980, reaching 8,396,000 m^3/year (23,000 m^3/day) in 1982. But the pumping quantity decreased to 5,255,000 m^3/year (14,400 m^3/day) in 1983. This is reported to prevent the ground water from contamination by sea water which has penetrated inland due to decrease in the ground water level caused by excessive pumping.

Under this situation, it was planned to maintain the average ground water pumping quantity of 22,000 m^3/day, and after 1985, the pumping schedule is shown in Table 5.2.

Table 5.2 Ground Water Pumping Plan after 1985

District	Max. pumping rate (m^3/d)	Average pumping rate (m^3/d)	No. of wells
Wadi Adey	50,000	10,000	approx. 30
Mawallaa	2,000	1,000	3
Seeb	18,000		12
Al-Khawd Dam Well Field	22,000	10,000	14
Old Government Well Field	10,000		20
Rusail	1,000	1,000	2
Total	103,000	22,000	approx. 80

5.1.2 Water supply and demand status and water rate

The water supply quantity in the Capital Area has made rapid growth recently along with concentration of population and economical development. As shown in Table 5.3, the actual supply record has increased from 386,000 m^3 in 1971 to 1,954,000 m^3 in 1976. Water supply sources in those days were restricted to wells and only the limited pumping quantity was available.

Since commissioning of the first desalination plant in Ghubrah in 1977 and subsequent expansion, the water supply quantity is increased at high pace from 4,555,000 m^3 in 1977, to 23,488,000 m^3 in 1984. Average annual growth rate was 50.4% for 1976 - 1980, and 20.4% for 1980 - 1984. Of the annual water supply quantity of 23,488,000 m^3 in 1984, 18% (4,204,000 m^3) was from wells, while 82% (19,284,000 m^3) was from desalination plants.

For the water rates in the Capital Area, there are two kinds of water rates; one is 2 Baizas/Imperial gallon for household service and the other 3 Baizas/Imperial gallon for industrial use.

Table 5.3 Water Supply Records for the Capital Area

Year	Population of Capital Area (x 1,000 person)	Annual Water Supply Quantity (1,000 m^3/d)			Average Water Supply/day (m^3/d)
		Wells	Desalination plants	Total	
	(Estimate)				
1971	65	386	-	386	1,100
1976	133	1,954	-	1,954	5,300
1977	148	1,440	3,115	4,555	12,400
1978	163	1,081	4,671	5,752	15,800
1979	178	1,345	6,593	7,937	21,700
1980	195	4,598	6,579	11,177	30,600
1981	210	6,741	6,789	13,530	37,100
1982	226	8,396	7,772	16,168	44,300
1983	241	5,255	14,203	19,458	53,300
1984	265	4,204	19,284	23,488	64,400
Average growth rate/year					
1976 - 80					54.7%
1980 - 84					20.4%

5.1.3 Characteristics of water demand fluctuation

Water supply record for each month is shown in Table 5.4 and seasonal fluctuation of water supply is shown in Fig. 5.2. The water demand exceeds the annual average water supply in summer (May - October) and is less than that in winter (December - March). Roughly speaking, the water demand remains within a range of $\pm$15% of the annual average water supply. And its fluctuation range is not so large as that of the electricity. The demand in the minimum water demand month in a year is about 2/3 of the demand in the maximum water demand month and there is not so much annual fluctuation.

Daily fluctuation of the water supply is as shown in Fig. 5.3, and the maximum daily water demand of each month is not so much related to the season. Rather the water demand is rather large in winter and, moreover, the water demand fluctuation between maximum and minimum is large in winter.

Table 5.4 The Average of Daily Water Supply for Each Month

(Unit: m^3/day)

Year / Month	1979	1980	1981	1982	1983	1984	1985
January	16,733	23,057	31,531	38,840	42,637	49,400	62,300
February	17,674	23,996	33,015	37,991	44,065	58,300	
March	18,367	26,720	38,783	36,636	46,949	57,300	
April	19,313	28,865	28,164	39,812	46,978	62,300	
May	21,259	32,164	38,369	44,723	55,729	64,100	
June	23,179	34,939	41,507	52,618	63,592	64,100	
July	25,187	32,067	41,827	47,629	57,308	63,500	
August	23,804	32,837	41,758	47,679	54,347	65,900	
September	24,140	33,585	42,005	49,013	56,473	68,200	
October	24,453	33,125	41,626	48,570	59,077	68,200	
November	22,959	36,342	29,971	45,661	59,490	65,000	
December	22,631	28,619	35,655	42,110	52,822	65,900	
Annual average	21,640	30,626	37,068	44,273	53,299	64,350	62,300

Note: Approximate values for 1984

Fig. 5.2 Monthly Fluctuation Record of Water Supply

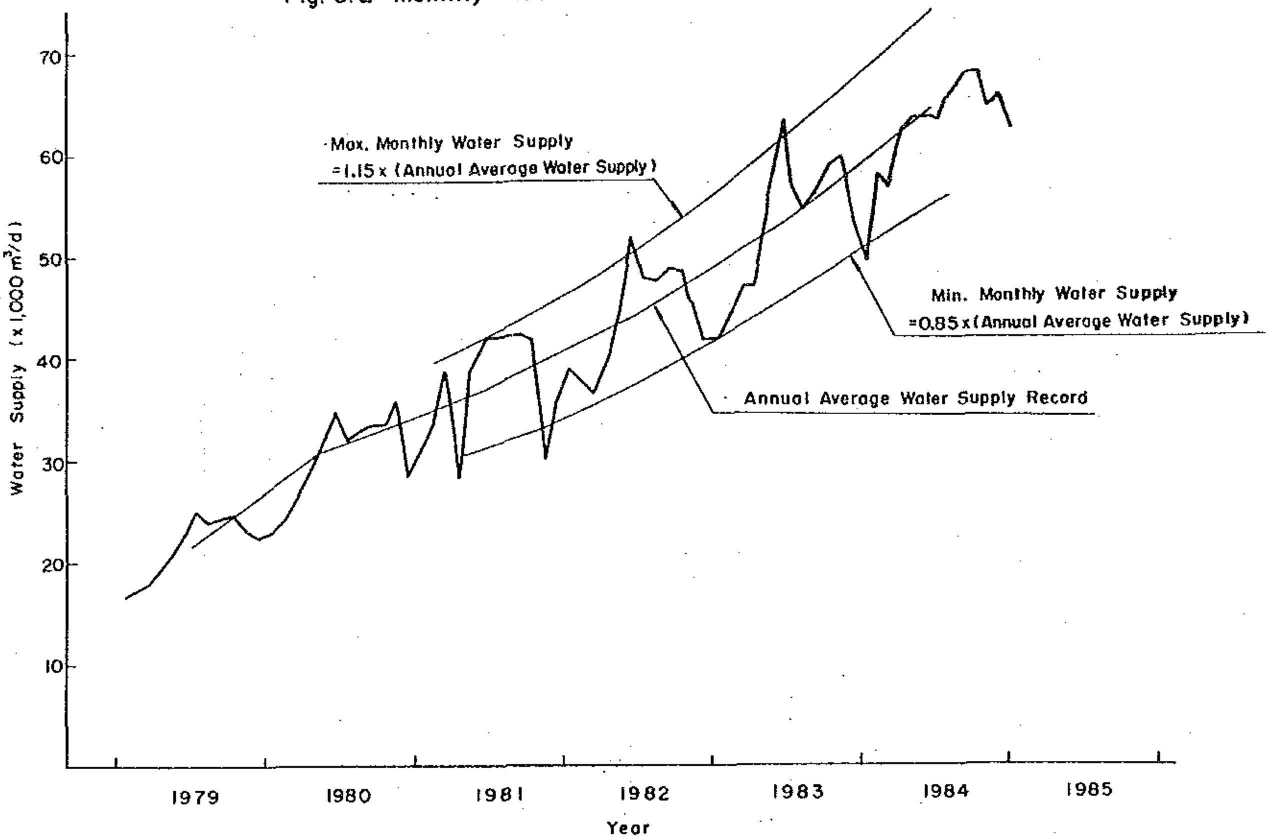
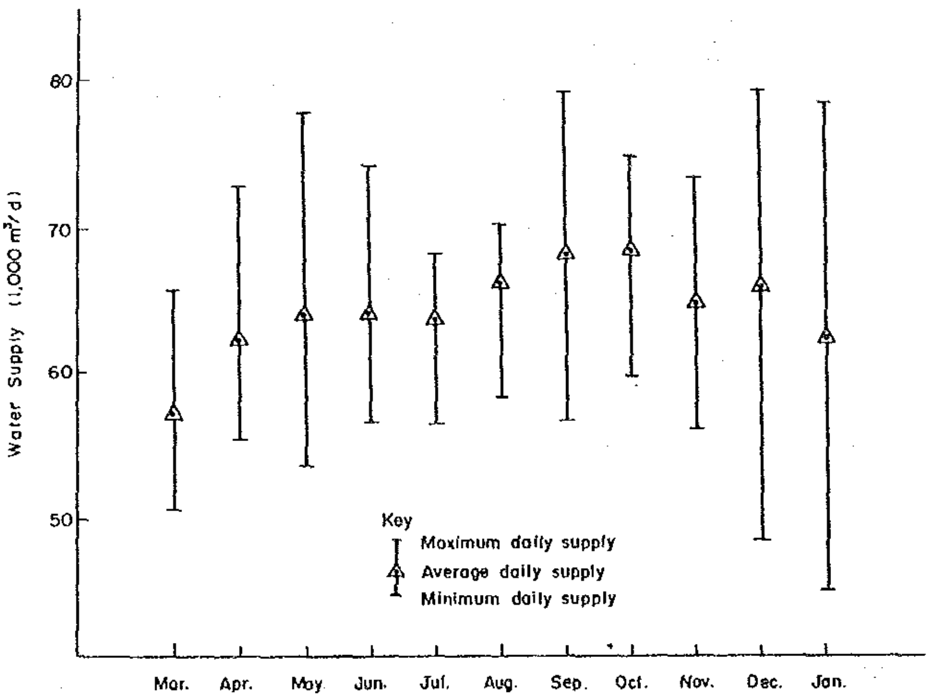


Fig. 5.3 Monthly Maximum and Minimum Water Supply



5.2 WATER DEMAND FORECAST

5.2.1 Forecast by MEW

The water demand forecast prepared by MEW is shown in Table 5.5 for the Capital Area. The MEW's water demand forecast is based on a cumulative method including the natural growth of existing water consumption (A) and planned new bulk consumption (B) from new projects.

The natural growth of consumption (A) includes demands from new housing areas (Seeb town, Medinat Al Nahda, Airport Heights, Khuwair North, etc.) for which water supply will be started soon. The forecasted MEW's water demand forecast is calculated on the condition that an annual water growth rate decreases by 1% every year, and an annual water demand growth rate will be predicted from 15% in 1985 to 10% in 1990.

The consumption (B) includes large amount of water supply to the Cement plant, Industrial Complex, Sports Stadium, University and Hospital, which are currently under development, as well as the area expansion of water supply and landscaping, etc.

The ratio of water consumption (B) to the water consumption (A) is 30% in 1985, and 43% in 1990.

Table 5.5 MEW's Water Demand Forecast for the Capital Area

Issued on February 6, 1985 (Unit: m^3/day)

	Consumer	1984 (Record)	1985	1986	1987	1988	1989	1990	1995
	1. Existing consumer (A) (Natural growth)		69,781	79,737	90,100	100,968	111,968	123,151	
New bulk consumer	2. Oman cement company		1,200	1,500	1,800	2,000	2,200	2,500	
New bulk consumer	3. Rusail industrial estate	-	1,500	2,000	2,400	2,600	2,800	3,000	
New bulk consumer	4. Bosher stadium	-	500	500	600	600	700	800	
New bulk consumer	5. Qaboos university	-	2,000	3,000	4,000	4,500	5,000	5,000	
New bulk consumer	6. Bowsher hospital	-	500	600	700	800	900	1,000	
New bulk consumer	7. MDO hospital and village	-	3,000	4,000	5,500	6,500	7,500	9,000	
New bulk consumer	8. Bustan hotal, Wadi Kabir	-	2,500	2,500	2,800	3,000	3,500	4,000	
New bulk consumer	9. Azaiba, Ghala, Bosher, Lansab	-	2,500	2,750	3,250	3,750	4,250	5,000	
New bulk consumer	Sub-total (2 to 9)	-	13,450	16,850	21,050	23,750	26,850	30,300	
New bulk consumer	Leak water (15%)		2,080	2,528	3,158	3,563	4,028	4,545	
New bulk consumer	Landscaping	-	5,000	7,600	10,200	12,800	15,400	18,000	
New bulk consumer	Total new bulk consumpt. (B)		20,468	26,978	34,408	40,113	46,278	52,845	
	Total (A + B)		90,249	106,715	124,508	140,989	158,246	175,996	
	10% Unforeseen		9,025	10,672	12,451	14,099	15,825	17,600	
	Grand total	64,350	99,274	117,387	136,958	155,088	174,071	193,596	Approx. 260,000
	Per capita per day (ltr/day.capita)	248	347	377	404	420	433	442	465

5.2.2 Review of MEW's water demand forecast

The water demand can be correlated to the population of the area concerned, and is also closely related to the economical development level. Accordingly, as previously described in the electricity demand, the multiple regression model was established using the population and Gross Domestic Production (GDP) as independent variables and the water demand as dependent variable. With this model, the future water demand was calculated and the result was compared with MEW's Water Demand Forecast in this study.

As shown in Table 5.6, the following multiple regression model equation was obtained by least squares method on the basis of actual data of the Capital Area population, GDP/capita, and water demand for a period from 1976 to 1983:

$$y_0 = 0.00385\ X_1 + 0.390\ X_2 - 51.936$$

where y_0 = Water Demand Forecast (x 1,000 m^3/day)
X_1 = GDP/capita (RO)
X_2 = Capital Area population ($x10^3$ person)

The numbers of GDP and population for the future were applied to the above equation, shown in Table 5.7 as described in 4.5.1 (2). As a result, the Water Demand Forecast as shown a column "y_0" of this Table was obtained.

The Water Demand Forecast (y_0) as determined from this multiple regression model is a forecast as obtained on the basis of the actual water demand record from 1976 to 1983. Consequently, the growth of water demand in line with the economical and population growth corresponding to the past growth rate is included in the forecast by the multiple regression model.

However, in the Capital Area, various large scale projects are either under construction or planned for completion in a few years for the purpose of rapid urban and industrial development. For these increase in large demand sources, due consideration has to be paid separately.

Table 5.6 Base Data for Multiple Regression Model

1. Parameters

Year	GDP at current prices	Comsumers prices index	GDP at 1978 price	Population of the country	GDP/capita	Population of Capital Area	Water consumption
	(RO million)	(1978=100)	(RO million)	(1,000)	(RO)	(1,000)	(1,000 m^3/day)
1976	884.3	85.0	1,040.0	790	1,316	133	5.3
1977	946.8	87.7	1,080.0	814	1,327	148	12.4
1978	947.5	100.0	947.5	839	1,129	163	15.8
1979	1,289.5	108.5	1,188.5	864	1,376	178	21.7
1980	2,066.6	119.3	1,732.3	890	1,946	195	30.6
1981	2,506.4	122.7	2,042.7	920	2,220	210	37.1
1982	2,609.7	124.0	2,104.6	950	2,215	226	44.3
1983	2,741.3	118.6	2,311.4	980	2,359	241	53.3
Total					13,888	1,494	220.5
Median					$\overline{X}_1$=1,736	$\overline{X}_2$=186.8	$\overline{y}_0$=27.6

2. Multiple regression equation

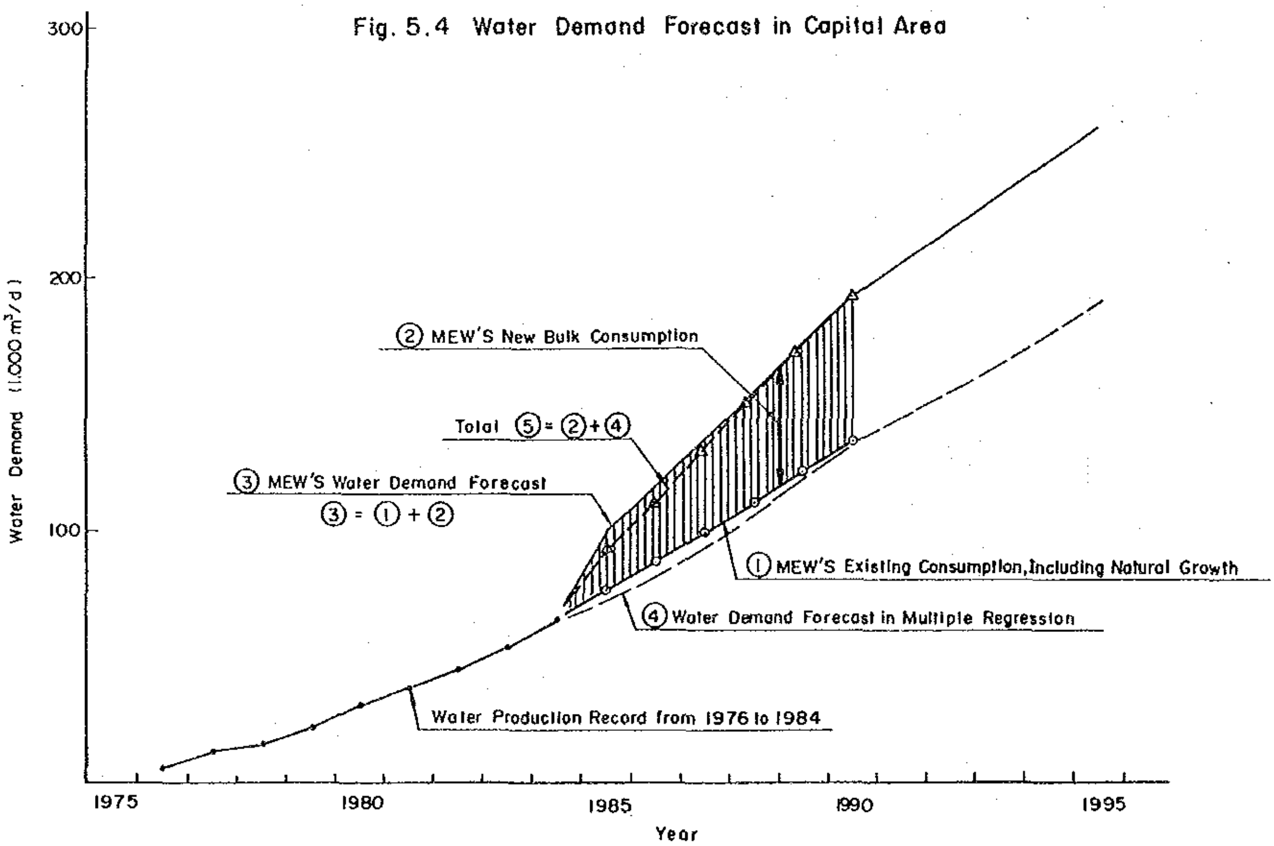
$$\overline{y}_0 = 0.00385\overline{X}_1 + 0.390\overline{X}_2 - 51.936$$

Source: GDP and consumers price index - Statistical Year Book (Development Council)
Population of the country - International Monetary Fund (United Nations)
Population of Capital area - Middle East Electricity (1983)

Table 5.7 Water Demand Forecast by Multiple Regression Model in Capital Area

Year	GDP at 1978 price	Population of the country	GDP/ capita	Population of Capital Area	1 Water demand y_0	2 New bulk consumption y_1	3 Total demand $y=y_0+y_1$	4 MEW's forecast
	(RO million)	(1,000)	(RO)	(1,000)	(1,000 m^3/d)	(1,000 m^3/d)	(1,000 m^3/d)	(1,000 m^3/d)
1985	3,206	1,043	2,941	286	70.9	22.5	93.4	99.3
1986	3,590	1,076	3,195	311	81.7	29.7	111.4	117.4
1987	4,021	1,109	3,475	339	93.7	37.8	131.5	137.0
1988	4,504	1,144	3,776	369	106.5	44.1	150.6	155.1
1989	5,045	1,180	4,104	402	120.6	50.9	171.5	174.1
1990	5,650	1,218	4,457	438	136.0	58.1	194.1	193.6
1991	6,215	1,256	4,754	460	145.8			
1992	6,836	1,296	5,068	483	155.9			
1993	7,520	1,337	5,404	507	166.6			
1994	8,272	1,379	5,764	532	177.7			
1995	9,099	1,422	6,148	559	189.7		(Approx.) 260	

Fig. 5.4 Water Demand Forecast in Capital Area



Considering the above fact, the forecast is re-evaluated and finally, total water demand forecast (y) becomes the values (Total Demand $y = y_0 + y_1$) shown in Table 5.7. This value is very close to the MEW's Water Demand Forecast, so the MEW's Water Demand Forecast is considered reasonable.

Water Demand Forecasts by MEW and by adjusting Multiple Regression Model are shown in Fig. 5.4.

By the MEW's water demand forecast, the average water supply per capita per day is prospected a grodual increase from 248 ltr/capita day in 1984 to 465 ltr/capita.day in 1995 and this figure is reasonable as compared with that of other countries (for examples, 379 ltr/capita.day for Gulf countries in 1982, 374 ltr/capita.day for Japan and 426 ltr/capita.day for Tokyo in 1983).

As a conclusion, it was decided to adopt the MEW's water supply demand forecast as a basis of this project.

5.3 DESALINATION PLANT DEVELOPMENT PROGRAM

5.3.1 Forecast of water demand and supply balance

Table 5.8 shows the yearly water supply and demand balance for coming ten years up to 1995 based on water demand forecast, and existing water supply facilities inculding under construction units. As is evident from this table, the supply shortage is foreseen within several months after completion (March 1986) of Ghubrah Plants No.3 and No.4. Subsequently this shortage for average water demand will increase annually at a rate of more than 11,000 m^3/day, possibly reaching 74,000 m^3/day in 1990 and 140,000 m^3/day in 1995.

Table 5.8 Forecast of the Water Demand and Supply Balance Based on the Existing Water Supply Capacity

(Unit: m^3/day)

Year	Average Water demand (A)	Existing water supply capacity			Balance (C=B-A)	Remarks
		Wells	Production of desali. plant	Total (B)		
1985	99,274	22,000	47,730	69,730	-29,544	
1986	117,387	22,000	97,750	119,750	2,363	Ghubrah No.3, No.4 will be completed in 1986.
1987	136,958	22,000	97,750	119,750	-17,208	
1988	155,088	22,000	97,750	119,750	-35,338	
1989	174,071	22,000	97,750	119,750	-54,321	
1990	193,596	22,000	97,750	119,750	-73,846	
1991	206,877	22,000	97,750	119,750	-87,127	
1992	220,158	22,000	97,750	119,750	-100,408	
1993	233,438	22,000	97,750	119,750	-113,688	
1994	246,719	22,000	97,750	119,750	-126,969	
1995	260,000	22,000	97,750	119,750	-140,250	

Note: The capacity of plants under construction is included.

5.3.2 Desalination plant development program

Water supply facilities must cover the peak water demand. As described in 5.1.3, past operation record shows that summer peak water demand is by 15 percent higher than that of yearly average water demand.

In a place where most of water source is depending on desalination plant and there is no large water reservoir (dam, etc.), it is essential to have the stand-by desalination unit to ensure stable supply of water considering emergency case or plant maintenance.

So, it is necessary to take into calculation the drop of water supply capacity due to the shutdown for periodical plant maintenance, when determining the unit capacity of desalination plant of this Project.

Considering above conditions, water demand and supply balance is shown in Table 5.9 and assuming the new desalination plant capacity as 180,000 m^3/day at Barka, this new plant covers the water demand of coming ten years. It is anticipated that reserve water supply capacity become short to some extent, at summer season in 1994 and 1995. But safe water supply scheme can be obtained by carrying out annual maintenance at winter season.

Therefore, for this project, it is proposed that the total capacity of desalination plant is 180,000 m^3/day.

To overcome urgent water shortage expected in early next year in 1986, as explained previous sections, the construction of new desalination plants must be completed as soon as possible. So first 3 units of each 30,000 m^3/d must be constructed by Feb. 1989 based on the shortest delivery schedule, and other remaining 3 units of each 30,000 m^3/d is to be constructed together with steam power plant construction schedule.

Power plant construction schedule at Baska new site is planned 720 MW to meet increasing power demand up to 1991, while water shortage still continues even after the completion of first 3 units desalination plant in 1989, so remaining other 3 units which will meet the water demand in 1995 is recommended to construct in advance together with steam power plant construction schedule.

Because, this plant is basically complex plant of power and desalination closely connected each other, so construction work must be carried out at the same time, so that construction cost will be saved. Moreover availability of desalination units including Ghubrah station will be much improved to secure sure and safe water supply to capital area considering annual maintenance of each unit and emergency shutdown of units if any.

The total water supply and demand balance is shown in Table 5.9 and Fig. 5.5, when all desalination units including Ghubrah station are put into operation.

Table 5.9 Forecast of the Water Demand and Supply Balance Considering Summer Peak Demand and Reserve Capacity

(Unit: m^3/day)

Year	Water Demand			Water Supply Capacity			Balance
	(1) Average	(2) Summer Peak	(3) Summer Peak Reserve Capacity	(4) Existing Water Source	(5) New Barka Plant	(6) Total (4) + (5)	(6) - (3)
1985	99,274	114,165	144,165	69,730	-	69,730	-74,435
1986	117,387	134,995	164,995	119,750	-	119,750	-45,245
1987	136,958	157,500	187,500	119,750	-	119,750	-32,250
1988	155,088	178,350	208,350	119,750	60,000	179,750	-28,600
1989	174,071	200,181	230,181	119,750	90,000	209,750	-20,431
1990	193,596	222,635	252,635	119,750	180,000	299,750	+47,115
1991	206,877	237,908	267,908	119,750	180,000	299,750	+31,842
1992	220,158	253,181	283,181	119,750	180,000	299,750	+16,569
1993	233,438	268,453	298,453	119,750	180,000	299,750	+ 1,297
1994	246,719	283,726	313,726	119,750	180,000	299,750	-13,976
1995	260,000	299,000	329,000	119,750	180,000	299,750	-29,250

Note: (1) Summer peak demand is increased by 15% in addition to average demand based on past water demand record in Oman.
(2) Reserve cap. 30,000 m^3/d (1 unit cap).
(3) Blending well water which will be developed at Barka area is not included in this table.

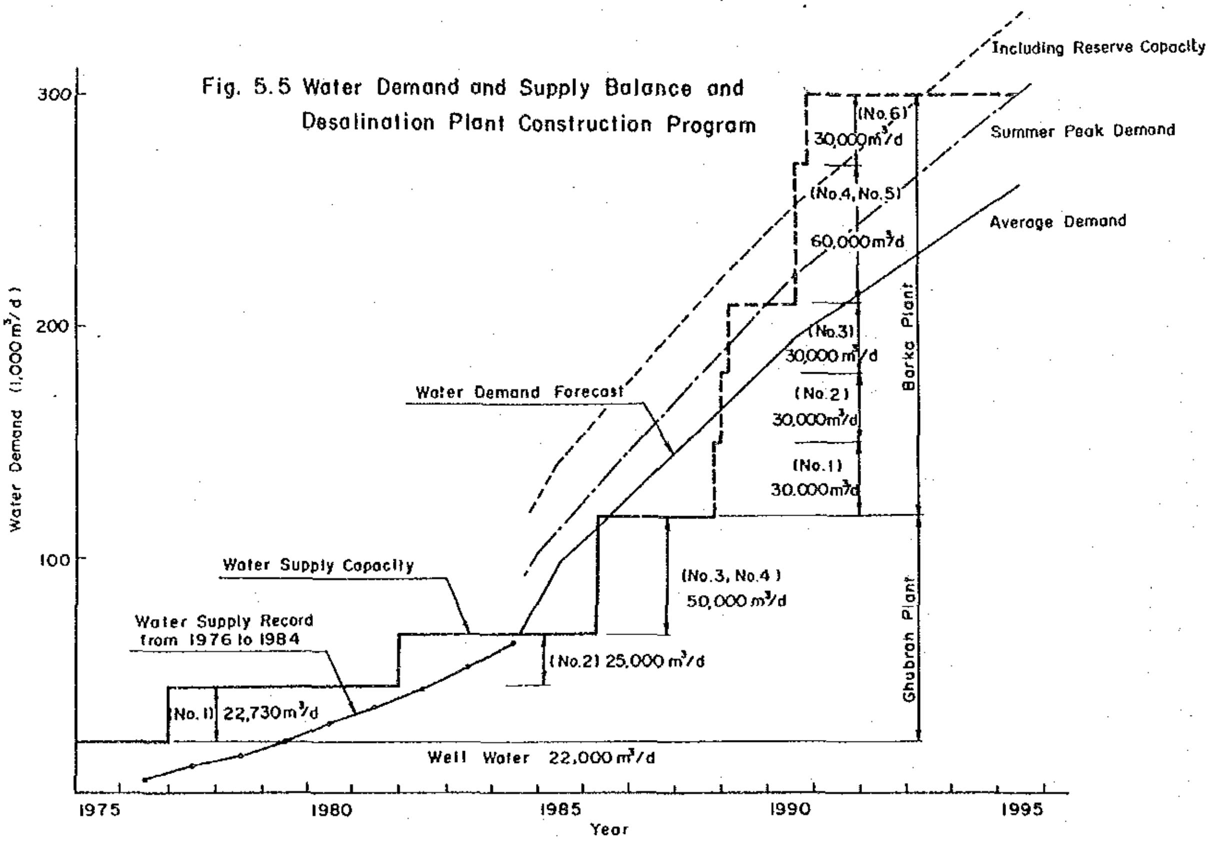


Fig. 5.5 Water Demand and Supply Balance and
Desalination Plant Construction Program
Including Reserve Capacity
Summer Peak Demand
Average Demand
Water Demand (1,000 m³/d)
300
200
100
Water Demand Forecast
Water Supply Capacity
Water Supply Record from 1976 to 1984
(No. 1) 22,730 m³/d
(No.2) 25,000 m³/d
(No.3, No.4) 50,000 m³/d
(No.1) 30,000 m³/d
(No.2) 30,000 m³/d
(No.3) 30,000 m³/d
(No.4, No.5) 60,000 m³/d
(No.6) 30,000 m³/d
Barka Plant
Ghubrah Plant
Well Water 22,000 m³/d
1975
1980
1985
1990
1995
Year

CHAPTER 6

SELECTION OF PLANT SITE

CHAPTER 6 SELECTION OF PLANT SITE

6.1 BASIC CONDITIONS FOR SITE SELECTION

Generally speaking, in site selection for a thermal power station or a seawater desalination plant, it is necessary to consider the following items from engineering and economic points of view. The items are:

(1) that flat land of sufficient area including space for future expansion can be secured,

(2) that ground conditions are favorable, and large sums will not be required for foundations of structures and heavy equipment,

(3) that acquisition of land will be comparatively easy,

(4) that there will not be damage sustained from monsoons, floods, storm surges, and littoral drifts,

(5) that intake of seawater required for plant operation will be easy,

(6) that the quality of seawater used for desalination is good,

(7) that supply of fuel required for plant operation will be easy,

(8) that the site is close to centers of demand for electric power and water, and the costs of constructing and maintaining transmission lines and water pipelines will be low,

(9) that accessibility from an existing trunk highway is good and transportation of materials and equipment for the plant and of heavy articles such as construction equipment will not be hindered,

(10) that construction and operation of the plant will not have too much effect on the environment of the vicinity area.

6.2 BACKGROUND OF CANDIDATE SITE SELECTION

According to the plans of MEW, the electric power generated at this thermal power and desalination complex plant is to be transmitted to the Capital area and the Batinah coast area, and the water produced piped to the Capital area. Meanwhile, at the stage of the Prefeasibility study of this project carried out in June 1984, there was a necessity to select the candidate site in the vicinity of the shoreline of approximately 40 km from Seeb airport to Barka town. Therefore, in field investigations at the time of the Prefeasibility study, the basic conditions for site selection listed in 6.1 were kept in mind and field reconnaissances were made of the sea coast from Seeb airport to Barka town in accordance with the wishes of MEW, and as a result, six candidate sites were selected. Studies were made of the individual sites from engineering and economic standpoints, and in the end with four prospective locations as recommended sites, a report was submitted to MEW. Based on the results, MEW judged Site-IV and Site-V shown in Fig. 6.3 as being most suitable and started preparations for land acquisition, but was unable to obtain the consents of landowners concerned and of residents of the area so that locating the plant at Site-IV or Site-V became impossible. Furthermore, since it was anticipated that land acquisition would be difficult at the other candidate sites also, MEW itself selected a new location at a point approximately 5 km west of Site-V selected at the time of the Prefeasibility study.

6.3 NEW SITE SELECTED BY MEW

Because of the circumstances of site selection described in 6.2, MEW selected the Barka Site shown in Fig. 6.3 as a new plant site. The area around this site is owned by the Royal Family. The JICA study team was requested by MEW to conduct a study whether the new location would be suitable as the plant site at the early stage of the current field investigations. Responding to this request, the JICA study team carried out a surface reconnaissance, topographic surveying, and sounding of the nearby sea area. As a result, it was considered that although this site would require raising of the ground level by about 1 m at the time of site preparation, it is not greatly different from engineering and economic standpoints compared with the places selected as possible sites at the time of the Prefeasibility study, and it was concluded that there was no problem as the location for the plant.

6.4 TOPOGRAPHY AND GEOLOGY

This site is located at a seashore area approximately 9 km east of Barka town and approximately 5 km west of Site-V, one of the candidate sites selected at the time of the Prefeasibility study. The site, as shown in Photo 6.1, is a flat area covered by beach sand containing gravel, and the area of 1,000,000 m^2 (1,000 x 1,000 m) required for plant construction can be amply secured. As shown in Fig. 6.4, the elevation of the ground as a result of topographic surveying is approximately 1 m above H.H.W.L., the highest predicted tide at Mina Quboos, and when the gradient required for discharging waste water from the plant to the sea area, and the effects of waves due to strong wind are considered, it is necessary for the present ground level to be raised about 1 m.

With regard to the geology of this site, geological investigations such as boring investigations, physical prospecting, and test pitting were not carried out in the present survey with only a surface reconnaissance made, but judging by the geological investigation results for the desalination and steam raising plant extension now under construction by MEW at Ghubrah, and the results of boring for groundwater investigations carried out in the vicinity of Barka town, it is estimated that N values of 20 or higher will be obtained in standard penetration test 5 to 6 m underground at this site. Consequently, with regard to the structure foundations and heavy equipment foundations of the plant, they are to be spread foundation structures consisting mainly of reinforced concrete double slab or mat foundations, and it is thought unnecessary for foundation treatment works such as pile foundations and large-scale soil stabilization works that require great expense to be provided. However, the Ghubrah site and Barka town are at distances from this site so that the results of geological investigations at these two sites would be limited to serving as reference material at the stage of the Feasibility study, and at the stage of definite design of the project it will of course be necessary for detailed field investigation works to be carried out and the types of the foundations for the various structures and heavy equipment decided based upon the results of those investigation works.

6.5 ACCESSIBILITY

This site is close to an existing trunk highway which runs parallel to the shoreline, and it will be an easy matter to reach the site by constructing an access road of a length of about 2.5 km, so that there will be no problem about accessibility to the site. The distance to the site from Mina Quboos scheduled to be the cargo unloading port during construction of the plant is approximately 70 km. The beforementioned trunk highway would be used for transportation of materials and equipment, but since there are roundabouts and grade separations as several places between Mina Quboos and Seeb airport, these will restrict weights and volumes of the material and equipment that can be transported to an extent.

6.6 SEAWATER TEMPERATURE AND DEPTH OF WATER

Seawater temperature measurements and sounding were carried out in the sea area near the site, and as shown in Fig. 6.4, the results of seawater temperature measurements were that the temperatures were more or less the same regardless of distance from the shore and depth. This is thought to have been because these measurements were made in the cool weather season of the region with mean outside air temperature around 24°C so that water temperature was the same as outside air temperature. However, according to records of water temperature measurements in the summertime, the average water temperature at the surface of the sea becomes 30°C or higher, and it is imagined that when outside air temperature is high, a layer of discontinuity, will be produced at a depth of 3 to 5 m.

As shown in Fig. 6.4, the results of sounding are that the sea bottom slopes gently at 1/110 to 1/280 to present a so-called shelving bottom condition. Therefore, in planning intake facilities for seawater required for plant operation it will be necessary to study the method of intake taking into consideration variations in water temperature distribution in the summertime and the gradual slope of the sea bottom.

Meteorological and marine phenomenon records at Mina Quboos are shown in Annex-2.

6.7 WATER QUALITY AND BOTTOM MATERIAL

Seawater and sea-bottom soils were sampled in the sea area near the site, and these samples were tested and analyzed in the laboratory after returning to Japan. As a result, it was ascertained that, quality-wise, the seawater posed no problem at all as cooling water for the power station and as raw material for desalination. The geological nature of the bottom material is that of a shell-bearing sand or silty sand, and it is thought there will be no special obstacle to civil works such as undersea excavation for construction of seawater intake facilities, however, it is important to keep mind seawater turbidity due to excavation works in the sea area during construction stage.

The locations where the seawater and bottom material were sampled are shown in Fig. 6.4.

The results of tests and analyses of the water quality and bottom material are as given in Annex 1.

6.8 CONDITION IN VICINITY OF SITE

The general area of the site consists of flat land covered by beach sand. However, on the inland side of the site, which is the south side, there is a gradual increase in the number of shrubs growing so that greenery can be seen. At the inland area approximately 2 km south of the site there is farmland spread out where date palms are grown, and pump stations for drawing groundwater can be seen here and there. To the east and west of the site, respectively, about 2 km away, there are traces of "wadi' which become streams when it rains, and sand-gravel deposits are scattered at the river beds. The villages closest to the site are Rumays to the southeast and Haradi to the west, both at distances of about 2 km. It appears that the residents of these villages are occupied in small-scale agriculture and coastal fishing using small boats. Existing structures or facilities to hinder construction and operation of the plant cannot be seen in the surroundings of the site.

6.9 SUPPLY OF FUEL

As fuel required for operating the plant in this project, it is planned to use natural gas produced at an inland area. Fuel supply facilities such as a gas pipeline to the site are to be planned and provided by MEW independent, and are not included in the present study of the JICA study team.

6.10 SUPPLY OF WELL WATER

It is planned to blend distilled water produced at the desalination plant with well water for making savory potable water. However, well water supply facilities such as pipeline to the site and provision of wells are to be prepared by MEW independent, and are not included in present study of the JICA study team.

6.11 ENVIRONMENTAL IMPACT

At the time of the field investigations by the JICA study team, there were no environmental standards or laws and ordinances to regulate air pollution, vibration, noise, effluent, etc., produced in construction and operation of the plant, the current situation being that the agencies concerned were carying out studies for preparation of standards, however, it is important to keep mind to minimize public influence caused during construction works and after starting operation of the plant.

6.11.1 Air pollution

(1) Boiler flue gas contains air pollution related substances, typically sulpher compounds.

(2) The flue gas containing sulpher compounds needs to be assessed using the following parameters:

(a) Fuel character
(b) Fuel consumption
(c) Chimney height

(3) Calculation of SO_x produced by the fuel containing sulpher compounds

Of fuels to be used in the project, distillate and heavy oil fuels contain sulpher compounds.
Maximum ground concentration and maximum grounding distance of SO_x were calculated for the above two types of fuel, as shown in Table 6.1.
The method of calculation is shown in Annex-4.

(4) Method of measuring air pollutant

1) To measure the air pollutant contained in the boiler flue gas by weight, gram per normal cubic meter ($gr/N\ m^3$) is used.

2) To measure the same by concentration, parts per million (p.p.m.) is used.

3) Unit conversion

$$\text{p.p.m.} = \frac{SO_2 \text{ volume in flue gas } (Nm^3)}{\text{flue gas volume } (N\ m^3)} \times 10^{-6}$$

$$gr/Nm^3 = \frac{SO_2 \text{ Weight in flue gas (gr)}}{\text{flue gas volume } (N\ m^3)}$$

example of unit conversion

$$S + O_2 = SO_2$$

$$32kg \quad \left[\frac{32\ kg}{22.4\ Nm^3}\right] \left[\frac{64\ kg}{22.4\ Nm^3}\right]$$

Weight of SO_2 per $1Nm^3$

$$= \frac{64\ gr}{22.4 \times 10^{-3} Nm^3}$$

$$= 2{,}857\ gr/Nm^3$$

when density and weight of SO_x as x and y respectively;

Density of SO_2 : x (p.p.m.)

Weight SO_2 per $1Nm^3$: y (gr/Nm^3)

Their relationship can be expressed by the following equation:

$$y = 2{,}857\ x \quad X\ 10^{-6}$$

for reference with actual value of SO_2

in case of x = 1 ppm ——> required y gr/Nm^3

$$y\ gr/Nm^3 = 2{,}857 \times 1\ (ppm) \times 10^{-6}$$

$$= 2{,}857 \times 10^{-6}$$

in case of y = 1 gr/Nm^3 ——> required x ppm

$$x\ (ppm) = \frac{1\ gr/Nm^3}{2{,}857 \times 10^{-6}\ gr/Nm^3} = 350$$

6.11.2 Prediction of diffusion and recirculation of discharged heated water

(1) Prediction of diffusion of discharged heated water

1) Study conditions

a) Data on discharged heated water

Quantity of discharged heated water

For power generation	$Q_p = 22.0\ m^3/s$
For desalination	$Q_d = 16.0\ m^3/s$
Total	$Q = 38.0\ m^3/s$

Temperature rise

For power generation	$T_p = 7.0°C$
For desalination	$T_d = 8.0°C$
Average	$T_{av} = 7.42°C$

Chlorinity

For power generation	$Cl_p = 22.14$ o/oo
For desalination	$Cl_d = 24.91$ o/oo
Average	$Cl_{av} = 23.31$ o/oo

Density of discharged heated water

$$\rho_o = 1.02432 \ t/m^3 \ (\text{when } To = 37.42°C)$$

b) Data on seawater

Temperature	Te	= 30.0°C
Chlorinity	Cle	= 22.14 o/oo
Density	ρ_e	= 1.02550 t/m^3

c) Flow condition in sea area

Static and reciprocating current of 0.25 m/s parallel to coast were considered.

d) Shape of outfall and assumption for calculation

The outfall of this project is to be installed near the shoreline, and surface-layer discharge is to be carried out. Prediction of the diffusion of discharged heated water will be made with respect to L.W.L. when the diffusion range becomes largest. The depth of water near the outfall at L.W.L. is about 30 cm. In this study, however, taking into consideration the safety side, it is assumed that the water discharged from the outfall is not subjected to heat-release diffusion and dilution in the middle. Instead, it is assumed that the water reaches a 200 m point in the offing and is thereafter subjected to heat-release diffusion and dilution. Also, the discharged water section at the 200 m point is assumed to be 2 m in height and 13 m in width.

e) Equation for predicting the diffusion of discharged heated water

The diffusion area of discharged heated water will be predicted by Shirage and Davis' equations of the U.S. Environmental Protection Agency.

2) Result of prediction of the diffusion of discharged heated water

The results of prediction of the diffusion of discharged heated water in the vertical and horizontal directions are shown in Fig. 6.1 and Fig. 6.2. According to these results, it can be estimated that the diffusion area of 3°C will extend up to about 0.04 Km^2 with the maximum length of 250 m distant from the end of outfall, that of 2°C, about 0.09 Km^2 with 350 m and that of 1°C, about 0.97 Km^2 with 1,030 m respectively.

(2) Study on recirculation of discharged heated water

As shown on Fig. 6.1, influence of discharged heated water is approximately extending up to the intake head in the horizontal direction. In the vertical direction, however, the affected zone is below 1.0 m under the water surface as shown in Fig. 6.2. Therefore, it is considered that there will be no recirculation of heated water discharged from the outfall.

Meanwhile, prior to making a detailed study, it will be necessary to confirm the diffusion area of discharged heated water by means of numerical simulation, model test, etc. based on the measured data on vertical distribution of sea water temperature in summer time and tidal current, etc. at the vicinity of the site.

6.11.3 Environmental safety of chemical dosing

(1) No toxicological hazards

Most of high temperature additives (HTA) and anti-foaming agents (AF) now being used commercially in many MSF desalination plants for scale prevention do not present any toxicological hazards under normal condition of use. This was proven by many studies carried out in animals and fishes and also about additives have been given authorized certificate for no toxic hazard.

[A certificate of "no objection on toxicological grounds" by the Netherland Waterworks Testing and Research Institute (KIWA)]

Therefore, HTA and AF are considered to present no toxic hazards under normal condition of use.

(2) Environmental safety

Environmental effects of HTA in applying MSF desalination plant have been studied and checked by several laboratory model tests. HTA do not contain phosphorus or nitrogen to act as a nutrient for micro-organism and are not rapidly biodegraded and keep unchanged, so in the vicinity of sea water outfall, there is no entrophication and oxygen starvation condition.

Also HTA and AF concentration level contained in discharge sea water from desalination plant is extremely low and additionally diluted by discharge sea water from power plant, and this discharged sea water is rapidly spread and diluted to negligible level.

HTA discharged in sea water are polyanomic, so it can be expected to be readily and irreversibly adsorbed on to insoluble inorganic materials such as sand and silts. Then, HTA is degraded by the influence of ultraviolet light and slowly eliminated in the environment.

Most of AF now available in the market is considered to present no toxic hazards under normal condition of use and is a nonionic surface active agent which is readily biodegraded.

In conclusion, no significant harmful effect on the environment caused by chemicals (HTA and AF) are anticipated.

Table 6.1 Prediction of Air Pollution

Item		Type-A						Type-F					
Plant output	(MW)	120						60					
Thermal efficiency	(%)	25						19					
Fuel consumption	(t/h)	38.6						25.4					
Sulpher content	(%)	1.0			1.6			1.0			1.6		
SO_x density	(ppm)	570			914			570			914		
SO_x emission	(Nm^3/h)	270.2			432.3			177.8			284.5		
Chimney height	(m)	80	100	120	80	100	120	80	100	120	80	100	120
Effective chimney height	(m)	165	185	205	165	185	205	141	161	181	141	161	181
Max. ground concentration	(ppm)	0.017	0.014	0.011	0.027	0.022	0.018	0.015	0.012	0.009	0.025	0.019	0.015
Max. distance of ground concentration	(km)	7.1	8.1	9.1	7.1	8.1	9.1	6.0	6.9	7.9	6.0	6.9	7.9

Fig. 6.1 THERMAL DISCHARGE DIFFUSION (HORIZONTAL DISTRIBUTION)

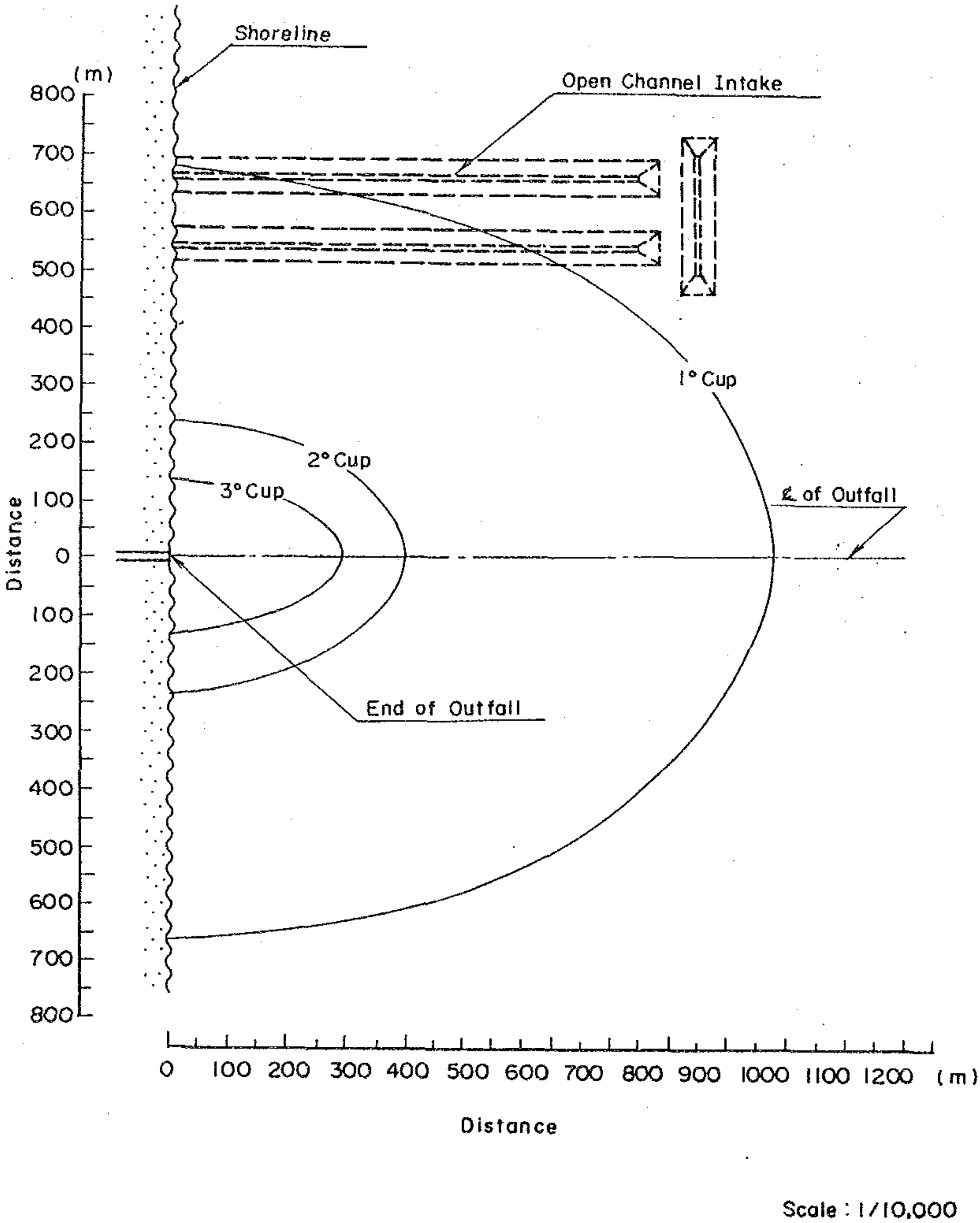


Fig. 6.2 THERMAL DISCHARGE DIFFUSION (VERTICAL DISTRIBUTION)

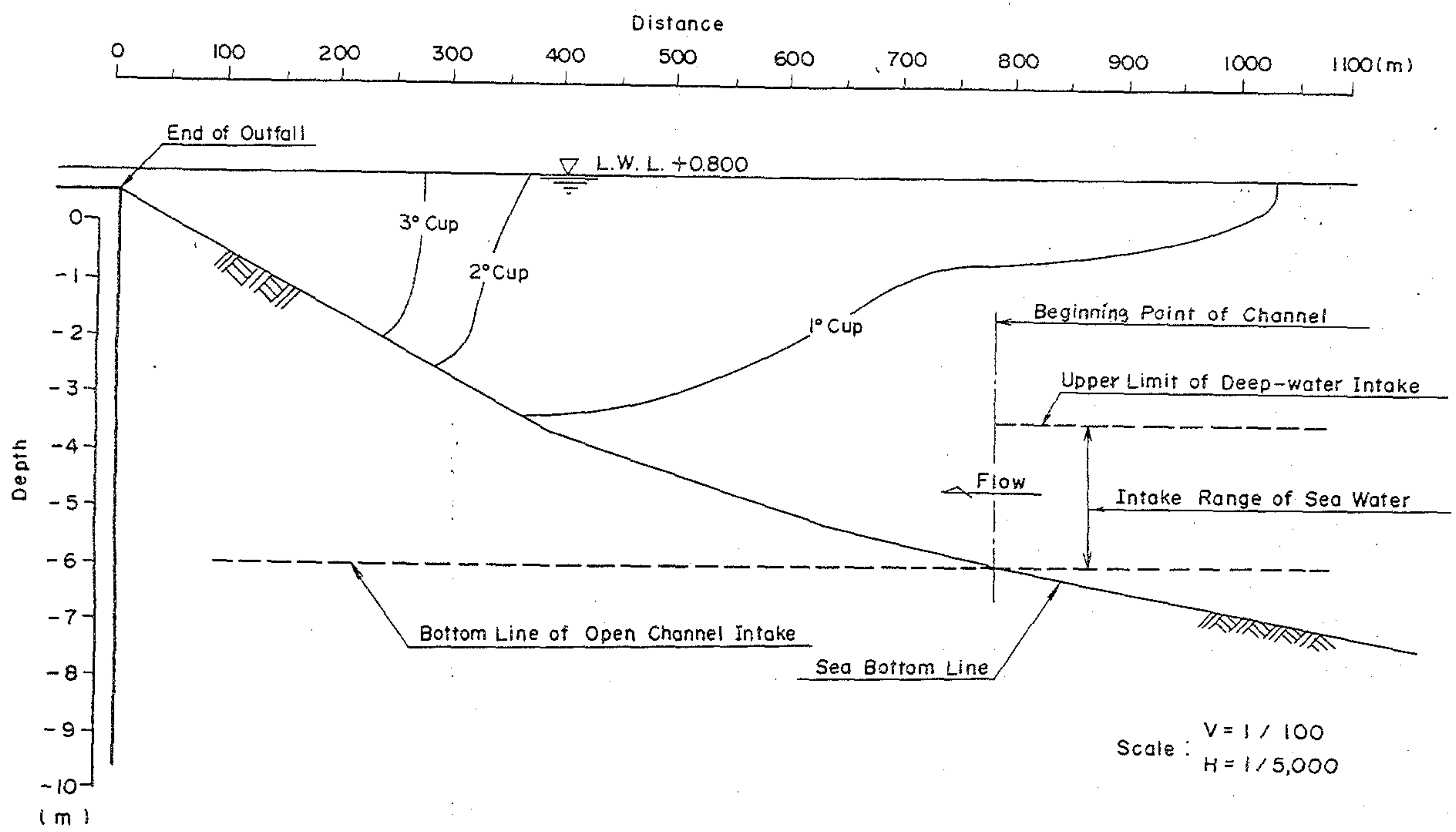


Photo 6.1 GENERAL VIEW OF BARKA SITE

ONSHORE VIEW

OFFSHORE VIEW

Fig. 6. 3 LOCATION OF BARKA SITE

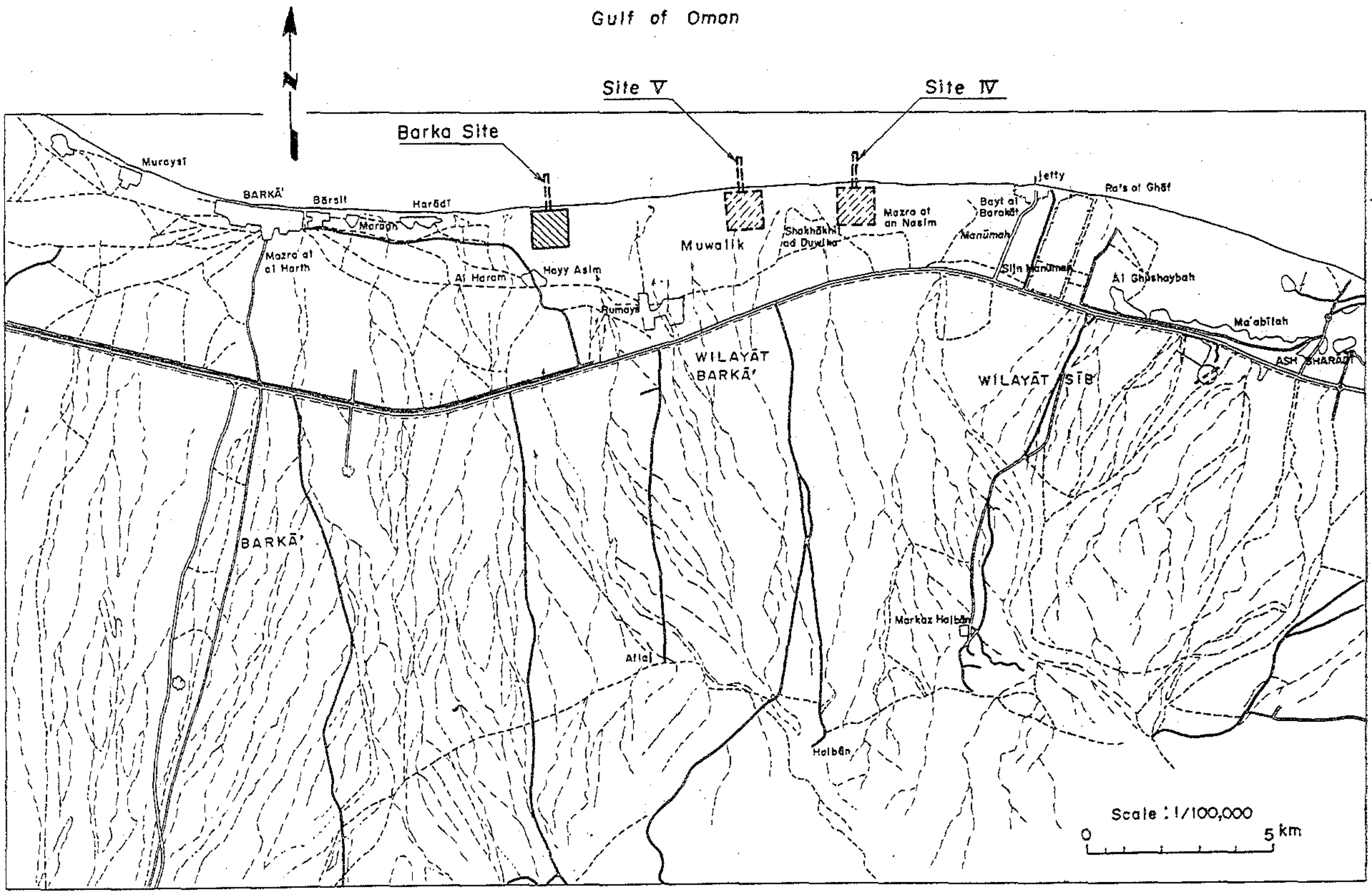
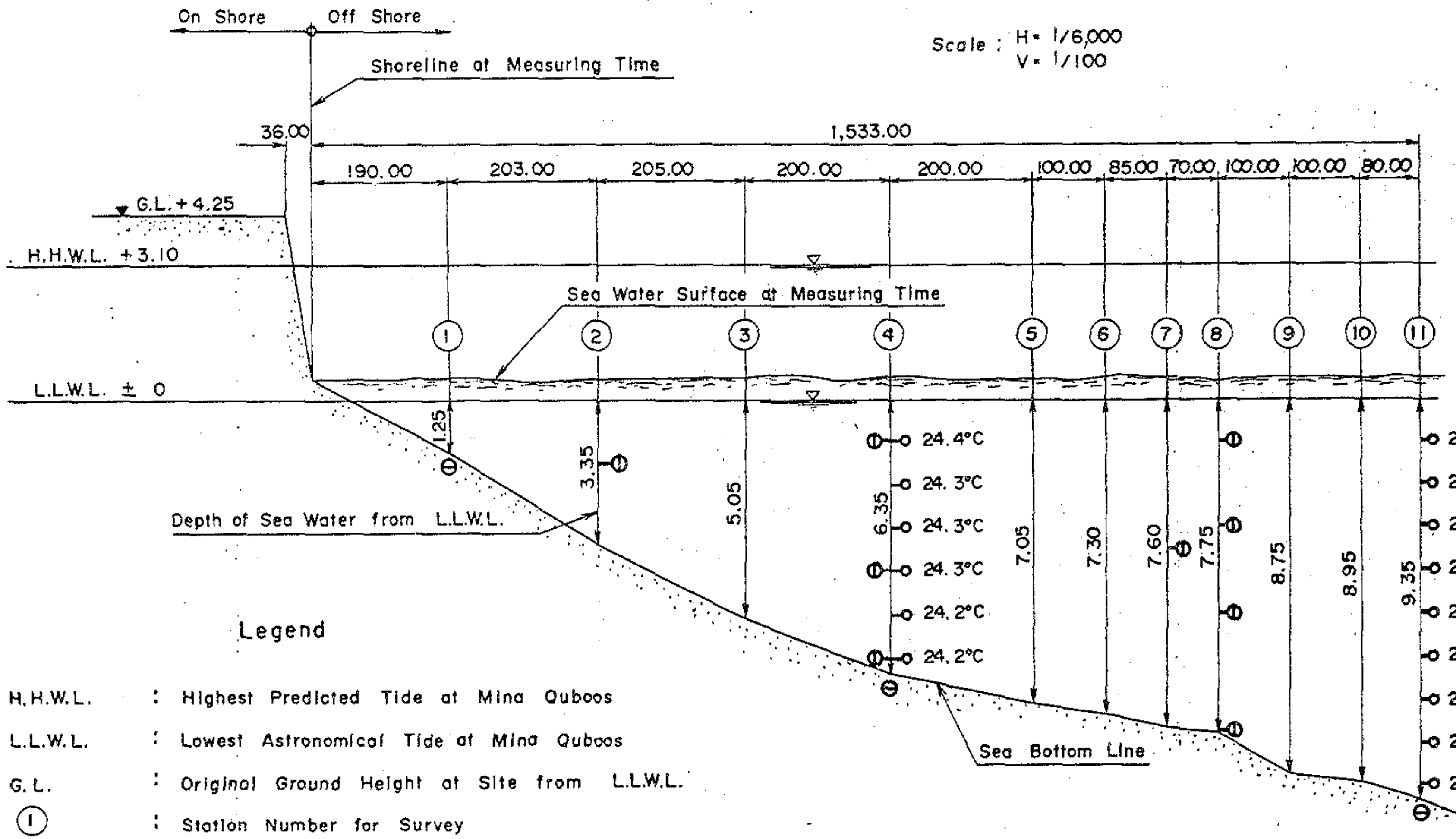


Fig. 6. 4 SUMMARY OF SURVEY RESULT AT BARKA SITE



Legend

H.H.W.L.	:	Highest Predicted Tide at Mina Quboos
L.L.W.L.	:	Lowest Astronomical Tide at Mina Quboos
G.L.	:	Original Ground Height at Site from L.L.W.L.
(1)	:	Station Number for Survey
-o 24.4°C	:	Location and Result of Sea Water Temperature Measuring
-Φ	:	Location of Sea Water Sampling
⊖	:	Location of Sea Bottom Soil Sampling

CHAPTER 7

SELECTION OF TYPE OF POWER PLANT AND SIZE OF POWER UNIT

CHAPTER 7 SELECTION OF TYPE OF POWER PLANT AND UNIT SIZE

7.1 BASIC PLANNING CONDITIONS

Based on the analysis and evaluation in Chapter 4, basic planning conditions for the proposed power plant were determined as follows:

Total capacity of power plant	ca. 700 MW
Maximum allowable size of unit from system operation	ca. 60 - 120 MW
Total capacity of desalination plant	ca. 180,000 m^3/day
Required steam quantity for desalination plant	ca. 990 t/h

7.2 OPERATION MANAGEMENT OF POWER PLANT AND ITS CAPACITY

7.2.1 Forecast load curve for the year 1991

Based on the study on power demand in 1984, load duration curve and typical daily load curve for 1991 are forecasted as shown in Fig. 7.1A and Fig. 7.1B.

As indicated in Fig. 7.1A, peak load occurs during 3 months in the summer season (from middle of May to early in August), low load apears during 3 months in the winter season (from middle of December to early in March) and medium load occurs during 6 months between summer season and winter season.

Each mode shows the deference of load at every season in Fig. 7.1B.

Mode 1 : Group of daily load in summer season
Mode 2 : Group of daily load in intermediate season
Mode 3 : Group of daily load in winter season

Fig. 7.1A Expected distribution of power demand in 1991

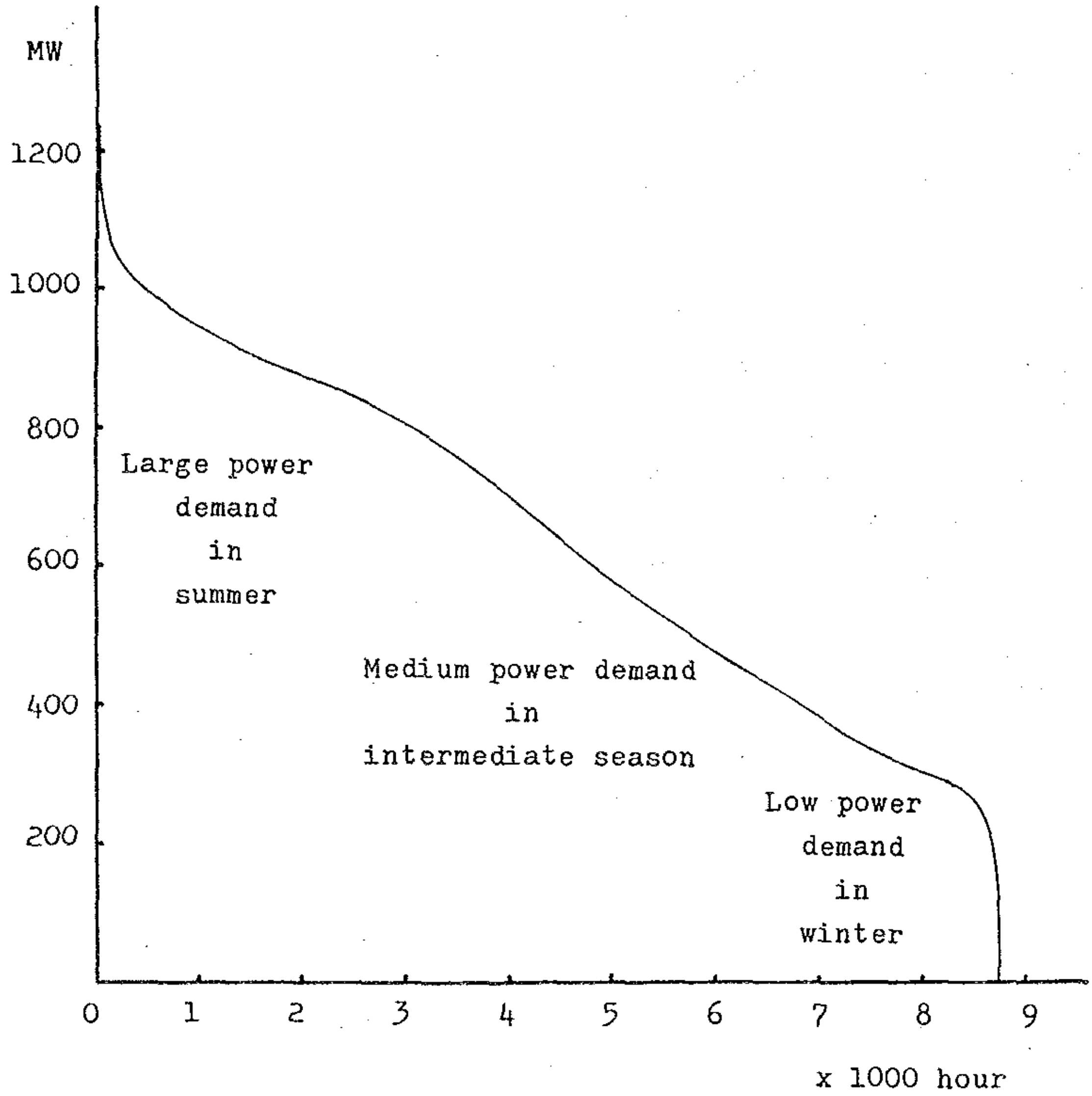
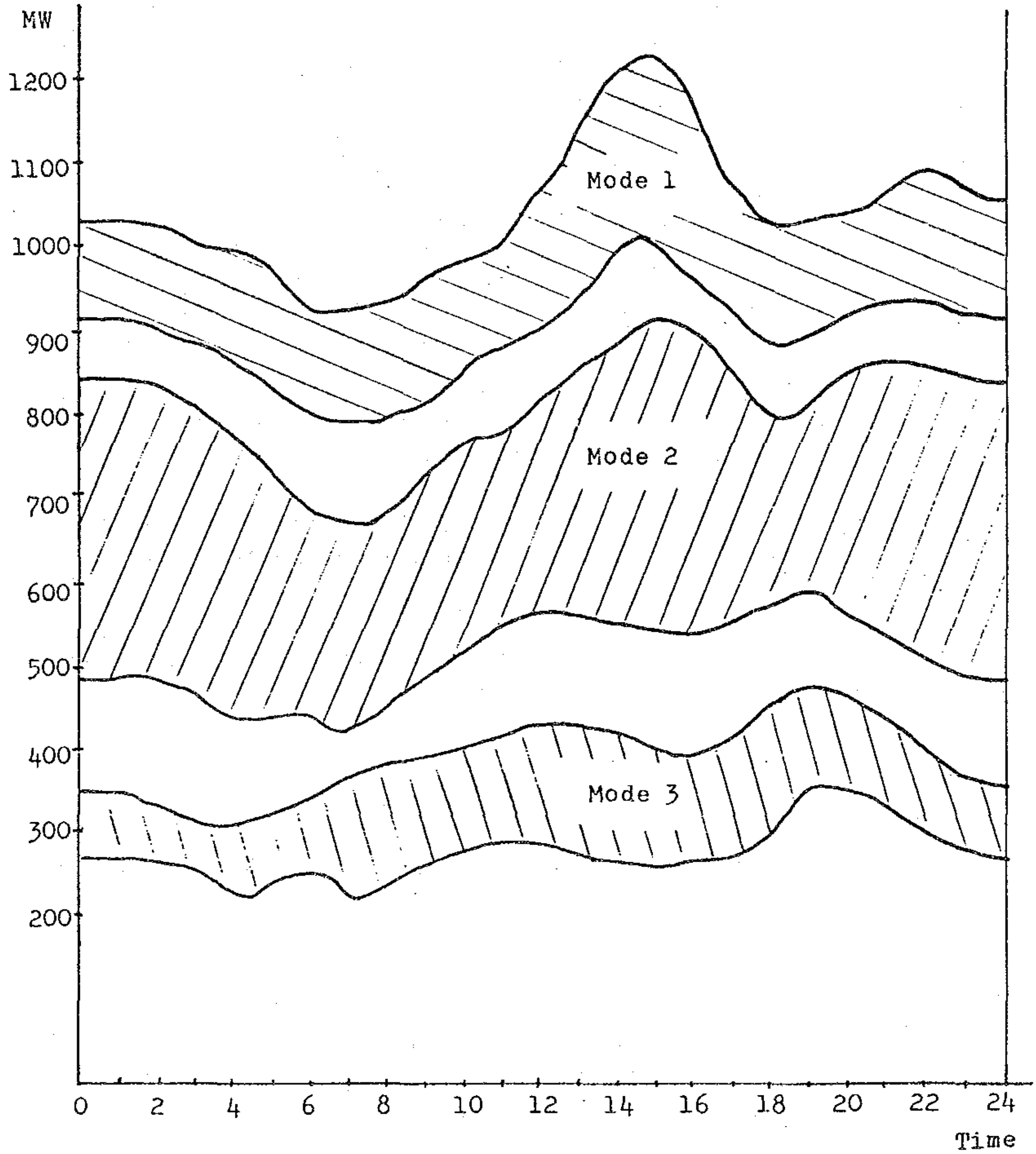


Fig. 7.1B Expected mode of daily power demand in 1991



7.2.2 Load expected for 1991

(1) General

If load expected for 1991 is classified into peak load portion and base load portion for each mode defined in Fig. 7.1B, it is possible to obtain values shown in Table 7.1.

Table 7.1 Expected load for 1991

	Base load portion (MW)	Peak load portion (MW)
Mode 1	800	400
Mode 2	450 - 600	300
Mode 3	300	150

Selection of type of power plant and unit size depends largely on what portion of load is supplied by the proposed power plant.

It is therefore necessary to examine load sharing for the proposed power plant, considering load sharing for the existing power plants at the same time.

Size of daily load varies largely with season, so the proposed power plant must be able to cope with variation of load.

(2) Load sharing by type of turbine generator

Main existing generating facilities in the Capital and Batinah Coast areas consist of gas turbine generators at Rusail, Ghubrah and Sohar and steam turbine generators at Ghubrah.

Since gas turbine generators have low thermal efficiency, they are not suitable for supplying base load. But they are suitable for supplying peak load because they can quickly respond to load variation. Steam turbine generators at Ghubrah are small sized and their thermal efficiency is relatively low. Therefore, Ghubrah steam power plant will have to be operated as a second ranking base load power station.

(3) Annual base load

Base load in the winter season (Mode 3 in Table 7.1) is approximately 300 MW and this value can be regarded as annual base load.

Base load in the intermediate season between summer season and winter season (Mode 2 in Table 7.1) is estimated at 450 to 600 MW. As this season continues rather long, the size of load changes to some extent. In this report, this base load is called intermediate base load.

The base load in the summer season (Mode 1 in Table 7.1) is estimated at 800 MW which is near the sum of annual base load and intermediate base load.

(4) Annual peak load

Peak load portion of any mode can be supplied by the existing gas turbine generators.

Therefore, the proposed power plant will have to play an important role in supplying annual base load and intermediate base load throughout the year.

7.2.3 Load sharing for the proposed power plant and the existing power plants

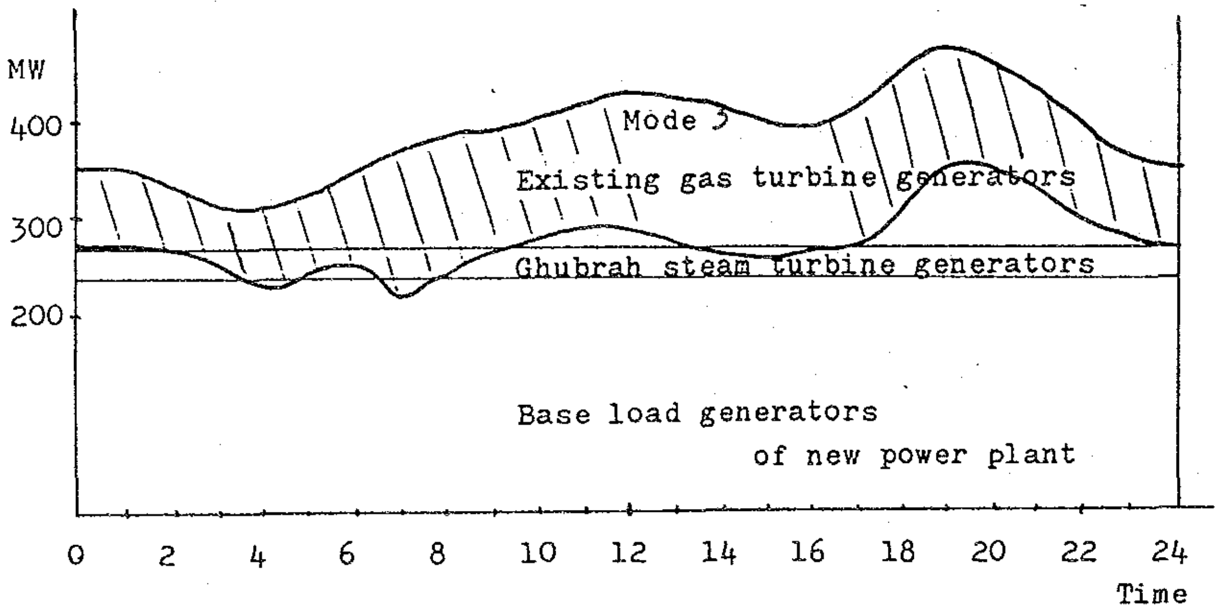
Base load in the winter season is estimated at 300 MW as shown in Table 7.1. Since Ghubrah steam power plant is operated to supply base load, the remaining portion of base load to be supplied by the proposed power plant during the winter season is estimated at approximately 240 MW.

The typical daily load sharing during the winter season is shown in Fig. 7.2.

Since power demand decreases during the winter season, inspection and maintenance of power plant are carried out during this period. Therefore, the proposed power plant must be able to provide base output of about 240 MW, with at least one unit out of service for inspection and maintenance.

Beside the above output requirement based on the power facility development plan, the proposed power plant needs to be operated to supply based load of 80 - 150 MW for a short period of time, as discussed in Chapter 4, in order to reduce the magnitude of a frequency drop due to a generator drop-out from the system.

Fig. 7.2 Representative daily load sharing during the winter season



Base load during the intermediate season is estimated at 450 to 600 MW in Table 7.1. This intermediate base load must be supplied by the proposed power plant, and when considering the operation of steam turbine generators at Ghubrah, the base load to be supplied by the proposed power plant is estimated to be at least 360 MW.

The typical daily load sharing during the intermediate season is shown in Fig. 7.3.

Base load in the summer season is estimated at 800 MW at Mode 1 in Table 7.1. This load will have to be supplied by the steam turbine generators of Ghuburah and those of the proposed power plant to feed annual base load and intermediate base load. The intermediate base load in the summer season is estimated to be approximately 320 to 360 MW.

The typical daily load sharing during the summer season is shown in Fig. 7.4.

It is considered appropriate that the peak load be supplied by the existing gas turbine generators.

Fig. 7.3 Representative daily load sharing during the intermediate season

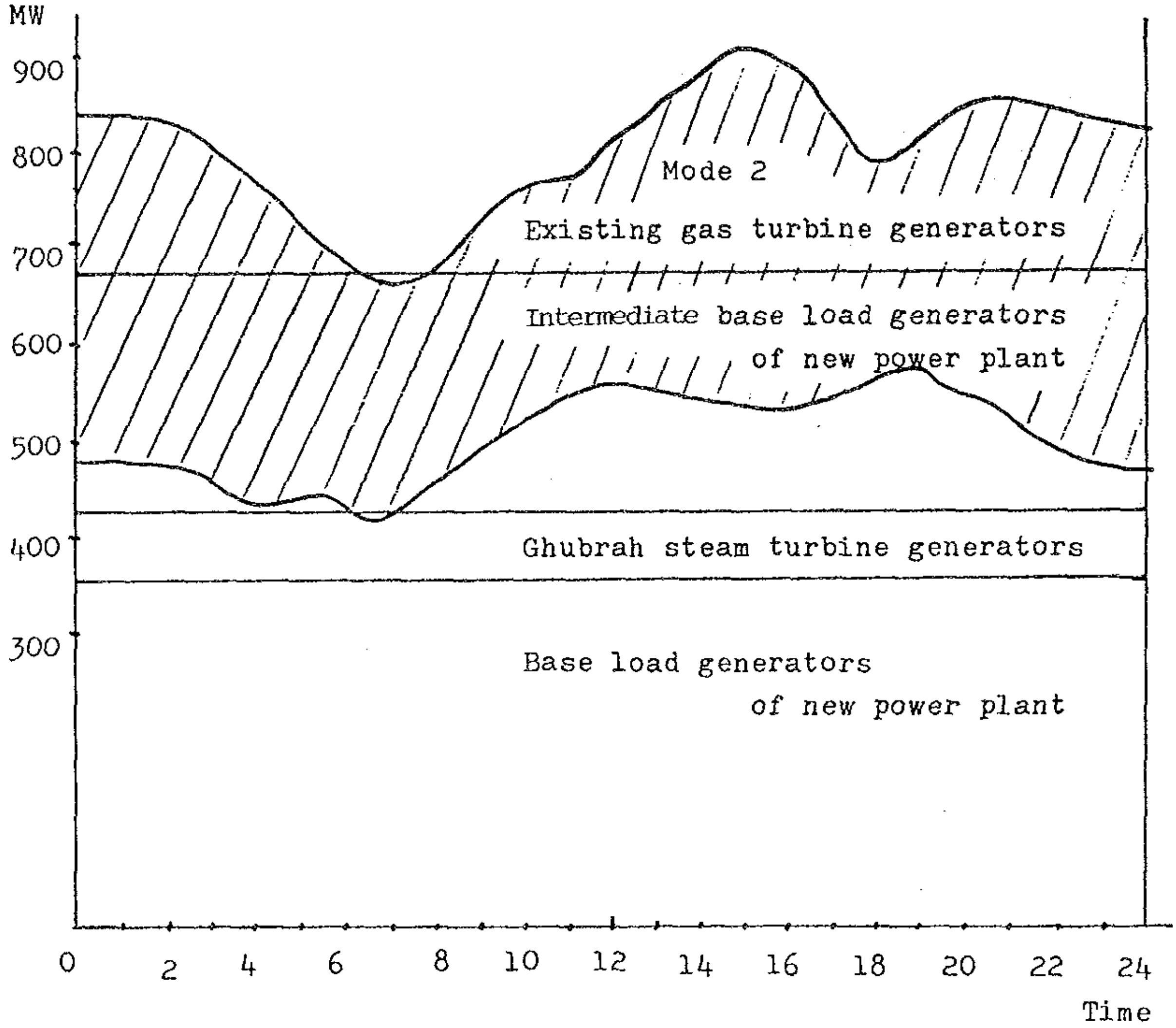
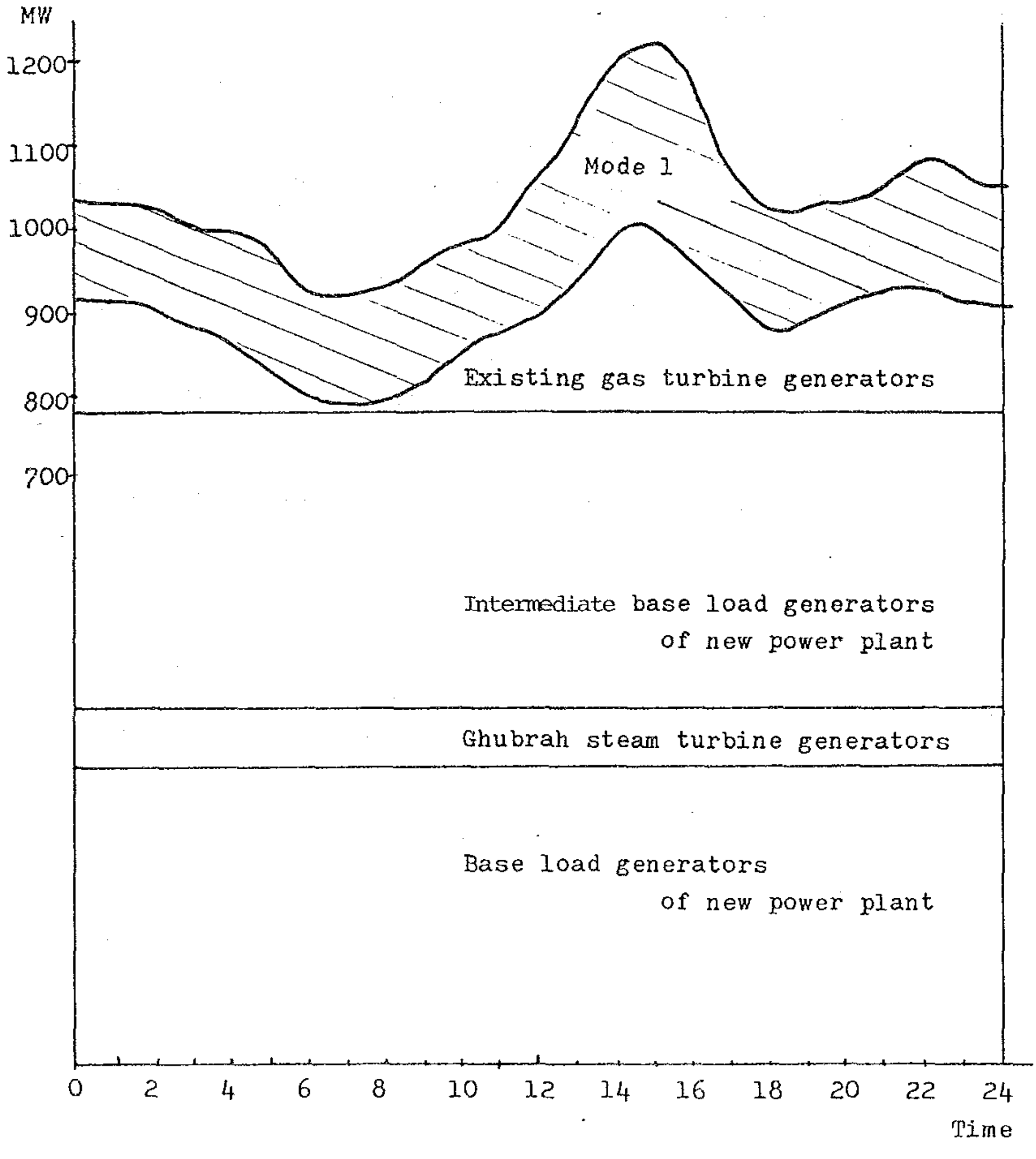


Fig. 7.4 Representative daily load shring during the summer season



7.3 SELECTION OF POWER PLANT TYPE AND UNIT CAPACITY

Based on the basic planning conditions determined from the load and water supply demand forecasts, the JICA survey team established generation system planning procedure (shown on the next page) to select the generation system which is best suited for the country's situation and management of MEW power system.

Main points of the planning procedure are described as follows.

At the first step, selection must be made whether a desalination plant and a power plant are made as a complex system or made as exclusive systems. The complex system has high overall thermal efficiency but lacks flexibility in plant operation since the desalination plant requires a constant rate of steam consumption while the power plant has to satisfy changing load demand. On the other hand, the exclusive systems have higher flexibility in plant operation but lower overall thermal efficiency than the complex system.

To compensate for disadvantages of both systems, the following system configuration is recommended:

a) Complex system will be used for water production and base load generation.

b) Exclusive systems will be used for generation to meet the changing load demand.

Since unit size of the steam turbine generator for base load will significantly affect system operation and desalination plant, it was selected in accordance with the following principle.

Generally, larger the unit size of a power plant, cheaper the construction, operation and maintenance costs per unit size. Therefore, it is appropriate to select unit size as large as possible in the standardized size. However, the selection of unit size of power plant has a close relation with operation of power system. Taking these into accounts, the most suitable unit size for the country's power system was considered for the following two points:

(1): Selection of unit capacity when the new Barka power station is made as a major power source in the system with emphasis on plant economy.

(2): Selection of unit capacity when the new Barka power station is included in the existing power stations in management of power system with emphasis on reliability (distribution of power sources) and stability against fluctuation of frequency in the system.

The system result indicates that unit size of 120 MW class is suitable when the economy is emphasized while 60 MW class is suitable when reliability and stability of the power system are emphasized.

More precisely, 120 MW class requires the total cost of 5% less than 60 MW class.

However, influence exerted on the power system by adopting a unit capacity of 120 MW is larger than that exerted by adopting a unit capacity of 60 MW, i.e. the frequency drop of the power system caused by fault of a turbine generator in the low load period of January and February in 1991 will be 48.75 to 47.50 Hz for the 120 MW unit and 49.17 to 48.33 Hz for the 60 MW unit.

The frequency fluctuation will affect turbine generators significantly; while normal frequency is 50 Hz, allowable lowest frequency of operation is 48.5 Hz and shut down frequency of operation is 47.5 Hz.

Thus, a 120 MW class unit will require a partial load shedding to prevent whole shut down of the power system. For this reason, a 60 MW class unit is recommendable from the viewpoint of reliability and stability of power system.

Generation System Planning Procedure - 1/2

Water Demand Forecast

Annual product value
Daily product value (180kt/d)
Summer and winter variation and day and night variation

Forecast on required Steam Quantity

Annual consumption value
Maximum consumption per hour (990 t/h)
Hourly variation - non
Feature
Steady steam supply to Desalination and ON-OFF operation mode

Kind of Fuel

Natural gas Distillate oil and Heavy fuel able to use both Fuel for steam generator and gas turbine

Power Demand Forecast

Annual power demand in Oman power system
Max and minimum power demand
Power demand variation through season and day

Output of Power at BARKA P/S

Annual generating energy	4,800 GWh
Annual load factor	76 %
Max. generating power	ca. 700 MW
Min. generating power regulated	ca. 200 MW (at 1991)

Feature

About half rated powr use for base load in this power supply plant. Left load will be used for power demand and due to season and daily variation.

Selection of Steam Supply and Power Supply System

Independent System

(1) Exclusive steam generator for desalination plant
- ° Estimated thermal efficiency 80 - 85%

(2) Exclusive power generating plant

a. Steam turbine (condensing)
b. Combined system by gas turbine and steam turbine
- ° Estimated thermal efficiency 40 - 44%
- ° Easy regulate for power demand variation

Complex System

(1) Steam turbine (Steam extraction or Back pressure)
(2) Combined system by Gas turbine and Steam turbine
(3) Gas turbine
- ° Estimated thermal efficiency 60 - 80%
- ° Power generating will be fixed by the water production plan. Steam turbine with back pressure type and Gas Turbine plant are fixed by above water production plan.

*

Technical Evaluation

(1) The point of view on the thermal efficiency. Complex system has higher efficiency than Independent system.

(2) The point of view on the power regulate performance. Independent system has higher performance than Complex system.

Selection of Optimum System

The optimum system will be composed by exclusive power generating system and exclusive complex power generating and desalination system, because excluding power generating system will be responsible for power demand variation through the year without the water production plan on the other hand.
Exclusive complex power generating and desalination system will expect higher performance through base load for power and water production.

* Supplemented explanation shown in Chapter-7 Clause 7.3

continue to "Selection of Power Generation Plant Type"

Generation System Planning Procedure - 2/2

from
"Selection of Steam Supply and Power Supply System"

Selection of Power Generation Plant Type

(1) Total thermal efficiency

a. Base power load and steam for Desalination will be supplied from complex system.

(2) The decision of power generating unit capacity

a. The decision of power generating unit capacity shall be considered by the conditions of influence for frequency variation due to shut down of one unit at Barka P/S. The value of frequency variation shall limit less 1.5 Hz in the Oman power transmission system.
Because, if the frequency variation occur over 1.5 Hz, steam turbine will damage due to turbine blade resonance of final stage.

b. Considering of steady steam and power supply at the time of trouble on one unit, it is better to adopt the plural power units, because plural unit system make large influence to the steam supply to the desalination plant.

(3) The capability for load variation and it's type of power plant

a. Independent system

The capability of steam turbine	100% - 15%
The capability of combine system with Gas Turbine and Steam Turbine	100% - 0%

b. Complex system

The capability of complex system	100% Usually 50% Temporality

(4) Examined type of generation plant (* for steam supply of Desalination)

Type-A	G/S Combined, Steam Turbine (extraction) *
Type-B	G/S Combined *
Type-C	G/S Combined *, Steam Turbine (extraction) *
Type-D	G/S Combined, Gas Turbine *
Type-E and F	G/S Combined, Steam Turbine (back pressure) *

Trial calculation for Fuel consumption of each type

(1) Annual Power generation

(2) Annual Steam consumption

(3) Plant thermal efficiency

Trial calculation for generation cost of each type

(1) Construction cost

(2) Fuel cost

(3) Operation and Maintenance cost

Review of Reliability

It will not be obstacle to each other plant when Generating plant or Desalination plant get any trouble.

Particular Conditions

° Policy of security for power system

° Policy of operation and maintenance work for power plant

Determine system and plant type of generation

Supplemental Explanation for Thermal Efficiency of each Plant Type

1. Introduction

Power and steam supply system was studied in point view of thermal technology. Above system is usually divided into two blocks. One is independent system and the other is complex system for steam and power supply. The independent system has a exclusive steam generator to supply steam to the desalination plant and power generation system will be designed by the exclusive purpose for power generating.

On the other hand, the complex system will be designed by having the capability of steam and power supply from same power unit. The result of comparison of both system shows that it is preferable to select the complex system than independent system.

2. Study Procedure

(1) Basic Conditions

Required thermal energy per one hour

Steam $990 \ ^{t/H} \times 10^3 \ ^{kg/H} \times (650 - 120) \ ^{kcal/kg}$
$\fallingdotseq 525 \times 10^6$ kcal/H

Power $720 \ ^{MW} \times 10^3 \ ^{KW} \times 860 \ ^{kcal/kWh}$
$= 619 \times 10^6$ kcal/H

Total energy $= 1,144 \times 10^6$ kcal/H

(2) Case Study Procedure

Case study is made for the following system.

(2)-1 Independent system

Composition (Steam by exclusive steam generator
Power by steam turbine plant

(2)-2 Independent system

Composition (Steam source is same as above.
Power by combined cycle plant of gas turbine and steam turbine

(2)-3 Complex system

Type-A
Type-B
Type-C
Type-D
Type-E
Type-F

(3) Calculation of required energy and system performance

Case (2)-1 Independent system

Required energy for exclusive steam generator
(thermal efficiency of above generator ≈ 0.8 - 0.85)
$= 525 \times 10^6$ kcal/H ÷ 0.85
$= 618 \times 10^6$ kcal/H

Required power energy for steam turbine plant
(Thermal efficiency of steam turbine plant ≈ 0.35 - 0.4)
$= 619 \times 10^6$ kcal/H ÷ 0.4
$= 1,548 \times 10^6$ kcal/H
Total required energy $= 2,166 \times 10^6$ kcal/H

Thermal efficiency as total system

$$= \frac{1,144 \times 10^6}{2,166 \times 10^6} \times 100 = 53\%$$

Case (2)-2 Independent system

Required energy for exclusive steam generator
= same energy in case of (2)-1
$= 618 \times 10^6$ kcal/H

Required power energy for combined cycle plant

(Thermal efficiency of combined cycle plant = 42 - 44%)

$= 619 \times 10^6$ kcal/H $\div$ 0.44

$= 1,407 \times 10^6$ kcal/H

Total required energy $= 2,025 \times 10^6$ kcal/H

Thermal efficiency as total system

$$= \frac{1,144 \times 10^6}{2,025 \times 10^6} \times 100 = 56\%$$

Case (2)-3 Complex system

The following values are introduced in the Chapter-7 in the Report.

Thermal efficiency as total system in each complex system.

Type-A	:	65%
Type-B	:	70%
Type-C	:	65%
Type-D	:	63%
Type-E	:	58%
Type-F	:	59%

3. Type-A and C

(a) G/S combined system

Power generation	360 MW
Thermal efficiency	44%

Required energy $360 \times 10^3 \times 860 \div 0.44 = 704 \times 10^6$ kcal/h

(b) S/T and desalination System

Power generation	360 MW
Steam generation (for desalination plant)	990 t/h
Thermal efficiency	78%

Required energy

$= \{360 \text{ MW} \times 10^3 \times 860 + 990 \text{ t/h} \times 10^3 \times (650-120)\} \div 0.78$

$= 1,070 \times 10^6$ kcal/h

(c) Thermal efficiency as total system

Total generating energy $1,144 \times 10^6$ kcal/h
(shown in 2-(1) basic condition)

Total required energy
$= (704 + 1,070) \times 10^6 = 1,774 \times 10^6$ kcal/h

Thermal efficiency as total system

$$= \frac{1,144 \times 10^6}{1,1774 \times 10^6} \times 100 \doteqdot 65\%$$

4. Type-B

(a) G/S combind and desalination system

Power generation	720 MW
Steam generation (for desalination plant)	990 t/h
Themal efficiency	70%

Required energy
$= \{720 \text{ MW} \times 10^3 \times 860 + 990 \text{ t/h} \times 10^3 \times (650-120)\} \div 0.7$
$= 1,634 \times 10^6$ kcal/h

(b) Thermal efficiency as total system

Total generating energy $1,144 \times 10^6$ kcal/h

Total required energy $1,634 \times 10^6$

Thermal efficiency as total system

$$= \frac{1,144 \times 10^6}{1,634 \times 10^6} \times 100 \doteqdot 70\%$$

5. Type-D

(a) G/S combind system

Power generation	360 MW
Thermal efficiency	44%

Required energy

= 360 MW x 860 ÷ 0.44 = 704 x 10^6 kcal/h

(b) Gas turbine and desalination system

Power generation	400 MW
Steam generation (for desalination plant)	900 t/h
Thermal efficiency	74%

= [400 MW x 10^3 x 860 + 990 t/h x 10^3 x (650-120)] ÷ 0.74

= 1,174 x 10^6 kcal/h

(c) Thermal efficiency as total system

Total generating energy 1,144 x 10^6 kcal/h

= (360+400) MW x 10^3 x 860 + 990 t/h x 10^3 x (650-120)

= 1,179 x 10^6 kcal/h

Total required energy

= (704 + 1,179) x 10^6 = 1,883 x 10^6 kcal/h

Thermal efficiency as total system

$$= \frac{1,179 \times 10^6}{1,883 \times 10^6} \times 100 \doteqdot 63\%$$

6. Type-E

(a) G/S combind system

Power generation	480 MW
Thermal efficiency	44%

Required energy

= 480 MW x 10^3 x 860 ÷ 0.44 = 938 x 10^6 kcal/h

(b) Gas turbine system

Power generation	80 MW
Thermal efficiency	29%

Required energy

= 80 MW x 10^3 x 860 ÷ 0.29 = 237 x 10^6 kcal/h

(c) Steam turbine with back pressure and desalination system

Power generation	160 MW
Steam generation (for desalination plant)	990 t/h
Themal efficiency	82%

Required energy

$= [160 \text{ MW} \times 10^3 \times 860 + 990 \text{ t/h} \times 10^3 \times (650-120)] \div 0.82$

$= 808 \times 10^6$ kcal/h

(d) Thermal efficiency as total system

Total generating energy $1,144 \times 10^6$ kcal/h

(shown in 2-(1) basic condition)

Total required energy

$= (938 + 237 + 808) \times 10^6 = 1,983 \times 10^6$ kcal/h

Thermal efficiency as total system

$= \frac{1,144 \times 10^6}{1,983 \times 10^6} \times 100 \doteqdot 58\%$

7. Type-F

(a) G/S combind system

Power generation	480 MW
Thermal efficiency	44%

Required energy

$= 480 \text{ MW} \times 10^3 \times 860 \div 0.44 = 938 \times 10^6$ kcal/h

(b) Gas turbine system

Power generation	80 MW
Thermal efficiency	29%

Required energy

$= 80 \text{ MW} \times 10^3 \times 860 \div 0.29 = 237 \times 10^6$ kcal/h

(c) Steam turbine with back pressure and desalination system

Power generation	180 MW
Steam generation (for desalination plant)	990 t/h
Themal efficiency	86%

Required energy

$= \{ 180 \text{ MW} \times 10^3 \times 860 + 990 \text{ t/h} \times 10^3 \times (650-120) \} \div 0.86$

$= 790 \times 10^6$ kcal/h

(d) Thermal efficiency as total system

Total generating energy

$= (560 + 180) \text{ MW} \times 10^3 \times 860 + 990 \text{ t/h} \times 10^3 \times (650-120)$

$= 1{,}161 \times 10^6$ kcal/h

Total required energy

$= (938 + 237 + 790) \times 10^6 = 1{,}965 \times 10^6$ kcal/h

Thermal efficiency as total system

$= \frac{1{,}161 \times 10^6}{1{,}965 \times 10^6} \times 100 \fallingdotseq 59\%$

7.4 TYPE AND FEATURE OF POWER PLANT

Type of thermal power plant can be broadly classified into two types; the one consisting of steam turbine cycle generators and the other consisting of gas turbine generators.

For this project, the plant type was studied in the form of combination of various types of turbine on the assumption that the power plant will be operated for dual purpose of power and desalination.

In this Study, a complex system having higher overall thermal efficiency was selected as discussed in 7.3. Then the following six types of power plant based on the complex system were compared:

Type-A: Power plant consisting of steam turbine cycle generators supplying steam to desalination plant and gas/steam combined cycle generators

Type-B: Power plant consisting of gas/steam combined cycle generators supplying steam to desalination plant

Type-C: Power plant consisting of steam turbine cycle and gas/steam combined cycle generators, supplying steam to desalination plant

Type-D: Power plant consisting of gas turbine cycle generators supplying steam to desalination plant and gas/steam combined cycle generators

Type-E: and Type-F Power plant consisting of back pressure steam turbine cycle generators supplying steam to desalination plant, gas/steam combined cycle generators and gas turbine generator.

The six types are roughly classified into Type A Series and Type B Series as shown below:

Type-A Series ... Type-A, Type-C, Type-E, Type-F
Type-B Series ... Type-B, Type-D

In Type A Series, steam required for the desalination plant is supplied by steam turbine cycle generators. On the other hand, in Type B Series, steam required for the desalination plant is supplied by gas/steam combined cycle generators or gas turbine generators.

(1) Type-A power plant

The system diagram of Type-A power plant is shown in Fig. 7.5. This type of power plant consists of 3 units of steam turbine cycle generator supplying base load and gas/steam combined cycle generators supplying intermediate base load.

Approximately a half of thermal energy in flue gas discharged from the gas turbine can be recovered and reused. Thus, the combined cycle is generally designed with two gas turbines and one steam turbine generator having the same output (e.g., two 80 MW gas turbines and one 80 MW steam turbine generators).

Since the intermediate base load is estimated at about 360 MW as described in paragraph 7.2 three units of each 80 MW gas turbine (240 MW), however are combined with steam turbine of 120 MW.

Since the combined cycle system has high efficiency under high load conditions, the recent systems are designed with 3 or more gas turbines and one steam turbine generator. In other words, small steam turbine generators can be employed for low load conditions or partial load operations. However, since it is anticipated that utilization factor of combined cycle power generation will increase in the country after 1991 with high load factor operations, 120 MW steam turbines considered in this Study appear to be suitable in terms of technology and economy.

As discussed in 7.3, steam to the desalination plant will be supplied only by steam turbine cycle generators which will supply base load, ensuring a constant amount of steam supply throughout the year.

When one or more units of the steam turbine cycle generators stops operation for periodical inspection and maintenance, the supply of steam to the desalination plant will be made by auxiliary steam generator, or steam turbine generators having surplus capacity for this purpose. Since partial stop of power plant for inspection and maintenance is carried out in general in the winter season when demands for electric power and water decrease, the supply of steam to the desalination plant by auxiliary steam generator is considered suitable. However, the desalination plant is also stopped for maintenance in the winter season, the operation of auxiliary steam generator will be rarely needed.

As the steam turbine cycle generators and gas/steam combined cycle generators, in the Type-A, are separated each other and operated independently for power generation, the operation and control of the Type-A power plant are simple and easy, and the automatic control technique for this type of power plant is well established.

The steam turbine cycle generators are capable to withstand continuous operation for a long period, having high reliability of operation to supply base load throughout the year.

Fig.7.5 Diagram of Type-A

Power plant consisting of steam turbine cycle generators supplying steam to desalination plant and gas/steam combined cycle generators

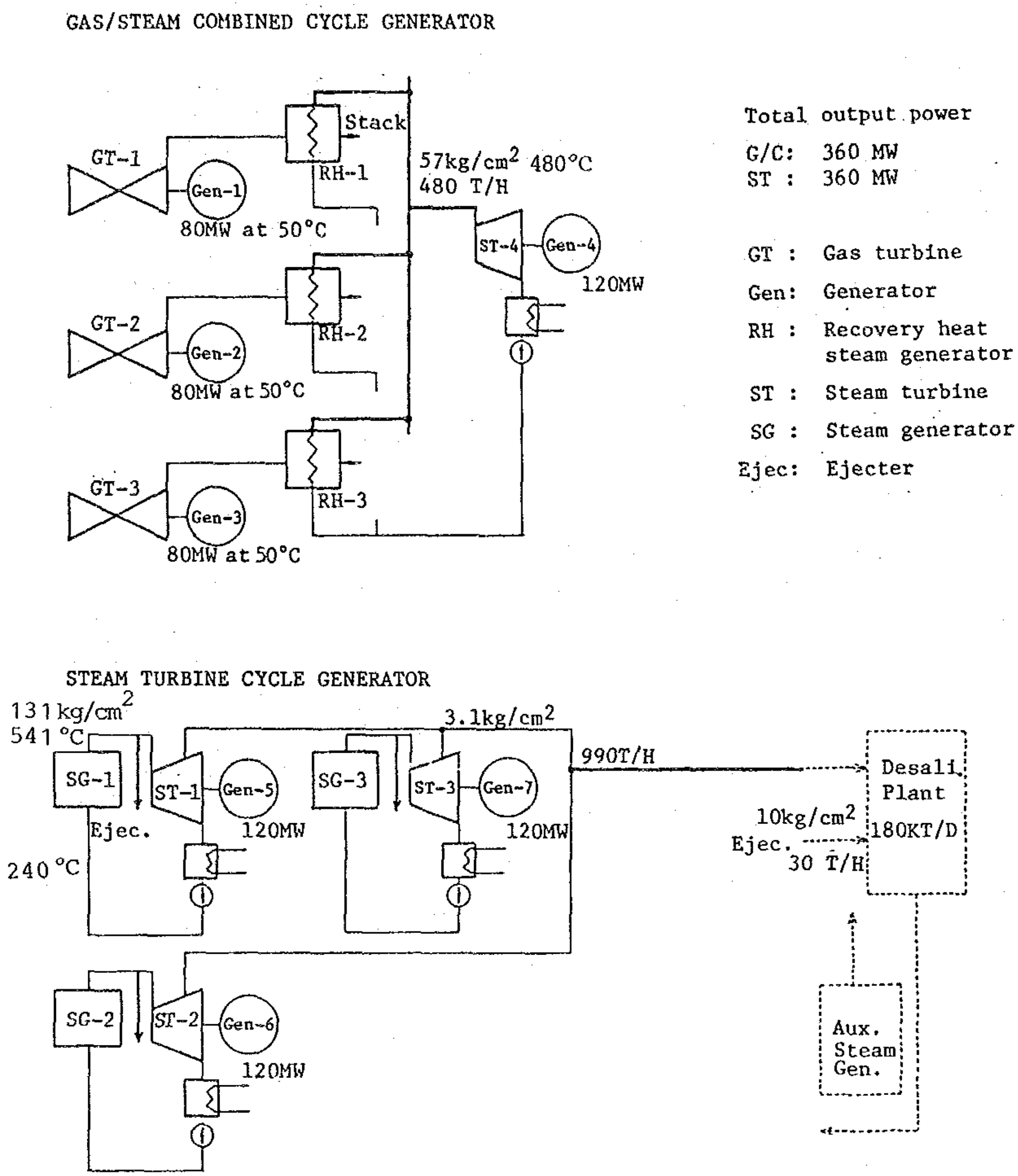
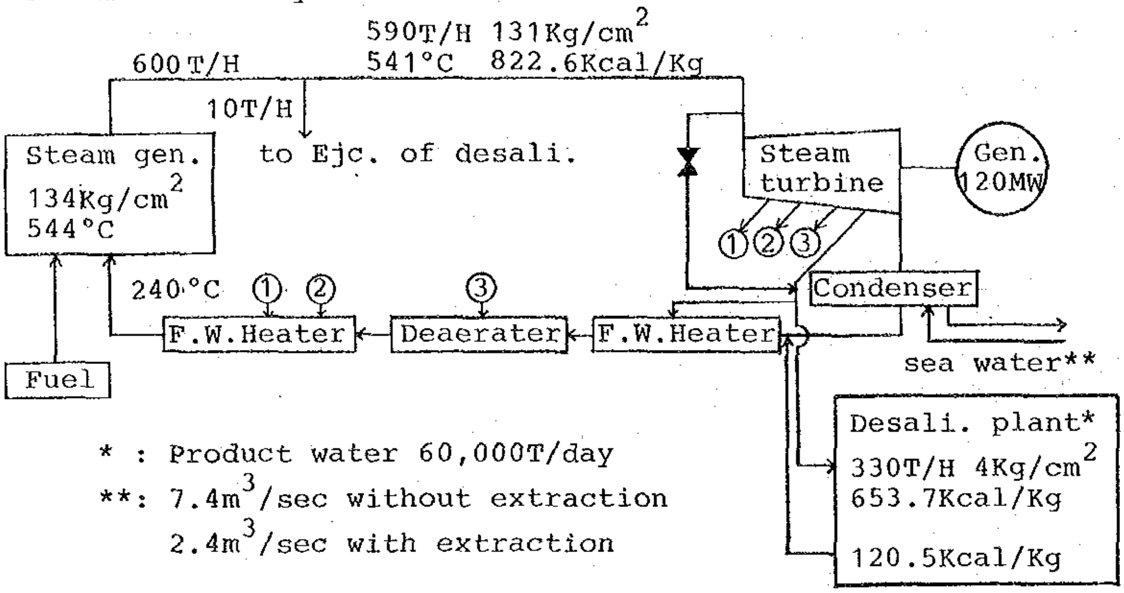


Fig.7.5B Pressure &temp. of Type-A power plant

Steam turbine cycle

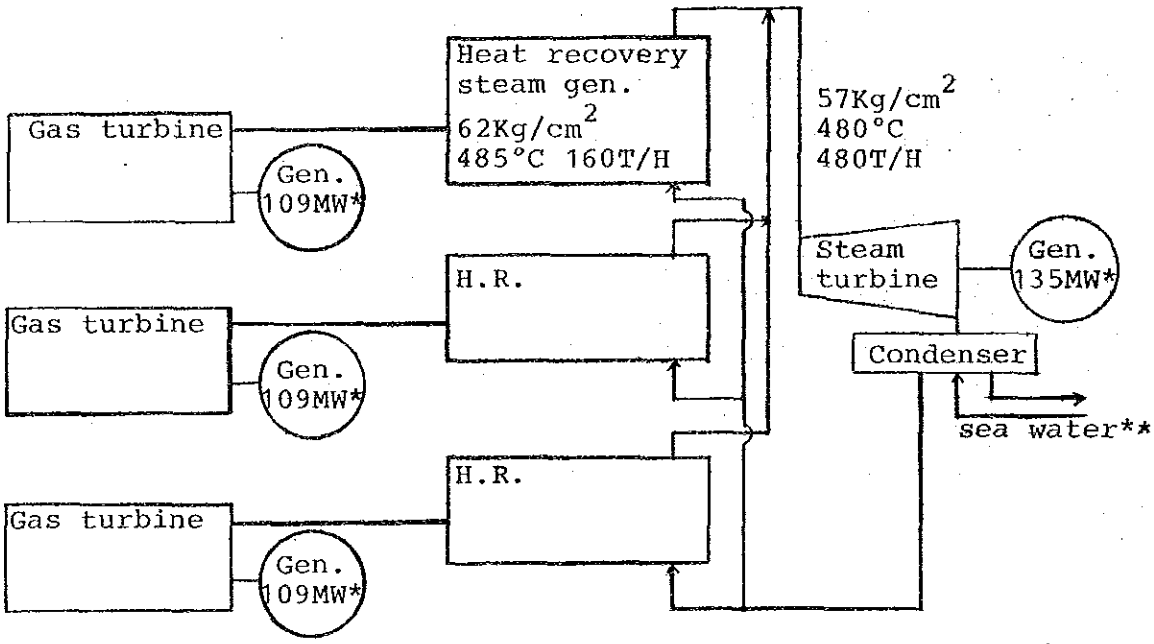


* : Product water 60,000T/day

**: 7.4m^3/sec without extraction

2.4m^3/sec with extraction

Gas/steam combined cycle



* : ISO rate

**: 12.5 m^3/sec

(2) Type-B power plant

The system diagram of Type-B power plant is shown in Fig. 7.6.

This type of power plant consists of gas/steam combined cycle generators only, and they are operated for supplying both the annual base load and the intermediate base load. The steam generating system is operated to supply steam to the power plant and the desalination plant.

When the desalination plant is operated at full capacity of 180,000 m^3/d and the power plant at full capacity of 720 MW, this power plant will have the highest thermal efficiency among the considered types of power plant.

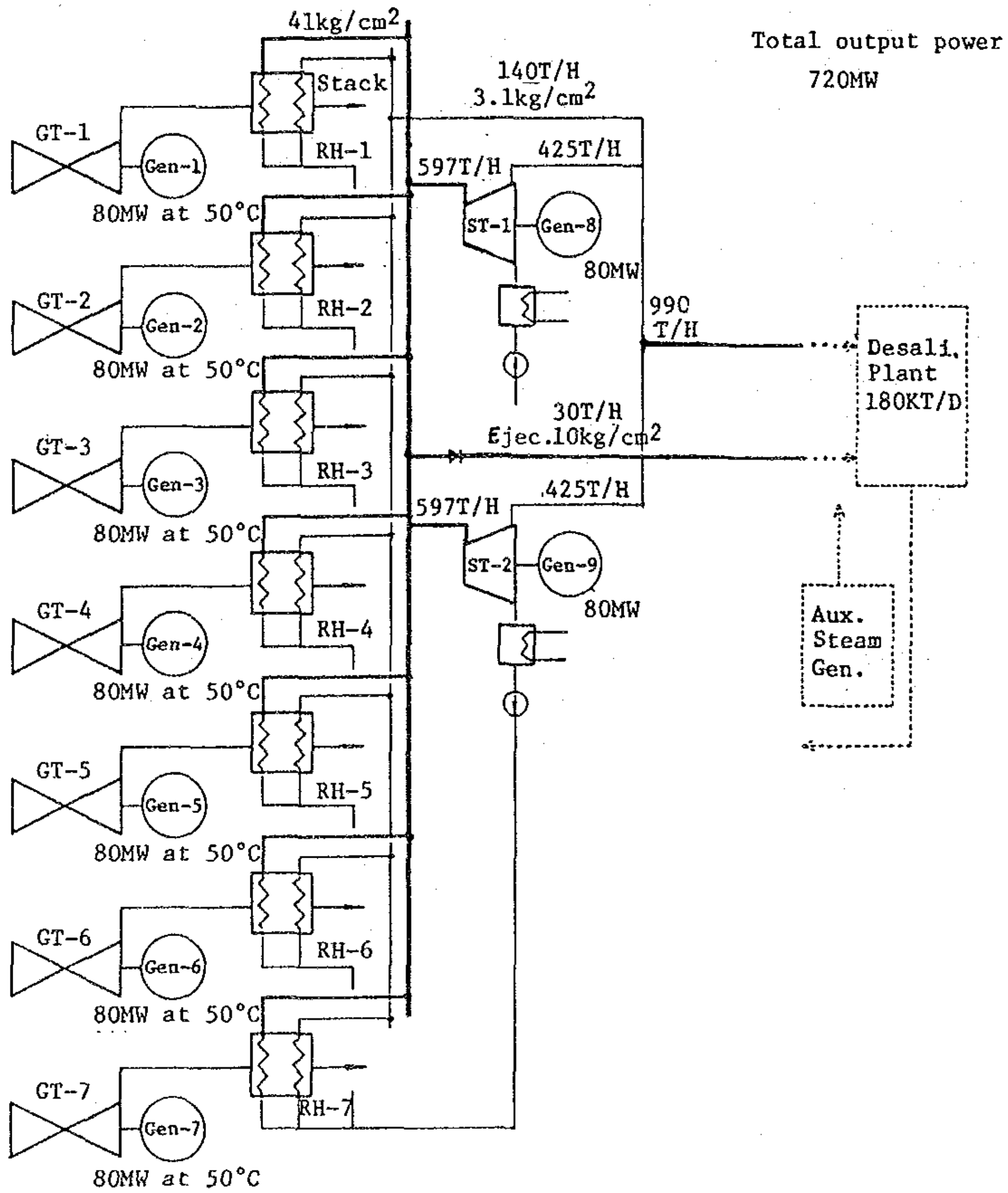
Theoretically, this type of power plant can cope with wide load variation, by reducing load or by stopping gas turbine or steam turbine cycle generators. Further, gas turbine cycle generators can be operated by turns throughout the year.

However, in order to produce required quantity of steam for the desalination plant, at least 5 units of gas turbine cycle generator (approximately 400 MW) must be operated.

Since 7 units of gas turbine cycle generator and 2 units of steam turbine cycle generator are combined in a single system, the operation and control of the power plant are complicated. In particular, since each unit has different characteristics, the automatic control technique will be further complicated and difficult. It is also difficult to realize protective devices and protective techniques to minimize effects on the normally operating portions by separating faulty points when partial failures occur.

Fig.7.6 Diagram of Type-B

Power plant consisting of gas/steam combined cycle generators supplying steam to desalination plant



(3) Type-C power plant

The system diagram of Type-C power plant is shown in Fig. 7.7.

This type of power plant is in such a configuration that the gas/steam combined cycle generators of Type-A power plant can also supply steam to the desalination plant. Therefore, its power generating system is basically the same as that of Type-A power plant.

When the power plant is designed under the condition of steam flow rate shown on Fig. 7.7, and both steam turbine cycle generators and gas/steam combined cycle generators are simultaneously operated, the power plant can operate at high thermal efficiency.

However, since it is impossible to expect continuous output power throughout the year from gas/steam combined cycle generators, attention must be paid to the fact that the quantity of steam supplied to the desalination plant varies accordingly. Therefore, the steam turbine cycle generators should have a capacity enough to supply steam in a given quantity to the desalination plant even when all the gas/steam combined cycle generators are stopped.

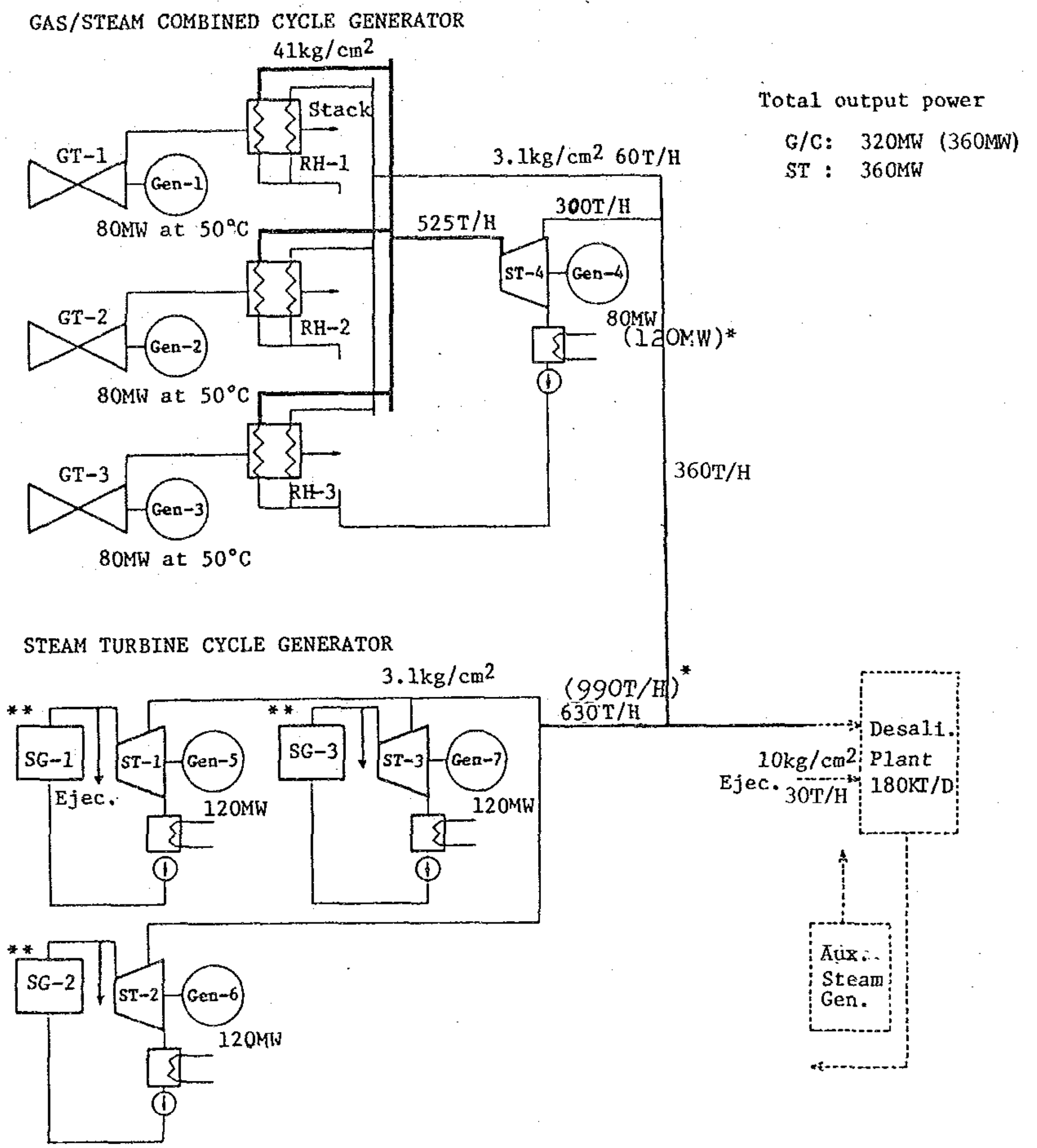
Therefore, it will be necessary to design the steam turbine cycle generators of Type-C power plant to have the same capacity as that of Type-A power plant.

As compared with Type-A power plant, the output capacity of ST-4 (Gen-4) of the gas/steam combined cycle drops to 80 MW because steam is supplied to the desalination plant. However, when steam is not supplied to the desalination plant from gas/steam combined cycle generators, ST-4 (Gen-4) can generate the same output as that of Type-A power plant. Therefore, it is appropriate to design ST-4 (Gen-4) to have the same capacity of 120 MW as in the case of Type-A power plant.

In the case of Type-C power plant, steam can be supplied to the desalination plant from both steam turbine cycle generators and gas/steam combined cycle generators even when they are partially stopped for inspection and maintenance. This is advantageous when compared with Type-A power plant.

In Type-C power plant, the steam generating system to feed desalination plant is common for steam turbine cycle generators and gas/steam combined cycle generators. However, since these two groups of generators are separated each other as in the case of Type-A power plant, the operation and control of the power plant are simple and easy, and automatic control technique and reliability for this type of power plant are well established.

Fig.7.7 Diagram of Type-C
Power plant consisting of steam turbine cycle and gas/steam combined cycle generators, supplying steam to desalination plant



* Numerical value in ( ) is max. rated capacity.

** Pressure & temp. of steam turbine cycle are same value of Type-A

(4) Type-D power plant

The system diagram of Type-D power plant is shown in Fig. 7.8.

This type of power plant has almost the same configuration as Type-A power plant. The steam turbine cycle generators in Type-A power plant are changed into gas turbine cycle generators in Type-D power plant.

Without having complicated combined cycle function, 5 units of gas turbine cycle generators are continuously operated to supply base load, and the whole quantity of steam produced by heat recovery steam generators is supplied to the desalination plant.

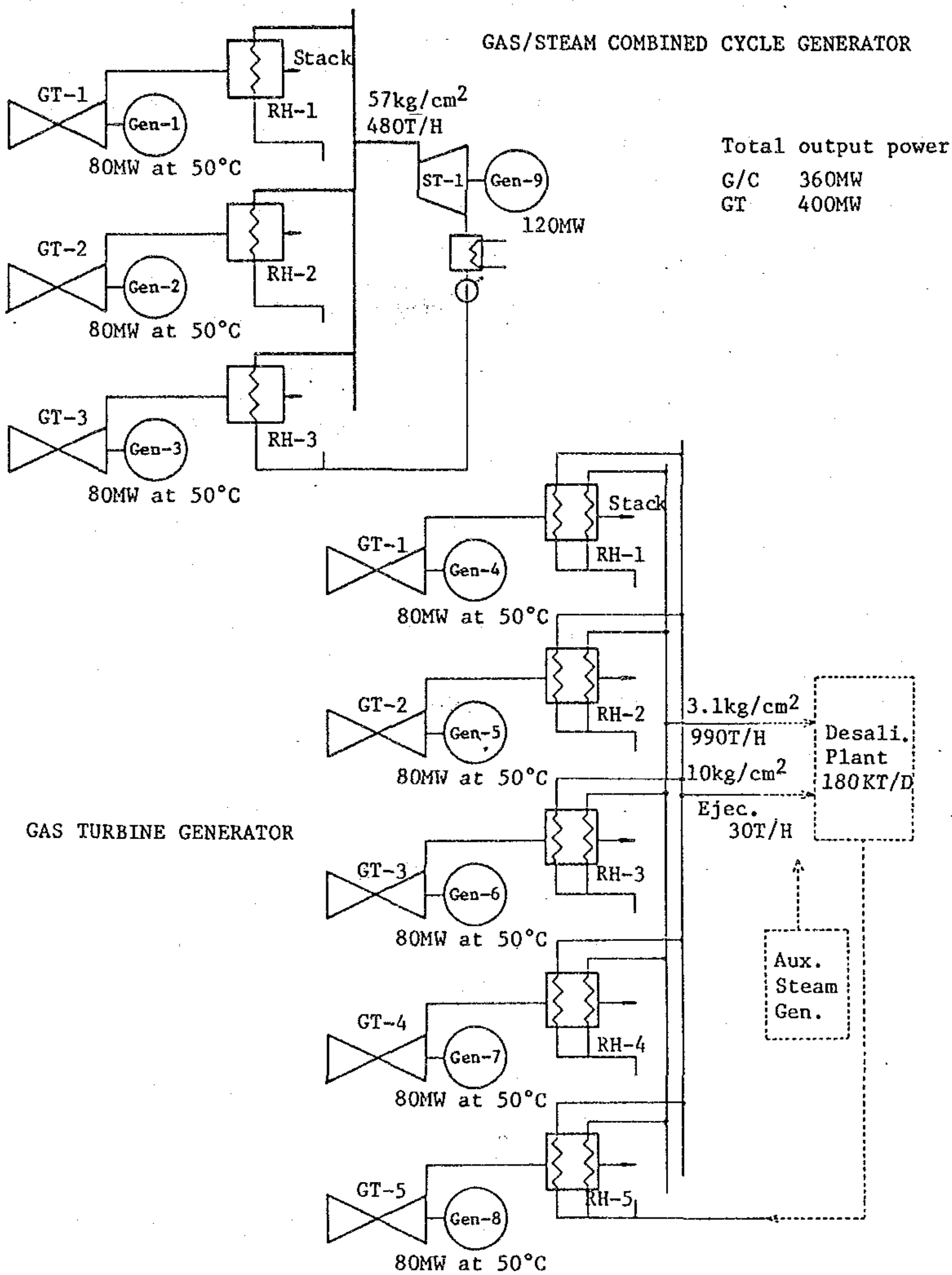
When the gas turbine cycle generators are partially stopped for inspection and maintenance, the steam supplied to the desalination plant becomes short. Therefore, the steam must be supplied by the auxiliary steam generator (or it is possible to provide a system capable to supply steam from gas/steam combined cycle generators as in the case of Type-C power plant).

Similar to Type-B power plant, the total output of approximately 400 MW is required for this power plant to produce necessary quantity of steam for the desalination plant.

Since the gas turbine cycle generators are divided into 2 groups which can be independently operated, the operation and control of this type of power plant are more simple than Type-B power plant, and the automatic control technique is well established.

Fig.7.8 Diagram of Type-D

Power plant consisting of gas turbine generators supplying steam to desalination plant and gas/steam combined cycle generators



(5) Type-E power plant

The system diagram of Type-E power plant is shown in Fig. 7.9.

This type of power plant consists of 2 units of back pressure steam turbine cycle generators to supply annual base load and gas/steam combined cycle generators to supply intermediate base load.

The steam from back pressure turbines is supplied to the desalination plant at almost constant flow rate throughout the year.

Because the quantity of back pressure steam is controlled by the quantity of water produced at the desalination plant, the power output cannot be controlled independently in accordance with load variation. Therefore, it is suitable that the annual base load be supplied by the back pressure steam turbine cycle generators.

Since the back pressure steam turbine has not condenser, the turbine system is more simple than that of other types of power plant.

The thermal efficiency of this power plant is low, but it becomes high when the turbine cycle is operated together with the desalination plant.

In this power plant, since the gas/steam combined cycle consists of 2 units of gas turbine and a steam turbine, the thermal efficiency at partial load is higher than that of type-A power plant.

A gas turbine generator (GT-3) is added to meet the peak load expected for 1991.

However, as described in 7.3, the combination of 3 units of gas turbine cycle generators and a steam generator is more advantageous in operation. Therefore, it is appropriate that the gas turbine (GT-3) be equipped with heat recovery steam generator to feed the steam turbine, as shown in Fig. 7.9.

Since this type of power plant has 2 systems of combined cycle generators and a gas turbine generator, the operation and control are simple and easy, except for the system of back pressure steam turbines.

This type of power plant has great advantage in giving less impact to the system when one unit fails down since its maximum unit size is 80 MW, in cimparison to 120 MW in other types.

Fig.7.9 Diagram of Type-E

Power plant consisting of back pressure steam turbine cycle generators supplying steam to desalination plant, gas/steam combined cycle generators and gas turbine generator

Total output power

G/C	480MW
GT	80MW
ST	160MW
Total	720MW

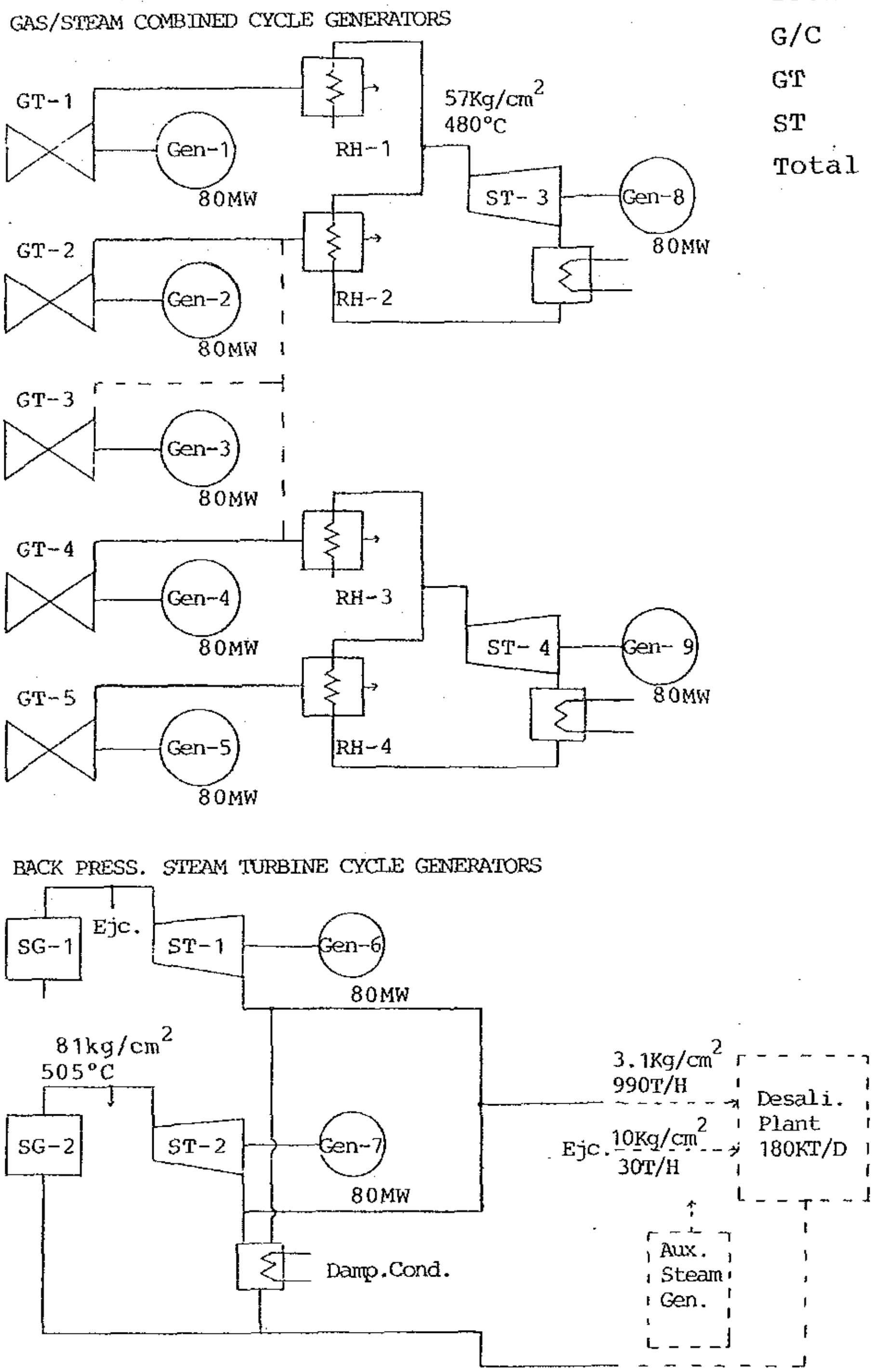
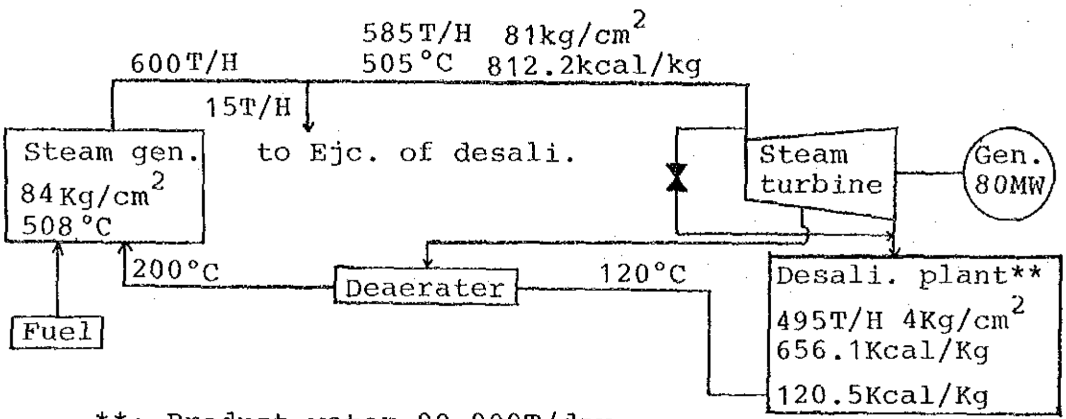


Fig.7.9B Back pressure steam turbine cycle
pressure & temp. per unit of Type-E power plant



**: Product water 90,000T/day

(6) Type-F power plant

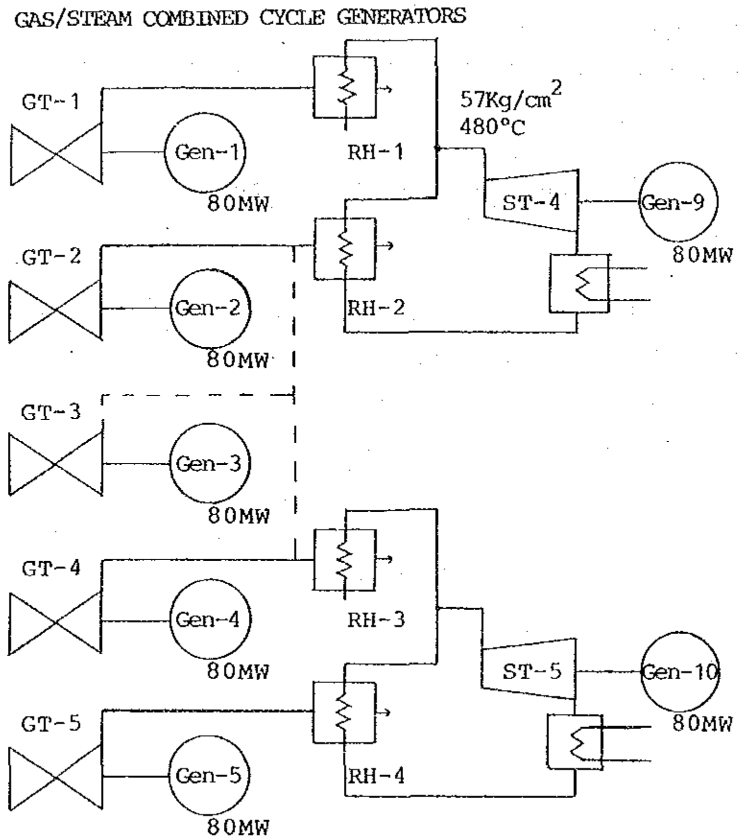
The system diagram of Type-F power plant is shown in Fig. 7.10. Since Type-F is basically the same system as Type-E, they have same performances and characteristics. In terms of plant operation and management, however, Type-F is more advantageous and reliable than Type-E in the following respects:

(a) As discussed in 7.3, Type-F causes less frequency drop when one unit fails down.

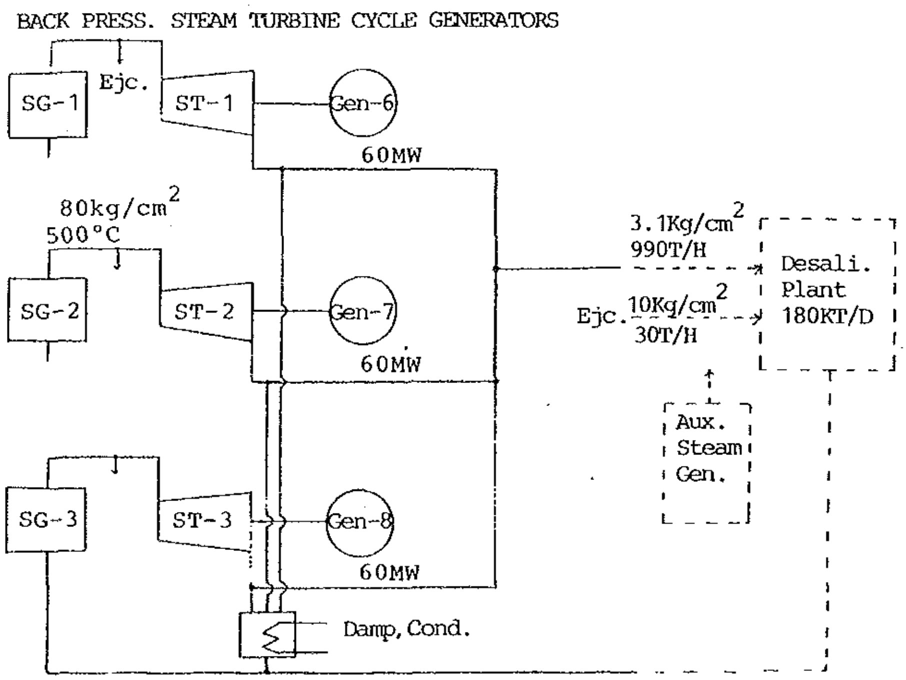
(b) During the annual inspection, one unit has to stop in the Type-E power plant. If another unit in operation stops for some reason, steam supply to the desalination plant from the power plant becomes nil. On the other hand, the Type-F power plant consists of three 60 MW steam turbines, so that two units can be operated during the annual inspection of one. Therefore, one unit can still supply steam to the desalination plant even if the other unit fails down.

Fig.7.10 Diagram of Type-F

Power plant consisting of back pressure steam turbine cycle generators supplying steam to desalination plant, gas/steam combined cycle generators and gas turbine generator



Total output power	
G/C	480MW
GT	80MW
ST	180MW
Total	740MW



7.5 SELECTION OF POWER PLANT TYPE

7.5.1 Comparison of alternative plant type

Alternative plant types described in 7.4 were compared as shown in Table 7.2.

The results are summarized as follows:

(1) Reliable operation for water producing and power generation

Stable operation is expected for all type other than Type-B.

(2) Economy

As discussed in Chapter 18, Type-A has the highest economic advantages.

(3) Reliability

Reliability in operation of equipment is more or less the same for all the types. However, reliability in terms of combination of desalination plant and power generation, namely the magnitude of impacts on either of plants due to failure in other plant, Type A, C, E and F have difinite advantage over other types.

(4) Suitability to the local conditions

In terms of suitability to the country's situation, Type-F is the best among the alternative types because of the following reasons:

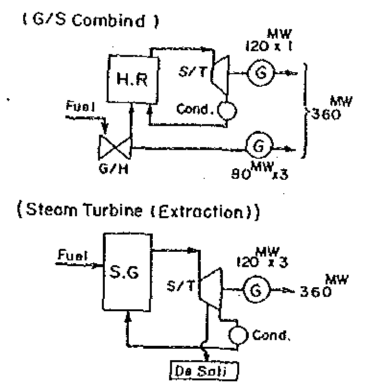
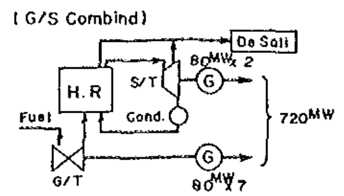
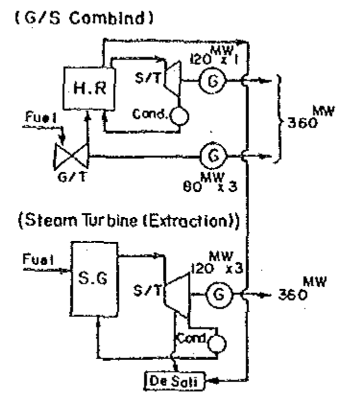
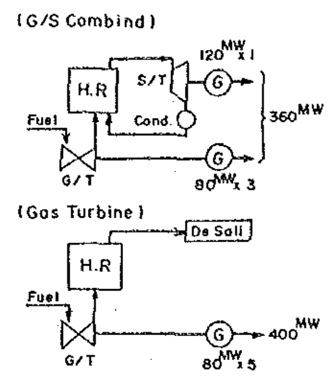
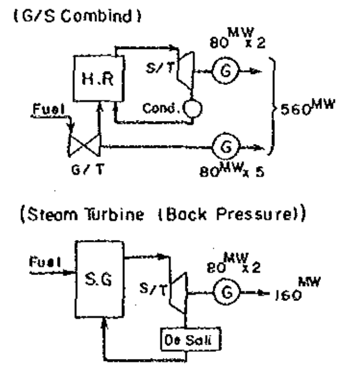
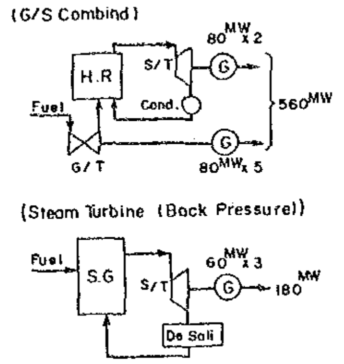
(a) Required power load in the country reaches a lowest level in the winter season, 20% of that in the summer season. Thus, drop out of one unit in the winter season will affect the power system to a degree proportional to unit size. Type F employs relatively small unit sizes; 80 MW at maximum and 60 MW for steam turbine generators to supply base load, resulting in lowest degree of impacts on the power system at the time of unit drop out.

(b) To secure stable power supply, it is desirable to decentralize power sources. Because of small unit sizes, Type-F is suitable for decentralizing power sources in the power system.

(c) MEW intends to carry out inspection and maintenance of steam turbine generators and other equipment by themselves. Since the steam turbines being used in the country are of small size, introduction of large unit particularly 120 MW, would be judged premature from MEW's present technical capabilities. In this respect, Type-F with relatively small unit sizes will suit the purpose.

(d) In the Type-F power plant, base load generators connected to the desalination plant are of small unit size, and thus load adjustment is not required frequently throughout the year to make the system operation relatively easy. Therefore, in terms of suitability to the country's situation, Type-F is considered the most suitable for the country.

Table 7.2 Comparison of Various Matters for Type of Power Plant

	Type-A	Type-B	Type-C	Type-D	Type-E	Type-F
Kind of Generators						
Total out put	720 MW	720 MW	720 MW	760 MW	720 MW	740 MW
Energy generation	4.8×10^9 kWH/Y	4.7×10^9 kWH/Y	4.8×10^9 kWH/Y	4.8×10^9 kWH/Y	4.8×10^9 kWH/Y	4.8×10^9 kWH/Y
Thermal efficiency (a) Max (b) Annual	 65% 55.7%	 70% 58.2%	 65% 55.7%	 63% 55.2%	 58% 54.9%	 59% 54.8%
Construction cost	167.4×10^6 R.O.	164.4×10^6 R.O.	168.2×10^6 R.O.	171.8×10^6 R.O.	178.9×10^6 R.O.	197.7×10^6 R.O.
Stability in operation (a) for Desalination (b) for Power generation	 good good	 good Difficult Variation for Power Demand	 good good	 good average	 good good	 good good
Durability in continuous operation	17,000 H (ST) 8,000 H (C/C)	8,000 H	17,000 H (ST) 8,000 H (C/C)	8,000 H	17,000 H (ST) 8,000 H (C/C & G.T.)	17,000 H (ST) 8,000 H (C/C & G.T.)
Reliability of operation	96 %/Y (ST) 86 %/Y (C/C)	86 %/Y	96 %/Y (ST) 86 %/Y (C/C)	86 %/Y	96 %/Y (ST) 86 %/Y (C/C)	96 %/Y (ST) 86 %/Y (C/C)
Fuel used	Natural gas Distillate Straight residue	Natural gas Distillate	Same as Type-A	Same as Type-B	Same as Type-A	Same as Type-A
Operation and maintenance cost	6.7×10^6 R.O.	$6.6 \times \times 10^6$ R.O.	6.7×10^6 R.O.	6.9×10^6 R.O.	7.2×10^6 R.O.	7.9×10^6 R.O.
Fuel consumption	1.618×10^6 Nm^3/Y	$1,526 \times 10^6$ Nm^3/Y	$1,618 \times 10^6$ Nm^3/Y	$1,619 \times 10^6$ Nm^3/Y	$1,645 \times 10^6$ Nm^3/Y	$1,639 \times 10^6$ Nm^3/Y
Reliability in joint operation of Desalination and power plants	good	no-good	good	average	good	good
Adaptability to stable power supply	normal	good	normal	normal	good	very good
Economic evaluation Benefit/cost ratio of Type-F	0.949	0.953	0.950	0.952	0.991	——

7.5.2 Recommended power plant type

As described in 7.4, the Study was made selecting 6 typical types of power plant, which belong to the complex system, for comparison and evaluation.

Out of 6 complex systems, Type-A, Type-C, Type-E and Type-F belong to the Type-A Series, while Type-B and Type-D to Type-B Series.

Since in the power plant types of Type-A Series steam required for desalination is supplied by steam turbine generators, they have higher reliability than other types in Type-B Series. For this reason, the power plant types in Type-A Series were selected.

Of all the types in Type-A Series, Type-A shows the highest economic advantage. On the other hand, Type-F shows the highest suitability to the Country's situation as shown in 7.5.1 (4), while its total cost is 5% higher than that for Type-A.

More precisely, despite of its cost advantage, Type-A has a drawback in being serviously affected by drop out of one unit in the winter season. However, this drawback is considered less serious than appeared because:

(a) The winter season lasts only 3 months.

(b) Since highest load in the winter season is expected to increase with increase in load demand in the future, impacts on the system due to fail down of one unit will becomes smaller year after year.

(c) The impacts can be reduced by low load operations of steam turbine generators in the winter season.

Taking the above factors into consideration, Type-A is recommendable becuase of high economic advantage. On the other hand, Type-F has many advantages in aspects related to the country's situation but requires the total cost of about 5% higher than Type-A, amounting 41 million RO (1985 price) for the total project life of 20 years. Thus, Type-F needs to be evaluated in comparing the advantages and disadvantages.

Although the advantages cannot be quantified, they are considered significant on the basis of the country's situation.

On the other hand, the economic disadvantage is not decisively large in comparison to the country's financial situation at present and during the project life.

Based on the above consideration, Type-F is most recommendable. Naturally, the final selection of either Type-A or F is left to the government of the Sultanute of Oman. Nevertheless, descriptions after Chapter 8 were made on the basis of Type-F.

CHAPTER 8

CONCEPTUAL DESIGN OF POWER PLANT

CHAPTER 8 CONCEPTUAL DESIGN OF POWER PLANT

8.1 BASIC CONCEPTS

(1) Conceptual design of the power plant is carried out for Type-F (described in Chapter 7) in accordance with the conclusion in Chapter 18.

(2) Design criteria for each equipment is established as follows:

Air temperature	
Maximum	50°C
Minimum	5°C
Design ambient temperature	50°C
Seawater temperature	
Design temperature	30°C
Maximum temperature	35°C
Relative humidity	
Annual mean	40%
Design mechnical/electrical	100%

8.2 CONCEPTUAL DESIGN OF POWER GENERATION EQUIPMENT

To minimize the manufacturing cost for all of power generation equipment to be used in the plant, standard types of equipment will be employed as far as possible. Therefore, construction period can be also minimized.

Design criteria, functions and quantity of each of power generation system (equipment) are summarized in the following sections.

8.2.1 Steam generator for back pressure steam turbine cycle

(1) Main fuel	Natural gas
Low heat value	9,024 kcal/Nm^3

(2) Emergency use fuel — Straight residue

Low heat value	17,840 BTU/pound	
Density at 15°C	kg/l	0.9267
Viscosity, kinematic at 50°C	cSt	176
Fulfur	%m	1.6
Pour Point	°C	-9
Ash	%m	0.02
Flash Point	°C	102
Water	%m	0.05
Sediment	%m	Trace
Carbon residue, Ramsbottom	%m	5.3
Sodium	ppm	26.4
Vanadium	ppm	16.0
Nickel	ppm	6.5
Copper	ppm	1.0
Iron	ppm	4.6

(3)	Type	Natural circulation module type finned water tube
(4)	Number	3
(5)	Rated steam flow	Ca. 400 t/h
(6)	Steam pressure at S.H. outlet	Ca. 80 kg/cm^2
(7)	Steam temp. at S.H. outlet	Ca. 500°C
(8)	Feed water temp. at economizer inlet	Ca. 160°C
(9)	Draft system	Forced draft
(10)	Economizer	Horizontal bare tube type
(11)	Air heater	Rotary type

(12) If straight residue is used, preheating equipment will be required to lower the viscosity. Also, provision should be made to prevent corrosion by sodium or vanadium.

(13) 15,000 kl tank is required for storing straight residue.

8.2.2 Steam turbine

		For back pressure steam turbine cycle	For gas/steam combined cycle
(1)	Type	Impulse type	Impulse type
(2)	Number	3	2
(3)	Rated capacity	60 MW	80 MW (at 50°C ambient temp.) 85 MW (at 15°C ambient temp.)
(4)	Speed	3,000 RPM	3,000 RPM
(5)	Inlet steam pressure	Ca. 80 kg/cm^2	Ca.60 kg/cm^2
(6)	Inlet steam temp.	Ca. 500 °C	Ca. 480 °C
(7)	Exhaust pressure	4 kg/cm^2	64 mmHg.abs
(8)	Type of rotor	Solid forged type	Same as left
(9)	Method of coupling	Rigid/bolt coupled	Same as left
(10)	Type of journal bearing	Elliptical overshot type	Same as left
(11)	Type of thrust bearing	Tapered-land type	Same as left
(12)	Type of casing	Casting or fabricates type	Same as left

8.2.3 Generator

		For back pressure steam turbine cycle	For gas turbine	For C/C
(1)	Type	Totally enclosed self-ventilated forced lubricated cylindrical rotor type	Same as left	Same as left
(2)	Number	3	5	2
(3)	Rated capacity	75 MW	140 MW	110 MW
(4)	Power factor	0.8	Same as left	Same as left
(5)	Voltage	11,500 V		
(6)	Short circuit ratio	Ca. 0.5		
(7)	Frequency	50 Hz		
(8)	Number of poles	2		
(9)	Number of phase	3		
(10)	Speed	3,000 RPM		
(11)	Insulation class	F with class B rises		
(12)	Cooling method Stater & roter	Air cooling open or closed cycle system		
(13)	Reactance	Xd — 200% Xd' — 20% Xd'' — 14%		

(14) Excitation system	Static excitation Peak voltage: 1.5 PU Response time: under 100 m sec in 0.95 PV	Same as left	Same as left

8.2.4 Gas turbine

(1) Main fuel	Natural gas		
(2) Emergency use fuel	Distillate		
Low heat value	18,400 BTU/pound		
Density at 15°C	kg/l	min	0.820
	kg/l	max	0.870
Color ASTM		max	2.5
Diesel index		min	50
Cetane number		min	47
Cetane index			report
Viscosity Kinematic at 40°C	cSt	min	1.6
	cSt	max	5.3
Cloud point	°C	max	---
Pour point	°C	max	0
Fulfur	%m	max	1.0
Copper corrosion (3h/100°C)			1
Carbon res. Ramsbottom	%m	max	0.1
Water	%V	max	0.05
Sediment	%m	max	0.01
Ash	%m	max	0.01
Flash point PMcc	°C	min	62
(3) Type	Heavy duty industrial type		
(4) Number	5		
(5) Rated max. capacity	84 MW at 50°C 109 MW at 15°C		
(6) Number of shaft	One		

(7) Direction of rotation facing in direction of air flow — Counterclockwise

(8) Air compressor:

Type	Axial, heavy duty
Casing sprit	Horizontal
Compressor speed	3,000 RPM

(9) Combustors: ---

(10) Bearings

Number	3
Journal type	Elliptical & tilting pad
Thrust type (loaded)	Equalizing
Drain system	Gravity

(11) It must be of construction to allow automatic change over from natural gas to distillate on load condition.

Results of evaluating fuels applicable to the gas turbine are shown in Annex 5.

(12) 23,000 kl tank is required for storing distillate.

8.2.5 Heat recovery steam generator

Type	Natural circulation module type finned water tube
Number	4
Pressure level	Single
Rated steam flow	Ca. 160 t/h
Outlet steam pressure	Ca. 60 kg/cm^2
Outlet steam temp.	Ca. 485°C

Feed water temp. at economizer inlet	Ca. 43°C
Exit gas temp.	170°C
Pressure drop. (at 15°C ambient air)	10 inch H_2O

8.2.6 Condenser

		For gas/steam combined cycle	Damping condenser
(1)	Type	Surface type	Surface type
(2)	Number	2	1
(3)	Cooling water quantity at max. temp. rize 7°C	9.15 m^3/s	3.7 m^3/s
(4)	Heat duty	221 x 10^6 kcal/h	88.4 x 10^6 kcal/h
(5)	Inlet water temp.	30°C	Same as left
(6)	Vacuum	64 mmHg.abs	Same as left
(7)	Condensate water outlet temp.	43°C	Same as left

8.2.7 Control system

The boilers, steam turbines and gas turbines will be centrally controlled through a computer which performs automatic control and monitoring. At the same time, they will be able to be manually operated and controlled at the central control room shown in Fig. 10.10.

The automatic control and operation systems will allow power generation units to be started or stopped safely and easily with only operators at central control room.

The automatic control system is divided into the following functions:

Boiler control
Combustion control

Water supply control
Main steam temperature (pressure) control
Steam turbine and generator control
Governer control
Automatic voltage control
Automatic load control
Gas turbine control
Combustion control
Governer control
Start/stop control in various operation modes
System control between units
Data collection, recording and indication

8.2.8 Electrical circuit system

The electrical circuit system for the Type-F power plant recommended in this Study is shown in Fig. 8.1. In this system, service power will be supplied from 275 KV circuit of the plant through 2 transformers (including one standby transformer).

8.2.9 Cooling water (seawater) system

Cooling water (seawater) system is shown in Fig. 8.2. Since the gas steam combined cycle system will not be continuously operated throughout the year, no standby cooling water pipes will be required.

Thus, cooling water pipes should be installed for ST-4 and ST-5 separately with standby intake pumps.

Damping condenser should be made into a system which can take in water from any cooling water system.

8.2.10 Equipment layout of the power plant and construction schedule

Equipment layout of the power plant is shown in Fig. 8.3. Construction schedule for the power plant is shown in Fig. 8.4.

Fig. 8.1 ELECTRICAL SYSTEM OF TYPE-F POWER PLANT

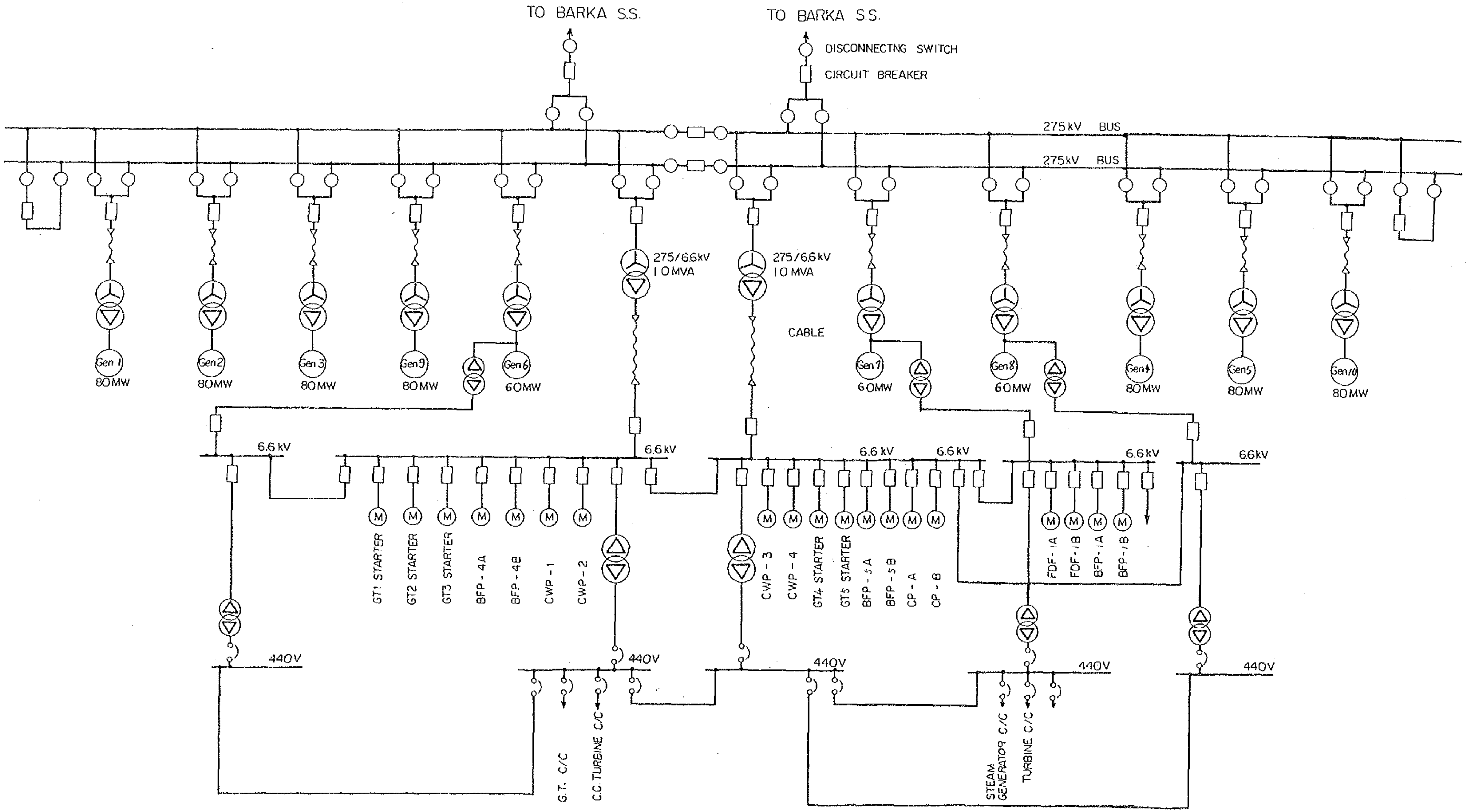
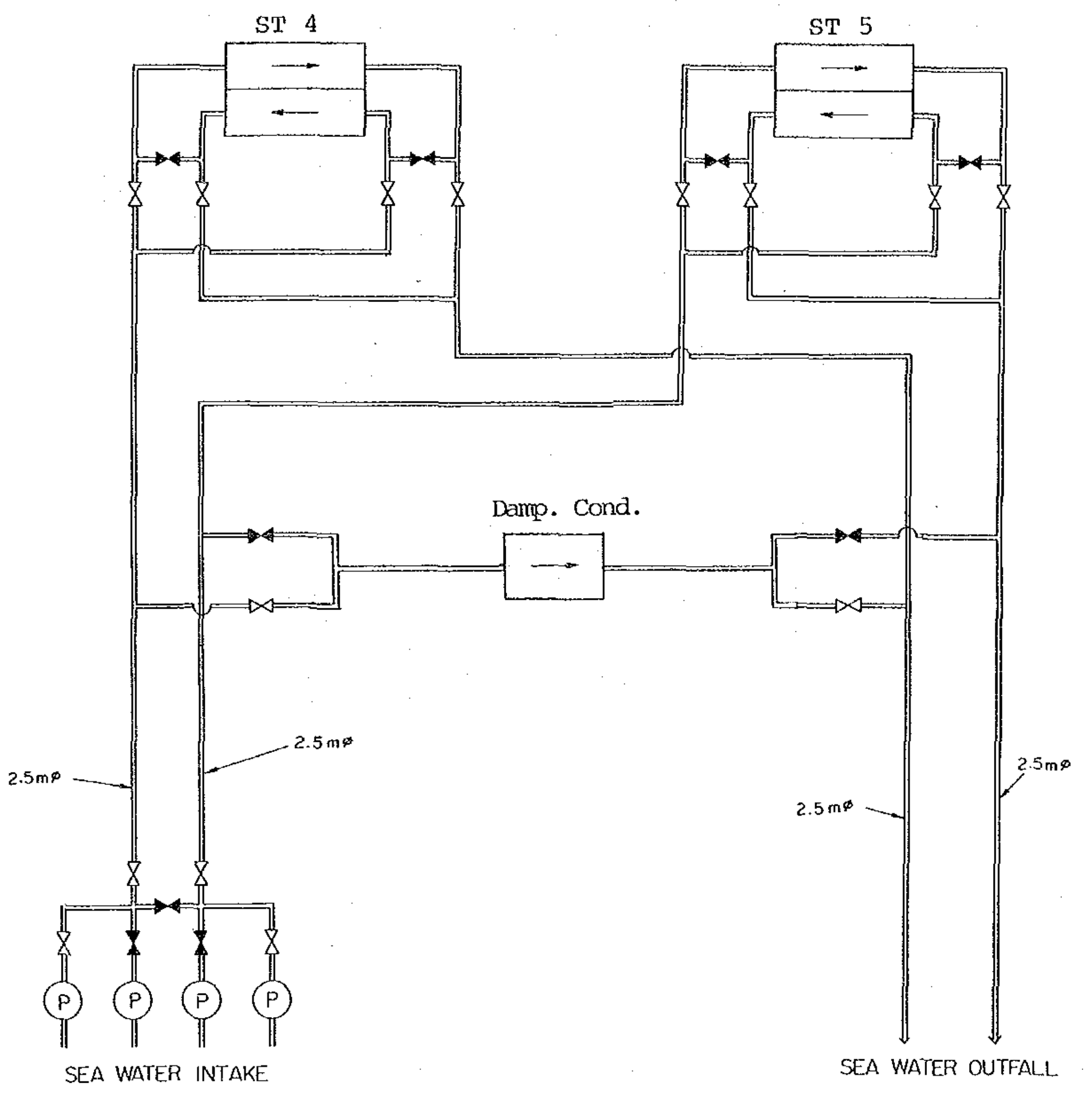
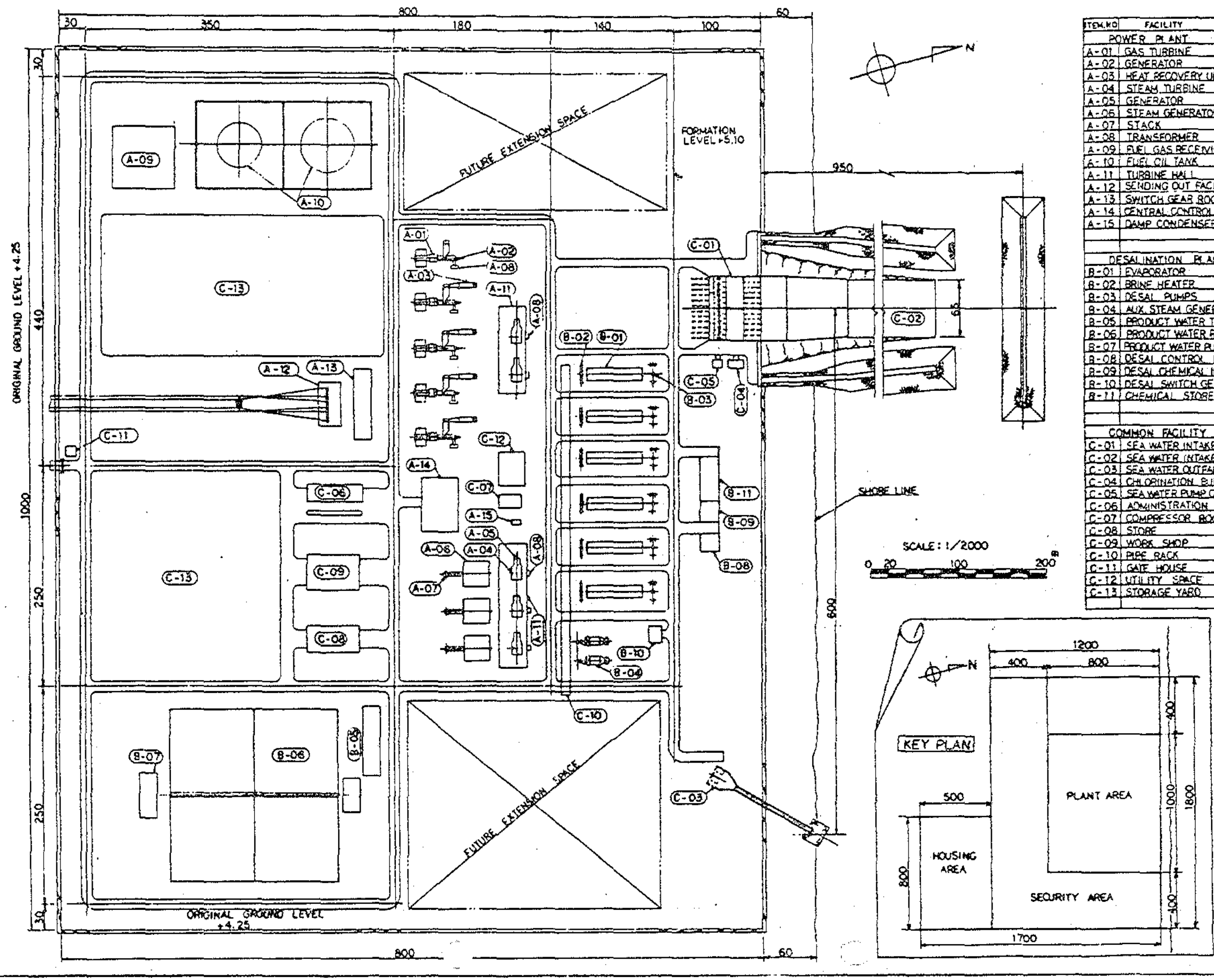


Fig. 8.2 SEA WATER COOLING SYSTEM



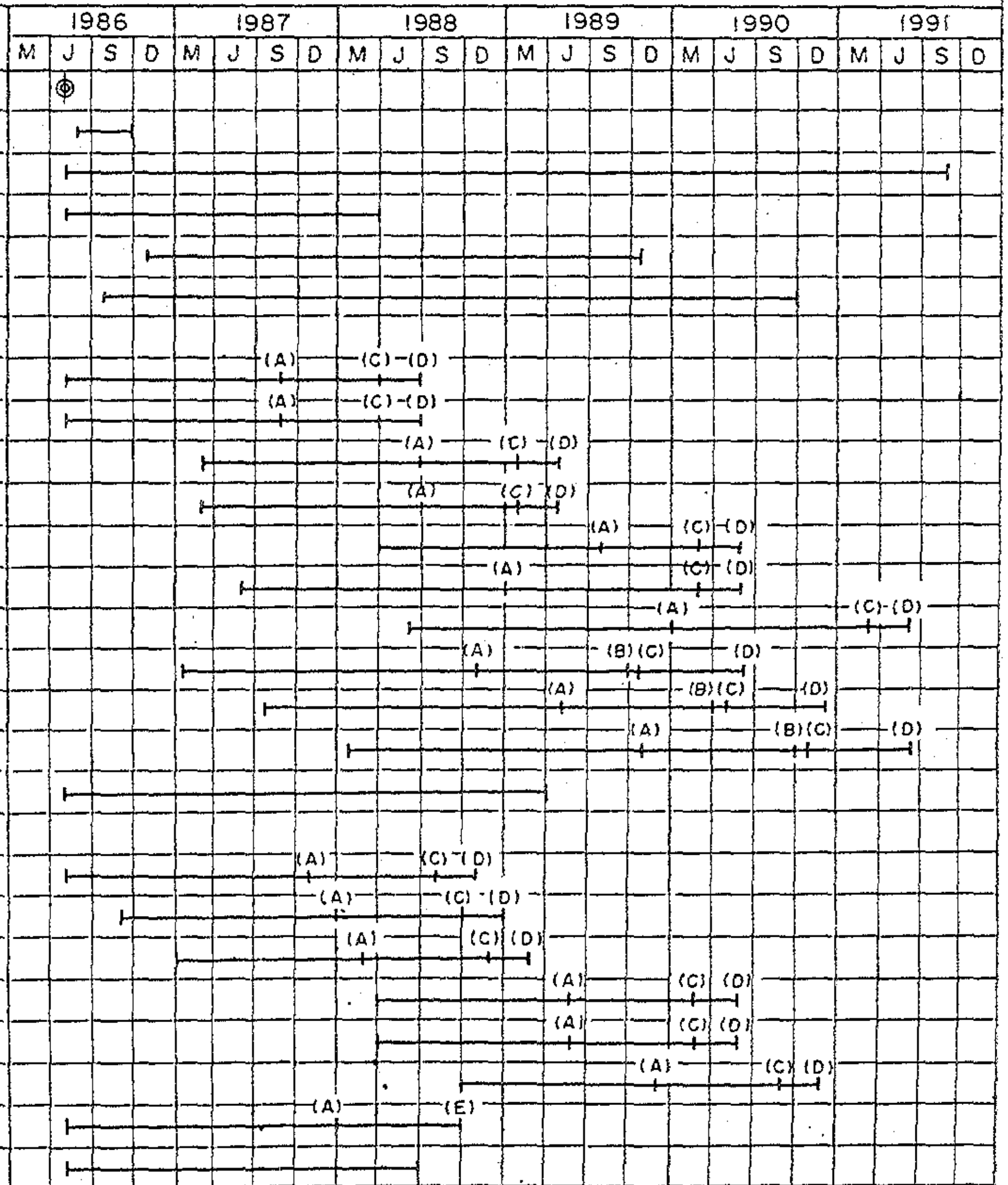


ITEM NO	FACILITY	REMARKS
	POWER PLANT	
A-01	GAS TURBINE	
A-02	GENERATOR	
A-03	HEAT RECOVERY UNIT	
A-04	STEAM TURBINE	
A-05	GENERATOR	
A-06	STEAM GENERATOR	
A-07	STACK	
A-08	TRANSFORMER	
A-09	FUEL GAS RECEIVING UNIT	
A-10	FUEL OIL TANK	
A-11	TURBINE HALL	
A-12	SENDING OUT FACILITY	
A-13	SWITCH GEAR ROOM	
A-14	CENTRAL CONTROL BUILDING	
A-15	DAMP CONDENSER	
	DESALINATION PLANT	
B-01	EVAPORATOR	
B-02	BRINE HEATER	
B-03	DESAL PUMPS	
B-04	AUX. STEAM GENERATOR	
B-05	PRODUCT WATER TREATMENT	
B-06	PRODUCT WATER RESERVOIR	
B-07	PRODUCT WATER PUMPING STATION	
B-08	DESAL CONTROL BUILDING	
B-09	DESAL CHEMICAL INJECT BUILDING	
B-10	DESAL SWITCH GEAR BUILDING	
B-11	CHEMICAL STORE HOUSE	
	COMMON FACILITY	
C-01	SEA WATER INTAKE & PUMP PIT	
C-02	SEA WATER INTAKE CHANNEL	
C-03	SEA WATER OUTFALL	
C-04	CHLORINATION BUILDING	
C-05	SEA WATER PUMP CONTROL ROOM	
C-06	ADMINISTRATION BUILDING	
C-07	COMPRESSOR ROOM	
C-08	STORE	
C-09	WORK SHOP	
C-10	PIPE RACK	
C-11	GATE HOUSE	
C-12	UTILITY SPACE	
C-13	STORAGE YARD	

FIG. 8.3
PLOT PLAN

Fig.8.4 Construction Schedule for Power and Desalination Complex Plant.

Description	Total Month
I. Civil Works	
1) Field Investigation of Site	4
2) Site Preparation & Others	64
3) Sea Water Intake & Discharge Facilities	23
4) Foundation for Equipment	36
5) Buildings & Stack	50
II. Power Plants	
1) Unit 1 ; GT_1 , Ge 1 , 80 MW	26
2) Unit 2 ; GT_2 , Ge 2 , 80 MW	26
3) Unit 3 ; GT_3 , Ge 3 , 80 MW	26
4) Unit 4 ; GT_4 , Ge 4 , 80 MW	26
5) Unit 5 ; GT_5 , Ge 5 , 80 MW	26
6) Unit 6 ; RH_{1-2}, ST_4 , Ge 9 , 80 MW	36
7) Unit 7 ; RH_{3-4}, ST_5 , Ge 10 , 80 MW	36
8) Unit 8 ; SG_1 , ST_1 , Ge 6 , 60 MW	40
9) Unit 9 ; SG_2 , ST_2 , Ge 7 , 60 MW	40
10) Unit 10 ; SG_3 , ST_3 , Ge 8 , 60 MW	40
11) Transmission Lines & Substation, 132 & 275kV	35
III. Desalination Plants	
1) Unit 1 , 30,000 m^3/D	30
2) Unit 2 , 30,000 m^3/D	28
3) Unit 3 , 30,000 m^3/D	26
4) Unit 4 , 30,000 m^3/D	26
5) Unit 5 , 30,000 m^3/D	26
6) Unit 6 , 30,000 m^3/D	26
7) Auxiliary Boiler, No.1 & No.2	29
8) F.W. Reservoir & Conduit Pipe Line	24



Note: ⊕ : Contract, May 1, 1986 (A) : Commencement of Erection (B) : Hydraulic Test (C) : Test (D) : Completion of Erection or Commissioning

CHAPTER 9

CONCEPTUAL DESIGN OF DESALINATION PLANT

CHAPTER 9 CONCEPTUAL DESIGN OF DESALINATION PLANT

9.1 DESIGN CRITERIA

Basic design conditions for the planning of the desalination plant are described in the following clauses.

9.1.1 Capacity of the desalination plant

According to the study result of water demand and supply in Chapter 5, the total capacity of the desalination plant of 180,000 m^3/day is determined and the desalination plant consists of six (6) identical units each having capacity of 30,000 m^3/day based on the reasons described in Clause 9.3.1(1).

9.1.2 Quality of raw sea water and sea bottom soil

Analysis results of sea water and sea bottom soil at Barka Site are shown in Annex 1.

On the basis of analysis results, quality of raw sea water shown in Table 9.1 is used as the design conditions for this project.

9.1.3 Sea water temperature

In determining the design sea water temperature, actual sea water suction point in the sea water intake system must be taken into consideration, especially like new Barka site area, where there is very shallow draft.

So, design sea water temperature of 35°C was decided after studying annual sea water temperature at Mina Qaboos Port and Ghubrah Power Station, which are shown in Annex 2 to cover all seasonal conditions considering the sea water intake structure.

9.1.4 Product water quality

The standard quality of drinking water in the Sultanate of Oman is prescribed in the Omanian Standard of OS 8/1978 shown in Table 9.2.

The product water quality of the desalination plant in this project is to comply with the Omanian standard level of maximum permissible or highest desirable whichever is severer.

Table 9.1 Sea Water Quality used for design condition

Item	Unit	Quality
Turbidity	°	0.5 - 1.4
pH	-	8.1
Electric conductivity	ms/cm	56.0
Acid Consumption (Alkalinity)	$mgCaCO_3/l$	116
Total Hardness	$mgCaCO_3/l$	6,750
Suspended Matter (SS)	mg/l	0.7
TDS (110°C)	mg/l	39,500
TDS (480°C)	mg/l	35,500
COD_{Mn}	mg/l	0.9
COD_{OH}	mg/l	0.2
TOC	mg/l	0.8
Cl	%	20.4
SO_4	mg/l	2,940
NH4-N	g-at/l	3.6
NO_2-N	g-at/l	0.06
NO_3-N	g-at/l	0.09
T-N	g-at/l	16.3
PO_4-P	g-at/l	0.73
T-P	g-at/l	1.19
SiO_4-Si	g-at/l	4.6
Na	mg/l	11,400
Ca	mg/l	426
Mg	mg/l	1,380

Table 9.2 Omanian Standard No.8 Drinking Water (OS 8/1978) - 1/3

Item	Unit	Condition	
1) Physical Properties		In General	
Color		Colorless	
Taste & Odour		Tasteless & Odourless	
Turbidity		Free	
2) Chemical Properties			
a. Toxic chemicals		Maximum Permissible Level	
Lead	mg/l	0.10	
Selenium	"	0.01	
Arsenci	"	0.05	
Cadmium	"	0.01	
Cyanide	"	0.05	
Mercury	"	0.001	
b. Chemicals that have special effects on health			
Fluoride	"	0.8	
Nitrate	"	45	
		Level	
		Highest desirable level	Maximum permissible level
c. Chemicals that effect the suitability of water			
Total dissolved solids	mg/l	500	1,500
Copper	"	0.05	1.5
Iron	"	0.1	1.0

Table 9.2 Omanian Standard No.8 Drinking Water (OS 8/1978) - 2/3

Item	Unit	Level: Highest desirable level	Level: Maximum permissible level
Magnesium	mg/l	Not more than 30 mg/l if there are 250 mg/l of sulphate; if there is less sulphate, magnesium up to 150 mg/l may be allowed	150
Manganese	"	0.05	0.5
Zinc	"	5.0	15
Calcium	"	75	200
Chloride	"	200	600
Sulphate	"	200	400
Phenolic compounds (as phenols)	"	0.001	0.002
Total hardness	"	100	500
pH range	-	7.0 - 8.5	6.5 - 9.0
		Level	
d. Minimum residual chlorine concentrations	mg/l	0.2 - 0.5	

Table 9.2 Omanian Standard No.8 Drinking Water (OS 8/1978) - 3/3

Item	Unit	Max. Level
3) Bacteriological properties		
a. Treated Water		
Escherichia Coliform	number/ 100ml	0
Coliform Organisms	number/ 100ml	10
Throughout any year, 95% of the samples examined should not contain any coliform organisms in 100ml.		
b. Untreated Water		
Escherichia Coliform	number/ 100ml	0
Coliform Organisms	number/ 100ml	10

9.1.5 Utilities and chemicals

(1) Electricity

The electricity required for operation of the desalination plant is supplied from the power station in this project. Supply condition and fee of electricity are shown in Table 9.3.

(2) Fuel

The natural gas (or heavy fuel oil in an emergency case), which is utilized for the fuel of auxiliary steam generators for the desalination plants, is supplied by Petroleum Development Oman (PDO).

(3) Chemicals

The chemicals required for both MSF processes are shown in Table 9.4 with their specifications and prices.

Table 9.3 Supply Condition & Fee of Electricity

Item	Supply Condition and Fee
Voltage	33 kV
Cycle	50 Hz
Phase	3 phases
Fee of Electricity	Consumption Slide Fee : 20 Baizas/kWh + Meter Rental Fee : 150 Baizas/month

Table 9.4 Specification & Price of Chemical

Chemical	Specification	Price
Scale Inhibitor	100% Concentration	1.800 R.O./kg
Anti-Foam Agent	-	1.190 R.O./kg
Lime Stone	100% Solid	0.104 R.O./kg
Soda Ash	100% Powder	0.324 R.O./kg
Chlorine	Liquefied gas	1.100 R.O./kg

9.1.6 Other design factors

In order to maintain higher operating condition and to make operation and maintenance easy for the desalination plant, the following considerations are to be applied for this plant.

(1) The normal operation of the desalination plant is established by the full automatic control system which is controlled in the desalination

plant control room excepting initial start up and shut down of the plant.

(2) Each process pump of the desalination plant have an installed stand-by unit excepting brine recirculation pump.

In case that brine blowdown pump is out of order, the function of concentrated brine discharge can be maintained by brine recirculation pump using a blowdown bypass piping so that any stand-by is not provided for brine blowdown pump.

(3) The spare parts for two years are provided to maintain operation and maintenance of the desalination plant.

9.2 SELECTION OF DESALINATION PROCESS

9.2.1 Processes to be evaluated

There are several processes for sea water desalination, but suitable processes in this feasibility study are considered to be two processes, namely, Multi Stage Flash Evaporation (MSF) and Reverse Osmosis (RO).

At the technical and economical view point, above mentioned two processes are evaluated briefly in this study. And the best process is selected for this project. The evaluation is made for the both process plants having the total capacity of 180,000 m^3/day (30,000 m^3/day x 6 units for MSF process and 15,000 m^3/day x 12 units for RO process).

The results of conceptual design of the evaluated RO process plant for this study are shown in Annex 3.

9.2.2 Comparison of MSF and RO process

(1) Comparison of technical factors

1) Unit capacity

In general, MSF process is suitable for comparatively large unit capacity. According to the study on water demand and supply forecast, the total capacity of 180,000 m3/day sea water desalination plants is required, and considering existing unit capacity of commercial plants in operation, 6 units of each 30,000 m^3/day are selected for this Project. While, in RO plant, the maximum unit capacity ever installed was 2,000 m^3/day, but technically, larger capacity of RO plant is feasible, so in this study, 12 units of each 15,000 m^3/day unit capacity are selected.

2) Energy consumption

RO process is in principle the most energy saving method at present and electric power demand is 4.27 kWh/m^3 (not including product water transfer pump) for above unit capacity. In MSF plant, electric power demand is 3.3 kWh/m^3 (not including product water transfer pump) based on same unit capacity and in addition to this electric power consumption, considerable amount of heating steam of 136 kg/m^3 is required. In this project, heating steam is supplied from dual purpose power plant, so compared with single purpose desalination plant, the steam cost becomes comparatively cheaper due to sharing its steam cost with dual purpose power plant.

3) Suitability of raw sea water quality

In MSF process, the lower temperature of raw sea water is preferable considering the thermal efficiency. And the water quality which is not contaminated by volatile matter such as phenol, ammonia and etc. is desirable to prevent mixing of such matters into distilled water during flashing process. Other foreign material except above mentioned does not affect distilled water quality and plant operation to a great extent.

In RO process, the higher temperature of raw sea water contributes to increase in water production rate within the tolerable temperature range of RO membrane. Difficulty of the sea water pretreatment and the maintenance of RO membrane are affected by the raw sea water quality to a great extent, so clear sea water which does not contain suspended matter is preferable. In general, the requirement of raw sea water quality in RO process is more severe than that of MSF process.

Raw sea water supplied to membrane modulus requires pretreatments such as removal of suspended solid and adjustment of pH etc. Also depending on the material composition of membrane applied, the adjustment of water quality such as de-chlorination and de-oxydization is required.

4) Sea water intake and discharge quantity

In MSF process, sea water intake quantity is approx. 8 times as large as that of product water and discharge quantity is approx. 7 times as large as that of product water.

In RO process, sea water intake quantity is smaller than that of MSF process, and is approx. 3 times as large as that of product water, and discharge quantity is approx. 65% of sea water intake flow.

5) Product water quality and product water treatment

The water quality obtained by MSF process is nearly pure distilled water and water hardness is very small, so it is necessary to increase hardness for drinking purpose. While, the water components produced by RO process is suitable for drinking water but pH value is lower side, so pH adjustment is required. Also, in both cases, product water must be sterilized by chlorination system. These water quality adjustments are carried out by product water treatment plants. The product water treatment plants are also necessary to protect product water tanks and pipe lines, etc. from corrosion.

In MSF process, this water treatment consists of CO_2 gas absorber and lime stone filter and in RO process, only calcium hydro-oxide is to be injected.

6) Chemicals

Both scale inhibiter and anti-foam agent are used in MSF process and consumption of these chemicals is comparatively small.

In RO process, there are various kind of chemicals required, such as coagulant pH adjuster, and deoxidizing agent etc. in pre-water treatment, and these chemical consumptions are comparatively large amount. Also coagulant applied in back wash water treatment for sand filter, chemical claning reagent for RO module etc. are required for intermittent use. Furthermore, depending on the material of membrane, the agent for membrane treatment is necessary to recover membrane performance.

7) Material selection

High quality corrosion protection materials are applied where there is contact with sea water. Specially, on high temperature part of evaporator internal surface in MSF plant, stainless clad steel is used, and for heat transfer tube, high grade materials such as cupro-nickel, aluminium brass and titanium are used. Also for corrosion protection of evaporation internal surface and associated equipments, make up sea water to heat recovery section is pretreated in vacuum deaerator to reduce oxygen content in make up water. In general, requirement for material selection for corrosion potection is more severer in MSF plant than in RO plant.

In RO plant, poly vinyl chloride and/or reinforced plastic for pipings can be applied. Because all handling water in RO plant is not heated up. For high pressure pump and energy recovery turbine, stainless steel and stainless casting are used and for large diameter pipe of high pressure part, carbon steel pipe internally lined or coated is applied. MSF plant generally requires high corrosion resistance material compared with RO plant.

8) Scale prevention

MSF process adopts the scale inhibitor system for the prevention of scale formation. The inhibitor is injected into the make up water and also by restricting brine top temperature to 110°C, the scale formation in high temperature part is also avoided.

In RO process, pH value of feed-water must be kept in acid condition so that scale formation in concentrated sea water side can be prevented.

9) Plant life

The life of both MSF plant and RO plant is estimated as 20 years.

10) Operation and maintenance

Start up and shut down of MSF plant takes some skill, but in normal operating condition, automatic operation is applied, so daily works of operators are watching the control panel in the central control room. Inspection and maintenance are carried out annually and checking of the corrosion and scale formation in heat transfer tubes, acid cleaning, calibration of instruments, inspection and maintenance of auxiliary boilers etc. are carried out, at that time, if necessary.

Start up and shutdown of RO plant is easy compared with MSF plant and normal operation is based on watching the instrument panel in the central control room. However, operations of pretreatment of raw sea water, maintenance and administration for RO plant is somewhat complicated. There are various kind of chemicals used for said operations such as coaglant, acid, alkali and agent for washing or treatment of membrane etc., so there are plenty of control works of chemical handling. Periodical inspection and maintenance is carried out once a year and replacement and cleaning of membrane is carried out at that time, if necessary.

11) Number of operators and maintenance personnel

Number of maintenance personnel and administration personnel for both process are not so different, but number of MSF plant operators are larger than that of RO plant operators considering routine work operating personnel for RO process is estimated to be approx. two third of personnel for MSF process.

Number of administration staffs for desalination plant are calculated as just half number of all administration staffs in the complex plant as a comparison purpose. Because administration staffs for power and desalination complex plant are working commonly for both plants.

12) Required construction area

Generally speaking, required construction area of RO process is slightly smaller than that of MSF process. In this feasibility study, the area of MSF process is approx. 54,000 square meters and that of RO process is approx. 48,000 square meters. So the area of MSF process is about 12 percentage larger than that of RO process.

13) Delivery time

Delivery time for construction of a large MSF plant is generally 3 years or more. In this feasibility study, according to water demand schedule, delivery time of No.1 desalination plant of the MSF process is within 30 month after contract. The delivery time of No.2 and remaining desalination plant follow at each two month pitch after No.1 plant.

Delivery time for No.1 plant of the RO process is within 24 month after contract. So delivery time of the RO process is shorter than that of MSF process.

14) Actual operating records

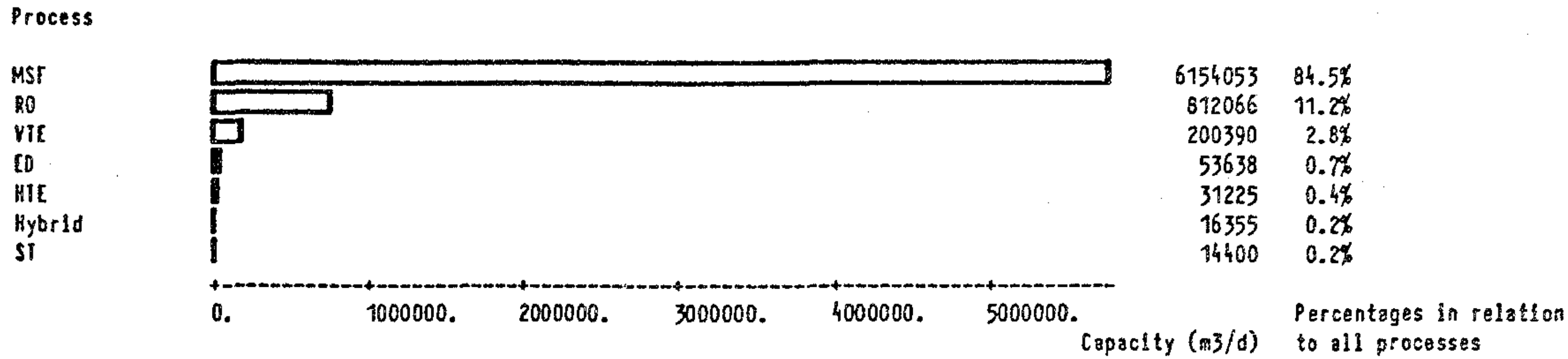
The distillation process has the longest history of the sea water desalination processes. Rough market share of the distillation process plants in capacity is about 75 percentage all over the world.

All desalination plants having unit capacity of 20,000 m^3/day or more adopted MSF process, so MSF plant is now well established process.

Recently, RO process has been researched and developed rapidly and there are many operating records for brackish water desalination.
In last 10 years, high rejection RO membrane has been developed, so RO process has been applied for sea water desalination plants gradually, and unit capacity of these plants has become larger step by step.

Actual operating records on MSF and RO process plants are shown in Fig. 9.1, Table 9.5 and Table 9.6.

Fig. 9.1 DESALINATION PLANT CAPACITY BY PROCESS



CAPACITY of all land-based desalting plants capable of producing 4000 m^3/unit or more fresh water daily vs. PROCESS

MSF	means	Multi-stage Flash Evaporation
RO	means	Reverse Osmosis
VTE	means	Multi-effect Vertical Tube Evaporation
ED	means	Electrodialysis
HTE	means	Multi-effect Horizontal Tube Evaporation
Hybrid	means	Two or more Desalting Processes combined
ST	means	Submerged Tube Evaporation

Table 9.5 The Record of Large-Scale MSF Plants

Manufacturer		Client			Unit Capacity (m^3/d)	Unit No.	Plant Capacity (m^3/d)	Use	Status in Operation	Year
Name	Country	Country	Location	Operator						
Sasakura	Japan	Hong Kong	Loc On Pai	Water Authority	30300	6	181800	Potable Water	in Operation	1975
		Iran	Bushehr	Atomic Energy organization	33333	6	199998	"	under Construction	1980
Sasakura/ Mitsubishi Heavy Industries	Japan	Saudi Arabia	Al Jobail (Phase I)	Saline Water Conversion Corporation (SWCC)	23000	6	138000	Potable Water	in Operation	1982
		Kuwait	Doha-West		32700	12	392400	Potable Water	under Construction	1981
Mitsubishi Heavy Industries	Japan	Saudi Arabia	Makkah Taif	SWCC	22000	10	220000	Potable Water	under Construction	1983
Ishikawashima-Harima Heavy Industries	Japan	Kuwait	Doha	Min. of Elec. & Water	27289	3	81867	Potable Water	in Operation	1978
		"	"	"	27289	4	109156	"	"	1980
		"	Shuaiba South E-F	"	22710	2	45420	"	"	1975
		Saudi Arabia	Al Jobail (Phase II)	SWCC	23500	10	235000	"	under Construction	1983
Hitachi Zosen/ Westinghouse	Japan/ U.S.A.	Saudi Arabia	Al Jobail (Phase II)	SWCC	23618	10	236180	Potable Water	in Operation	1983
		Oman	Ghubrah	MEW	22710	1	22710	Potable Water	"	1984
		"	"	"	22710	2	45420	"	under Construction	1984

Table 9.5 The Record of Large-Scale MSF Plants (Continued)

Manufacturer		Client			Unit Capacity (m^3/d)	Unit No.	Plant Capacity (m^3/d)	Use	Status in Operation	Year
Name	Country	Country	Location	Operator						
Mitsui Shipbuilding/ Envirogenics	Japan/ U.S.A.	Saudi Arabia	Jeddah (Phase IV)	SWCC	22710	10	227100	Potable Water	under Construction	1980
Weir Westgarth	United Kingdom	Qatar	Ras Abu Fontas	Min. of Elec. & Water	22710	4	90840	Potable Water	in Operation	1978
		Saudi Arabia	Jeddah (Phase III)	SWCC	22710	4	90840	"	"	1980
Mannesmann	Germany, West	Oman	Ghubrah	Sultanate	22710	1	22710	Potable Water	in Operation	1975
SIDEM	France	UAE	Umm Al-Nar Abu Dhabi	Water & Elec. Dept.	27500	3	82500	Potable Water	in Operation	1979
		Saudi Arabia	Al-Khobar (Phase II)	SWCC	26700	10	267000	"	"	1984
		UAE	Umm-Al-Nar Abu Dhabi	Water & Elec. Dept.	27500	4	110000	"	"	1984
		"	Taweelah	WED	33333	3	99999	Potable Water	under Construction	1984
Compagnie generale d'automatisme	France	Kuwait	Shuaiba North G	Min. of Elec. & Water	23845	1	23845	Potable Water	in Operation	1971
		"	Shuaiba South A-D	"	23845	4	95380	"	"	1971
SIR/Euteco	Italy	Italy	Port Torres	Societa Italiana Resine	35999	1	35999	Industrial Water	in Operation	1973
Franco Tosi	Italy	UAE	Sharjah		24490	2	48960	Potable Water	in Operation	1981

Table 9.5 The Record of Large-Scale MSF Plants (Continued)

Manufacturer		Client			Unit Capacity (m^3/d)	Unit No.	Plant Capacity (m^3/d)	Use	Status in Operation	Year
Name	Country	Country	Location	Operator						
Franco Tosi	Italy	UAE	Jebe Alill	WED	32100	3	96300	Potable Water	in Operation	1983
		"	Sharjah	"	24490	2	48960	"	"	1984
Italimpianti	Italy	UAE	Umm Al-Nar	WED	27000	3	81000	Potable Water	Under construction	1983
		Bahrain	Sitra	-	30000	3	60000	Indus-trial Water	in Operation	1984
		"	"	WED	22500	1	22500	"	"	"
Ansaldo	Italy	Kuwait	Doha-West		25210	4	90840	Potable Water	in Operation	1983
Sumitomo Heavy Industries	Japan	Qatar	Abu Fontas	-	25210	4	90840	Potable Water	in Operation	1983

Note: These records are referred from "Desalting Plants Inventory Report No. 8" published, February, 1985 by International Desalination Association (IDA).

Table 9.6 The Record of Large-Scale RO Plants

Manufacturer		Client			Unit Capacity (m^3/d)	Unit No.	Plant Capacity (m^3/d)	Use	Status	Year
Name	Country	Country	Location	Operator						
Fluid system	U.S.A.	Saudi Arabia	Jeddah	Saline Water Conversion Corporation (SWCC)	1345	9	12105	Potable Water	in Operation	1978
		"	Umm Lujj	SWCC	4542	1	4542		"	1984
Kobe Steel	Japan	Japan	Chigasaki	Water Re-Use Promotion Center	800	1	800	Test	in Operation	1979
Kurita	Japan	Japan	Chigasaki	Water Re-Use Promotion Center	800	1	800	Test	in Operation	1979
Water Service of America	U.S.A.	U.S.S.R.	Baku	v/o Makino import	1514	7	10598	Indus-trial	in Operation	1979
		"		"	1041	2	2082	"	"	1979
		U.S.A.	Key West	Florida Keys Aqueduct	1893	6	11352	Potable Water	"	1981
Permutit	U.S.A.	Venezuela	Punta Moron	Cadae-Plant Center No.1	654	4	2616	Indus-trial	in Operation	1979
		"	"	" No.2	757	1	757	"	"	1980
		"	"	" No.3	757	5	3785	"	"	1981
		Colombia	Portete	Carrejon Coal	1665	1	1665	"	"	1983
Polymetrics	U.S.A.	Malta	Ghar Lapsi	Municipality	2000	10	20000	Potable Water	in Operation	1983
		Saudi Arabia	Yanbu	Royal Commission	1009	3	3027	"	"	1980
		"	"	"	946	2	1892	"	"	1980
Al-Kawther Water	Saudi Arabia	Saudi Arabia	Al Birk	Min. Defence	1135	2	2270	Potable Water	in Operation	1982
		"	Tanajib	Aramco	13626	1	13626	Indus-trial	"	1983

Table 9.6 The Record of Large-Scale RO Plants (Continued)

Manufacturer		Client			Unit Capacity (m^3/d)	Unit No.	Plant Capacity (m^3/d)	Use	Status	Year
Name	Country	Country	Location	Operator						
Envirojenics	U.S.A.	Saudi Arabia	Hagl	SWCC	4542	1	4542	Potable Water	under Construction	1982
		"	Duba	SWCC	6756	1	6756	"	"	1982
Preussag	West Germany	Saudi Arabia	Ras Tanajib	Aramco	775	2	1560	Indus-trial	in Operation	1983
		"	Ras Tanajib	Aramco	776	1	776	"	"	1984
Sasakura	Japan	Saudi Arabia	Safaniya	Aramco	1300	3	3900	Indus-trial	under Construction	1984
		Bahrain	Abu Jarjor	MEW	4600	10	46000	Potable Water	in Operation	1983
Weir Westgarth	U.K.	Bahrain	Al-Dur	SWCC-MEW	2300	20	45000	Potable Water	under Construction	1984
Basic	U.S.A.	Bermudas	St. Brendan	Public Works	5678	1	5678	"	in Operation	1982
Overhoff	Austria	Libya	Misurata	Municipality	2000	5	10000	Potable Water	under Construction	1984
		"	"	SOHT	1000	1	1000	Indus-trial	in Operation	1982
NCP. Microfl	U.S.A.	Mexico	Rosarita		757	1	757	"	in Operation	1983
Hydronautics	U.S.A.	Saudi Arabia	Jeddah	Ameron	757	1	757	Indus-trial	under Construction	1984
Metito	U.K.	Saudi	Al Kharj	Min. Defence	1500	1	1500	Military	in Operation	1976
Mitsui	Japan	Singapore	Seraya	Publ. Utility	1000	2	2000	Indus-trial	under Construction	1983
Degremont	France	Spain	Las Palmas	Municipality	530	2	1060	Potable Water	in Operation	1984

Note: These records are referred from "Sesalting Plants Inventroy Report No. 8" published, February, 1985 by International Desalination Association (IDA).

(2) Comparison of economical factors

1) Construction cost

Construction cost for the MSF process plants in this project is approx. 100,274 x 1,000 RO x (293,200 x 1,000 US$).

Rough estimate of construction cost for the RO process plants in this study is approx. 95,760 x 1,000 RO x (280,000 x 1,000 US$).

The RO process plants are slightly cheaper than the MSF process plants.

2) Product water cost

Product water cost for the MSF process plant in this project is approx. 0.425 RO/m^3 (1.244 $US\$/m^3$) (at the delivery point of the plant).

Rough estimate of product water cost for the RO process plant in this study is approx. 0.306 RO/m^3 (0.896 $US\$/m^3$) (at the delivery point of the plant).

The RO process is cheaper than the MSF process.

(3) Results of evaluation

1) Required condition of this Project and suitability of process

Technical and economical evaluations are described in the preceding clauses, and it become apparent that both the MSF and RO processes have its own characteristics.

On the other hand, evaluation of process suitability required in this project, whether MSF process or RO process, is described as follows.

a) Operation records

This project have direct influence on the daily life of capital area people. So in selecting sea water desalination process, the most important factor is that the selected process has abundant reliable records in practical operation and the process is technically established and reliable.

The process of large scale sea water desalination plants with a capacity of more than 20,000 m^3/day per unit are all MSF process as shown in Table 9.5 and Table 9.6.

As for RO process, production capacity has much increased in recent years and a number of installed plants for producing fresh water from sea water have been gradually increased.

This installation records in Table 9.5 and 9.6 are taken from the Desalting Plants Inventory Report No.8 published by the International Desalination Association in February 1985.

b) Suitability for Large Capacity

The plant total capacity of sea water desalination plant for this project is 180,000 m^3/day. Therefore, it is necessary to adopt a process that is suitable for large capacity. Namely, the process must have a scale merit or it is possible to enlarge the production capacity per unit. Enlargement of unit capacity and to minimize number of unit will result in shortening of construction period and reduction of construction cost and simplification of operation and maintenance.

Conceptual design conducted in this Project is to construct 6 units of each 30,000 m^3/day MSF plant. The largest unit capacity of the existing MSF plant up to now is 36,000 m^3/day, and the unit capacity taken up in this Project has well proven experience for the practical sea water desalination plant. Fabrication technology for a plant of 100,000 m^3/day per unit has already been established in Japan, and there is no technical problem in fabricating larger plant.

Construction of 12 units of the RO desalination plant with a unit capacity of 15,000 m^3/day is studied comparing with the MSF plant. The largest unit capacity of the existing RO desalination plant is 2,000 m^3/day, and installation record and actual operation experience of large scale RO desalination plant is limited at present. But, it is technically possible to fabricate the RO desalination plant with a unit capacity of 15,000 m^3/day.

c) Suitability for dual purpose plant

The MSF desalination plant can improve efficiency of total heat cycle by sharing its steam cost with the electric power plant, and these two plants have common facilities related to operation and maintenance. Therefore, large scale dual purpose plant of desalination and electric power generation had long been practically applied, and records of operation are abundant.

On the other hand, it was evaluated in this study that the dual purpose RO desalination plant is economical compared with dual purpose MSF plant, so the RO process has its advantage. However, operation records of large scale RO process plant is not available at present.

d) Easiness of operation and maintenance

In general, it is preferable to adopt a process that is easy to operate and maintain and that can be operated by automatic control system.

The MSF desalination plant in this Project requires relatively complicated procedures at the time of initial startup and shutdown, but it is operated by the automatic control system under normal operation. Also it would be necessary to pay suitable attention to prevent scale formation and material corrosion. But these were overcome by well established technique and operation.

The RO desalination plant is fundamentally easy to operate and maintain, and is almost fully furnished with automatic control system. Therefore, the RO plant requires smaller number of operators than the MSF plant.

But the pretreatments of raw sea water such as removal of the supended solid, pH control, adjustment of de-chlorixation, de-oxidization etc. are required depending on membrane material.

e) Construction period

The present balance of water supply and demand in the capital area is so severe that critical shortage of fresh water is anticipated. So, it is preferable to install desalination plant with a minimum construction period. Thus, shorter construction period is important factor in selecting suitable process.

In general, the RO plant is easy to shorten the construction period compared with MSF plant.

However, there is no big difference in actual construction period of both MSF and RO processes considering past records and running projects of large unit capacity.

2) Selection of recommended process

Summarizing the results of above studies, and evaluating the two processes, it is concluded as follows:

The MSF and RO processes have their advantages and disadvantages as described in the above comparisons.

The MSF process has a superiority so far as operation records are concerned. On the other hand, the RO process has an advantage of short construction period, and easy operation and maintenance. And, both processes are feasible for practical application if the operation records are disregarded.

As for the construction cost and water production cost, the RO process is slightly cheaper than the MSF process. However, the MSF plant have overwhelming number of operation experience so far as the large scale desalination plants are concerned. No large scale dual purpose power plant combined with the RO process has never been installed.

In case that the operation records are considered to be the most important factor in this Project, the MSF process can be said the most suitable process.

Therefore, the MSF process is recommended for this Project.

9.3 CONCEPTUAL DESIGN OF DESALINATION PLANT

9.3.1 Design base

In carrying out conceptual design, basic philosophy are described as follows.

(1) Unit capacity

Unit capacity of the desalination plant is decided by several factors. Within the boundary of the state of the art for the construction of desalination plant, generally speaking, a larger unit capacity of the plant results in smaller capital and operation costs per unit of water produced. So, more economical product water cost is obtained by the larger plant. The desalination plant can be applied with the rule of scale merit as well as the other conventional chemical plants.

In the commercial operation of the desalination plant, there are seasonal increase and decrease of water demand and also there is necessity of the plant shutdown for maintenance and/or in an emergency case. So, there is necessity to increase and decrease total water production capacity in response to water demand, and several units of the plant are normally installed at one site to have flexibility of plant operation.

As described in Chapter 5, the water demand is expected to increase to average 260,000 m^3/day in 1995 and seasonal difference of the water demand is about plus & minus 15 percentage for the mean demand. Therefore water demand of winter in 1995 becomes about 220,000 m^3/day, and total water supply capacity in 1955 is expected to be about 300,000 m^3/day so the difference between above demasnd and supply capacity becomes 80,000 m^3/day in 1995. So two units of each 30,000 m^3/day can be shutdown in winter season in 1995. Up to 1995, total water production capacity satisfies actual water demand even if one unit capacity of 30,000 m^3/day is shutdown throughout the year.

Taking into consideratin of above matters, it is recommended that 30,000 m^3/day unit capacity of six units are suitable for total capacity of 180,000 m^3/day.

(2) Tube configurations for the evaporator cndenser

There are two basic configurations for the condenser tube layout of MSF evaporator, namely cross tube type and long tube type.

Judging from the construction cost of desalination plant, cross tube type is suitable for a smaller unit capacity of the plant, on the contrary long tube type is suitable for a larger unit capacity of the plant.

In case that maximum recirculation brime temperature is about 110°C, border line of a unit capacity of the plant to select cross tube type or long tube type lies between approx. 40,000 - 50,000 m^3/day. In this feasibility study, a unit capacity of the plant is 30,000 m^3/day. So cross tube type is adopted.

(3) Scale prevention method

There are two methods for scale prevention of the MSF desalination plant. One is pH control method and the other is chemical dosing method.

PH control method has the possibility of corrosion of the plant material if proper operation is not maintained, so operation and maintenance of the plant must be cautious.

Several year ago, the most of the plant had been operated with chemical dosing method with maximum recirculation brine temperature of 90°C.

But recently new chemicals for scale prevention at high temperature was developed and some commercial plants are now operated with the new chemicals.

In this Project the new chemicals is used exclusively and the plant is operated at maximum recirculation brine temperature of 110°C. Ball cleaning system on load cleaning is also applied.

(4) Performance ratio

Generally definition of performance ratio (lb/1,000 Btu) is the ratio of *product water quantity (lb) and required steam heat quantity (1,000 Btu).* Product water cost is influenced by performance ratio to a large extent. Because product water cost consists of mainly steam cost (fuel cost) and amortization of the plant and there is close relations between performance ratio, steam cost and plant cost.

A higher performance ratio result in larger capital cost and smaller steam cost. On the contrary, a lower performance ratio result in smaller capital cost and larger steam cost.

It is preferable to adopt comparatively high performance ratio in the area where energy cost is high, while comparatively low performance ratio is economical in the area where energy cost is low.

As dual purpose plant for electricity and desalination has a common steam generating system and sharing its steam cost each other, steam cost for desalination plant is more economical as compared with that of single purpose desalination plant having exclusive low pressure boiler even if the energy cost is same. So in dual purpose plant energy cost becomes cheaper and single purpose plant, energy cost becomes higher.

In this feasibility study, energy cost is calculated as 3,606 Baiza/10^3 kcal.

Based on above conditions, cost performance of product water for performance ratio of 6, 8 and 10 (refer to Chapter 18) are studied. The result of this study is that the cheapest product water cost is obtained by performance ratio of 8 as described in Chapter 18, 18.4. So performance ratio of 8 is recommended.

(5) Driving method for brine recirculating pump

At present, there are two methods aplied in driving brine recirculating pump, one is steam turbine, the other is electric motor. Both driving methods have their own advanages and disadvantage.

Steam turbine is able to be controled its speed in response to the plant load change from normal condition to partial load condition and vice versa to save steam energy, but skilled operation especially for initial start-up and plant shut down is necessary.

While, electric motor is not able to be controled its speed in responese to the plant load from normal condition to partial load condition and vice versa, so delivery valve of the brine recirculating pump must be throttled and there is some energy loss. But the operation of electric motor is easy as compared with steam turbine in initial start-up and plant shut down procedure.

In evaluating energy consumption of both methods, overall efficiency of both electric motor driving method and steam turbine driving methods must be compared.

Overall efficiency of electric motor driving method is decided by multiplication of electric power generating turbine internal efficiency, electric generator efficiency, electric cable transfer efficiency, and electric motor efficiency. While overall efficiency of steam turbine driving method is the internal efficiency of pump driving turbine itself.

In this feasiblility study, electric power generating turbine (Type-F, refer chapter 7) is a large unit having a capacity of 60,000 kW. On the contrary, pump driving turbine are comparatively small units having a capacity of 3,000 kW x 2 units, so the internal efficiency of electric power generating turbine is higher than that of pump driving turbine. Consequently, overall efficiency of electric motor driving method, which is including not only large turbine internal efficiency but also other efficiency such as electric generator efficiency, cable transfer efficiency, electric motor efficiency etc., is still slightly better than that of steam turbine driving method.

Comparing the construction cost including turbine, elect. motor, switch gear, cable, piping etc., both methods are almost same cost level and there is no big difference in cost.

So, considring above mentioned factors, electric motor driven method is applied in this feasiblility study.

(6) Concentration ratio

Definition of concentration ratio is the ratio of total dissolved solid (TDS) of recirculation brine and that of raw sea water. There is some upper limit for concentration ratio in relations to the scale formation in heating tubes.

In this feasibility study, TDS of recirculation brine of 65,000 mg/l and TDS of raw sea water is 39,600 mg/l. So concentration ratio is 1.64.

(7) Maximum temperature of recirculation brine

As described in this Chapter 9.3.1 (3), maximum temperature of recirculation brine of 110°C is selected in this feasibility study.

(8) Number of stages of multi-stage flash evaporator

Generally speaking, there is some relationship between number of stages and heating tube area.

If number of stages is increased, the cost the evaporator shells and water boxes are increased, on the contrary, heating tube area of the evaporator is decreased under the same performance ratio. In this feasibility study, total 23 stages including 20 stages for heat recovery and 3 stages for heat rejection are selected considering to minimize total plant cost.

(9) Number of tier of MSF evaporator

Both single and double tier evaporators have been commercially operated for the cross tube type evaporator.

For single tier type, each stage shell is arranged tandem. Larger area is required for construction but maintenance is easy as compared with the double tier type.

For double tier type, the bottom shell plate of high temperature part is commonly used as the top shell plate of low temperature part. So, there are some influence of heat transfer from high temperature chamber to low temperature chamber and also thermal expansion between top shell and bottom shell especially in high brine top temperature of 110°C operation in this feasiblility study.

Comparing the layout of single tier type with that of double tier type, the brine heater deaerator, ejector system and essential pumps are able to be arranged separately at both end of the evaporator for single tier type. This results in simple and short piping. On the contrary, the brine heater, deaerator, ejector system and essential pumps have to be arranged in one group at one end of the evaporator for double tier type. So this results in complicated and long piping layout. Judging from above mentioned reasons, single tier type is adopted in this feasibility study.

9.3.2 General specification

(1) Plant specification

Type	:	Cross tube type multi-stage flash distillation process
Total Production Capacity	:	180,000 m^3/d
Number of Unit	:	30,000 m^3/d x 6 units
Process Type	:	Brine recirculation type
Scale Prevention	:	Scale inhibitor injection & Ball cleaning type
Evaporator Stage No.	:	Heat recovery section 20 stages Heat rejection section 3 stages Total 23 stages
Product Quality	:	To comply with OMANIAN STANDARD No.8 (DRINKING WATER)

Water Balance (for total 6 units)	:	Sea water supply: 1,440,000 m^3/d Discharge : 1,260,000 m^3/d

Operation Condition

Performance Ratio	:	8.0 LB/1000 Btu
Brine Top Temperature (Max.)	:	110°C
Brine Blow-down Temperature (Max.)	:	44°C
Product Water Temperature (Max.)	:	42.3°C
Concentration Ratio	:	1.64

(2) Plant facility

Desalination Plant	:	6 units
Evaporator	:	6 units
Brine Heater	:	6 units
Venting system	:	6 units
Deaerator	:	6 units
Ball Cleaning System	:	6 units
Pumps	:	6 units
Chemical Feed System	:	1 set
Intake & Discharge Facilities	:	1 set
Auxiliary Steam Generator	:	2 units
Product Water Treatment	:	1 set

(3) *Utility & chemical consumption (for total 6 units)*

Natural Fuel Gas (for Auxiliary steam generator)	:	40,500 Nm^3/h
Electric Power	:	24,600 kWh/h

Chemicals

Chlorine	:	7.9 kg/h
Scale inhibitor	:	99.4 kg/h
Anti-foam agent	:	1.66 kg/h
Lime stone	:	450.0 kg/h
Caustic soda	:	11.3 kg/h

9.3.3 Process description

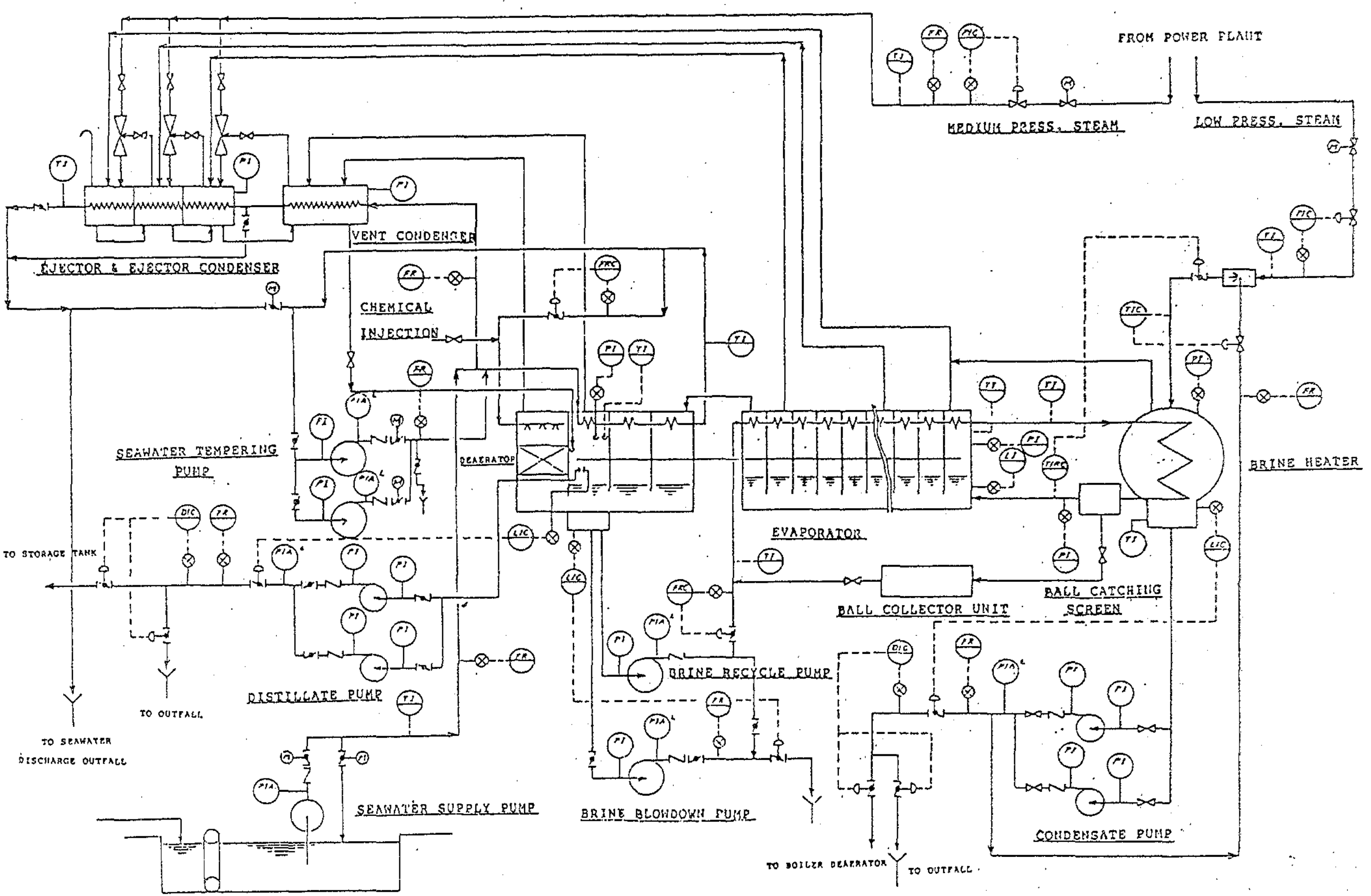
(1) Process flow

Process flow is shown in Fig. 9.2. Sea water is introduced into sea water pit near shore line from intake head which is located approx. 950 m away from the shore and passes through the heat rejection section as cooling water by sea water supply pump. A portion of sea water is introduced to venting system condenser and discharged into cooling sea water outlet line from the heat rejection section. Above venting system contains ejector, vent condenser and ejector condenser which remove noncondensable gases and maintain vacuum in evaporator.

Sea water from the heat rejection section is mainly discharged into the dislcharge culvert and the rest is combined with brine through deaerator as make-up water. Scale inhibitor and anti-foam agent are injected into make-up water for prevention of scale by metering pumps.

The greater part of brine at the last stage chamber is introduced into the last condenser tube of the heat recovery section by brine recycle pump. At each stage recycle brine gains the latent heat of flash vapour condensing on the external tube surfaces and its temprature increases as it passes through the heat recovery condensers to the first stage.

Fig. 9. 2 DESALINATION PLANT PROCESS FLOW SHEET



Preheated recycle brine from the first stage condenser is then fed to the brine heater where it is further heated by steam. Heated brine is introduced into the first stage flash chamber and the flash evaporation is repeated from stage to stage by pressure difference per stage.

In addition, a part of brine is discharged out of evaporator before combined with the make-up water by brine blow-down pump to keep brine salinity constant.

Ball catching screen is provided with in brine line between the brine heater and the first stage flash chamber. In addition, the tube cleaning balls are introduced into brine recycle pump discharge line through the ball collector and recycle through the condenser tubes in the heat recovery section and the brine heater to keep cleaness of condenser tubes.

Medium pressure steam and low pressure steam from of the power plant or from auxiliary steam generator are utilized for venting system ejector and the brine heater respectively.

The brine heater condensate is returned to the steam generating facility by condensate pump.

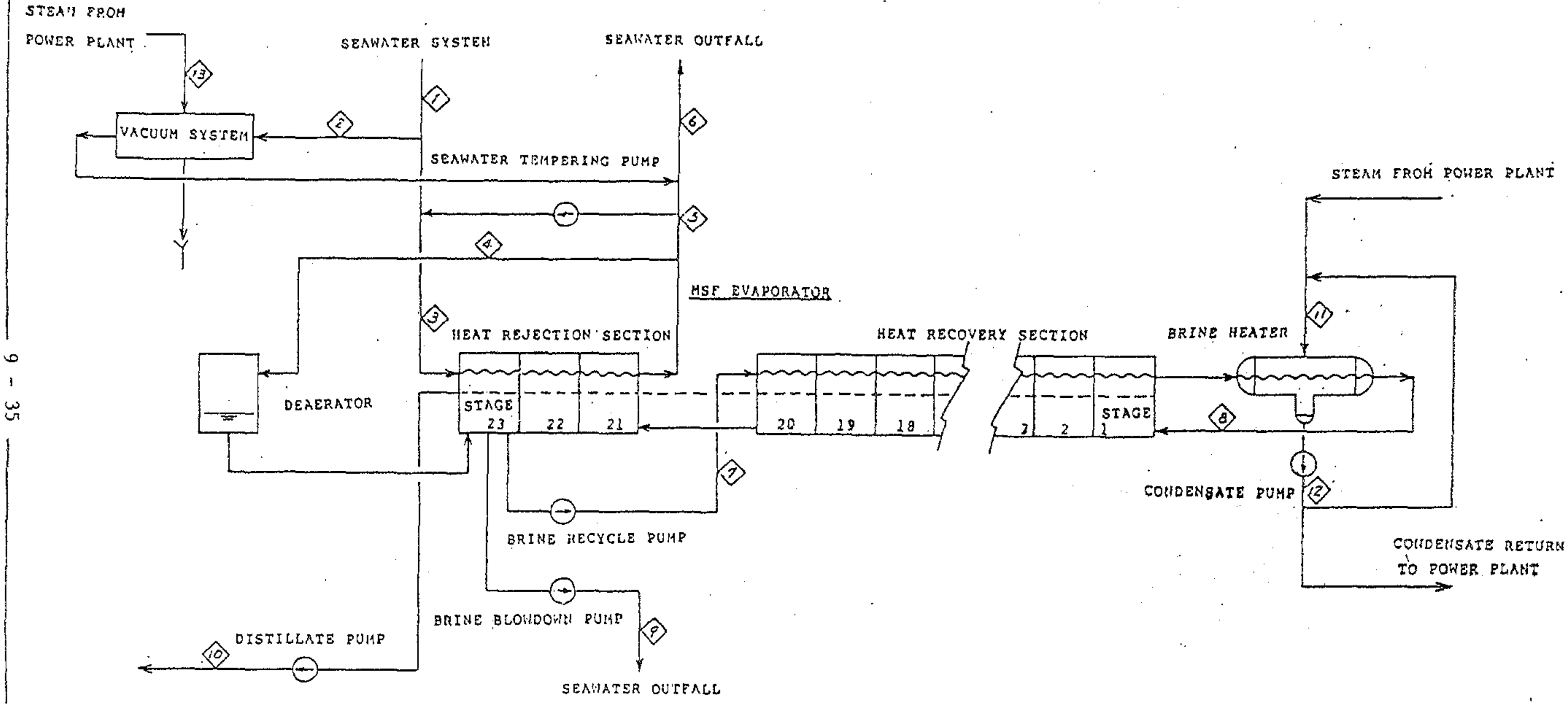
Distillate is produced by the repeated flash evaporation from stage to stage and delivered from the last stage of evaporator to product water treatment by distillate pump. Discharged brine and cooling sea water are introduced into sea through discharge culvert.

The heat and mass balance diagram and the general arrangement of desalination plant are shown in Fig. 9.3 and Fig. 9.4 respectively.

Heating steam for the brine heater is supplied from power turbine exhaust steam line or auxiliary steam generator via pressure reducing value. At initial construction stage steam supply from power turbine is not available for first 3 units of desalination plant from the construction schedule, so auxiliary steam generators are installed. After the completion of whole steam power plant, these auxiliary steam generator are used as stand-by system in case of shutdown of steam power plant.

Low pressure steam and ejector steam flow diagram is shown in Fig. 9.5.

Fig. 9.3 DESALINATION PLANT HEAT & MASS BALANCE



STREAM NO.	1	2	3	4	5	6	7	8	9	10	11	12	13
STREAM NAME	INTAKE SEAWATER	EJECTOR CONDENSER SEAWATER	HEAT REJECTION SEAWATER	SEAWATER MAKE UP	SEAWATER DISCHARGE	SEAWATER TO OUTFALL	BRINE RECIRC.	BRINE RECIRC	BRINE BLOWDOWN	DISTILLATE	HEATING STEAM	BRINE HEATER CONDENSATE	EJECTOR STEAM
FLOW(Ton/hr)	11,100	1,200	9,900	2,760	7,140	8,340	11,910	11,910	1,510	1,250	165	165	5
TEMPERATURE (°C)	35.0	35.0	35.0	44.0	44.0	43.0	43.7	110.0	44.0	42.3	120.0	120.0	179

Fig. 9.4 GENERAL ARRANGEMENT OF DESALINATION PLANT

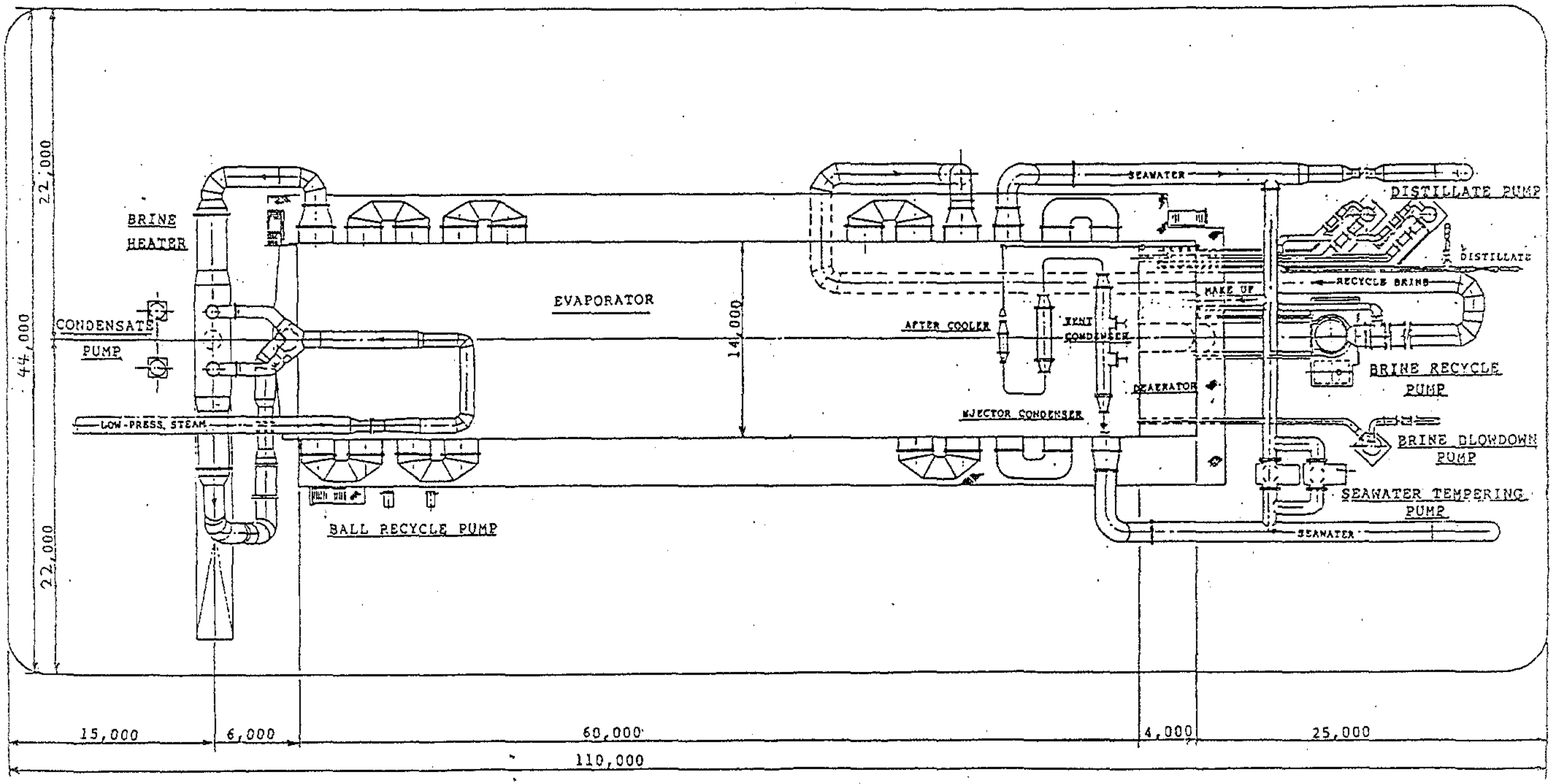
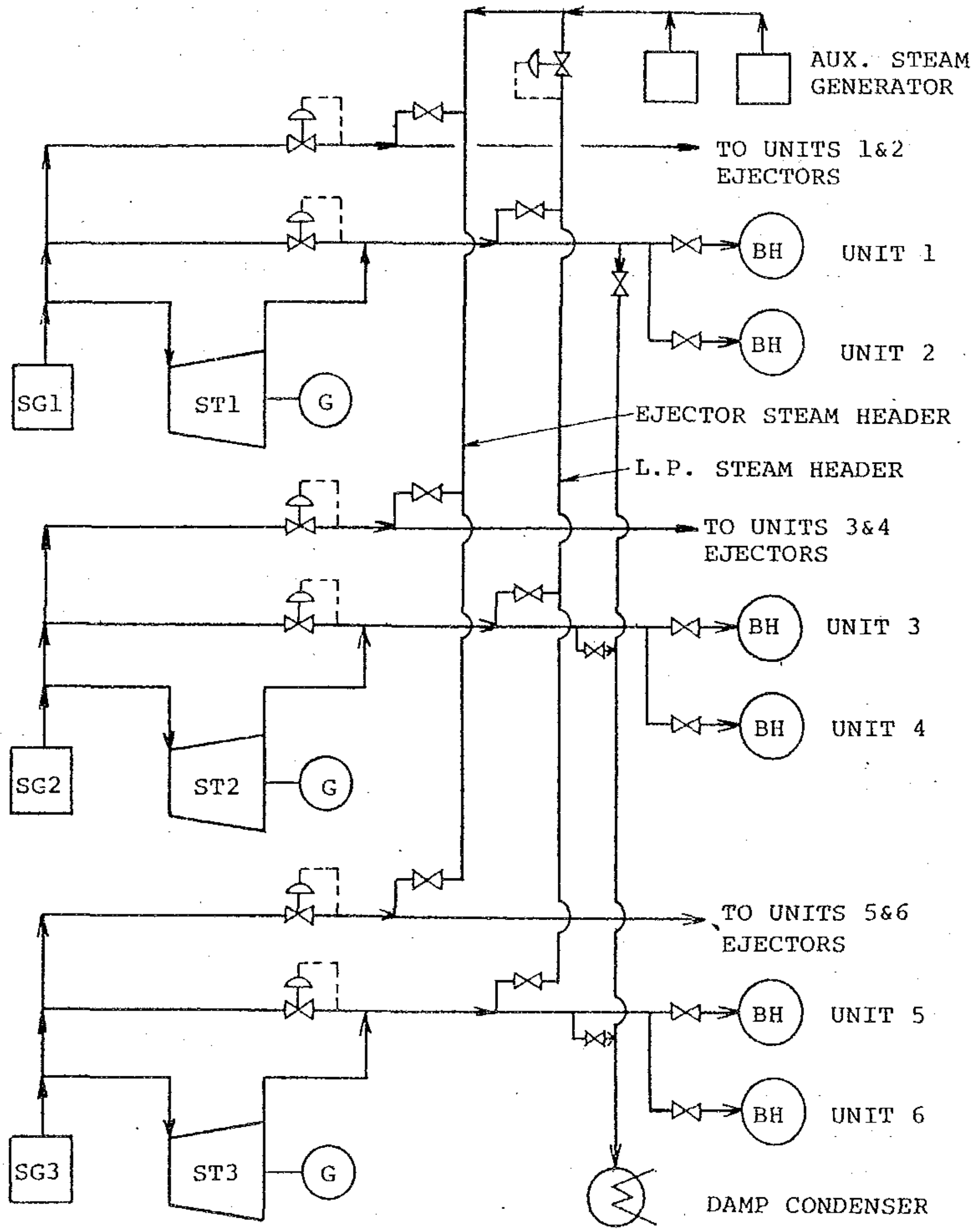


Fig. 9.5 L.P. STEAM & EJECTOR STEAM FLOW DIAGRAM
FOR
DESALINATION PLANT



POWER PLANT (TYPE-F)

SG : STEAM GENERATOR
ST : STEAM TURBINE
G : ELECTRIC GENERATOR

DESALINATION PLANT

BH : BRINE HEATER

Sea water is supplied from sea water supply pumps provided for respective evaporator and is led into each evaporator. Discharged sea water from each evaporators is led into common discharge channel and then discharged into sea through sea water outfall. Cooling sea water flow diagram is shown in Fig. 9.6.

(2) Process control

Desalination plant is supposed to be run continuously all the year around and to be started and shut down with less frequency. Consequently, desalination plant is operated by manual operation for initial start up and shutdown and by automatic control under the normal continuous load condition. The automatic control system is provided with to set up required production. The control and watching of the desalination plant under normal operation are carried out at the control room.

The required interlock system is provided for safety protection and equipment protection. In addition, the plant automatic shutdown mechanism for emergency case is provided with. The control system is prepared for the steady and continuous operation for long period and process flow diagrams are shown in Fig. 9.2.

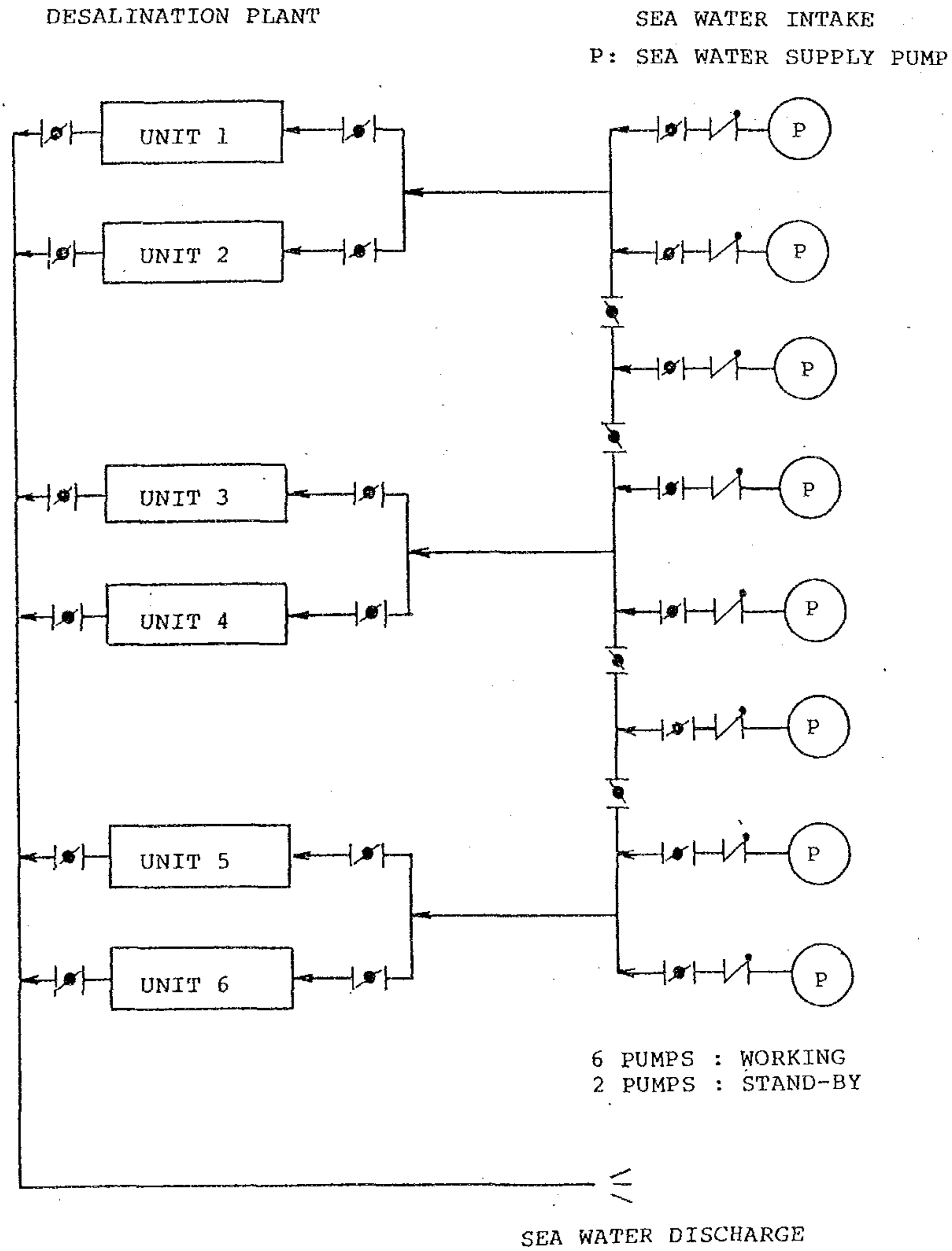
The control system for each line is described as follows:

1) Heating steam line

Heating steam for the brine heater is low pressure steam from steam turbine exhaust or auxiliary steam generator and there is the pressure control valve to adjust the above pressure.

The steam flow control valve is installed before brine heater to maintain brine temperature at 110°C. The brine heater inlet steam temperature is adjusted by the desuper-heating water branched from the condensate line. The heating steam is saturated to prevent scale formation in the brine heater tubes by the above mentioned desuper heater.

Fig. 9.6 COOLING SEA WATER FLOW DIAGRAM
FOR
DESALINATION PLANT



2) Brine recirculation line

Brine recirculation flow is adjusted by the flow control valve at brine recycle pump outlet and maintained with the constant flow.

The partial load operation of the desalination plant is carried out by reduction of the brine maximum temperature and it's recirculation flow.

3) Brine blow-down line

Brine blow-down flow is adjusted by the control valve which signal comes from brine level at the last stage of the evaporator to maintain brine concentration and brine level at constant in the system.

4) Distillate line

Distillate water from each stage is collected at the last stage of the evaporator and flow is adjusted by control valve which signal comes from distillate level at the last stage. Conductivity meter and blow down valve are installed in distillate line and when distillate conductivity increase, distillate is discharged into discharge culvert in place of sending distillate to the reservoir to keep distillate conductivity constant.

5) Make-up water line

Make-up water flow is controlled to maintain brine recirculation concentration and self controlled by measuring flow. Scale inhibitor is injected into make-up water for alkaline scale prevention before combined with recycle brine and dissolved oxygen in sea water is removed by deaerator for corrosion protection. In addition, antifoam agent is injected into make up water to make smooth flashing. Above chemicals are injected at constant rate into make-up sea water by metering pumps.

6) Condensate line

Condensate flow is adjusted by the control valve which signal comes from condensate level in the hot well of brine heater. The greater part of condensate is returned to steam generating system. For this purpose, conductivity meter and blow down valve are installed in condensate line and when condensate conductivity become high, condensate is discharged into discharge culvert in place of sending condensate to steam generating system.

(3) Miscellaneous equipments

1) Product water treatment system

In this feasibility study, the product water of the desalination plant is blended with well water and is supplied to the consuming area. But in case of the shortage of the well water, the product water treatment system is installed.

The product water system is useful for corrosion protection of reservoir and equipment of water supply system and also palatable for drinking water. Main equipment of this system are CO_2 absorber and limestone filter. Flow diagram of this system is shown in Fig. 9.7.

The product water of each desalination plant is pumped up to the absorber. The CO_2 gas in the exhaust gas from the evaporator and dearator is compressed by compressors and is contacted with the product water in the absorber. Then the CO_2 rich watǝr in the absorber pases through the limestone filter. In this filter, the ions of Ca^{++} and HCO_3^- are made by $CaCO_3$ in limestone and the CO_2 gas.

The treated water is chlorinated and pH is adjusted by injection of soda ash. The quality of the treated water is to be adjusted as follows:

Total hardness	:	60 $\pm$ 10 mg/l (as $CaCO_3$)
Langelier index	:	+0.2 $\sim$ 0.5
pH	:	7.0 $\sim$ 8.5

So, this water is not agressive for corrosion and satisfies the WHO Standards for drinking water and Omanian Standards (Drinking water).

Fig. 9. 7 PRODUCT WATER TREATMENT PROCESS FLOW SEET