ENVIRONMENTAL IMPACT OF SEAWATER DESALINATION PLANTS

IBRAHIM S. AL-MUTAZ

Chemical Eng. Dept., College of Eng., King Saud University, P.O. Box 800, Riyadh 11421, Saudi Arabia

(Received April 1989)

Abstract. Enormous amounts of seawater are desalted everyday worldwide. The total world production of fresh water from the sea is about 2621 mgd (9.92 million m^3 day^{-1} 1985 figures). Desalting processes are normally associated with the rejection of high concentration waste brine from the plant itself or from the pretreatment units as well as during the cleaning period. In thermal processes, mainly multistage flash (MSF) thermal pollution occurs. These pollutants increase the seawater temperature, salinity, water current and turbidity. They also harm the marine environment, causing fish to migrate while enhancing the presence of algae, nematods and tiny molluscus. Sometimes micro-elements and toxic materials appear in the discharged brine.

This paper will discuss the impact of the effluents from the desalination plants on the seawater environment with particular reference to the Saudi desalination plants, since they account for about 50% of the world desalination capacity.

Introduction

There are bout 4600 desalination plants throughout the world with a total capacity of 2621 mgd (9.92 mm^3 day^{-1}), according to 1985 statistics [1]. Table I shows the desalination market in 1985. Two basic processes are used for desalination:

(1) Thermal processes (distillation): of these, multistage flash (MSF) is the principal process in current use.

(2) Membrane processes: these include reverse osmosis (hyperfiltration) or electrodialysis, ED.

MSF accounts for 67.6% (i.e. 1772 mgd) of the total world desalting capacity and is preferred for with a large desalination capacity above 1 mgd. About 84.5% of the world's plants with a capacity of more than 1 mgd are of the MSF type. However, its share in the world capacity of desalting is about 23% - mostly for small plants of less than 1 mgd.

Desalination in Saudi Arabia started in 1907. The first MSF plant was built in Duba and Al-Wajh in 1928 with a capacity of 60000 gpd (227.1 m^3 day^{-1}). In 1978, the Saline Water Conversion Corporation (SWCC) was established to carry out the necessary feasibility and preliminary studies for installing desalination plants in the Red Sea and the Arabian Gulf and to maintain the operating ones. It is planned to supply fresh water to coastal and inland cities and towns from the sea with ground water as a back up. So at present, there are 21 desalination plants in operation with a design total capacity of 481 mgd (1.82 mm^3 day^{-1}). Table II shows the total number of desalination projects in Saudi Arabia in operation, under construction, at planning stage or still at the study phase. The total projected capacity of these plants will be 725.4 mgd (2.74 mm^3 day^{-1}).

In the following section, the impact of desalination plants on the environment will be discussed with reference to monitoring results on the Jeddah (Saudi Arabia) desalination plant.

Environmental Monitoring and Assessment **16**: 75-84, 1991.

TABLE I

World desalination market in 1985

Total No. of plants		4600
Total Capacity		2621 mgd (9.92 mm^3 day^{-1})
Sales growth rate from 1980 to 1984		7%
Market share according to (%):		
Capacity	MSF	67.6
	RO	23.0
Feed	Seawater	66.6
	Brackish water	23.0
Use	Drinking water	67.0
	Industrial water	20.0
	Boiler feed water	5.0
Manufacturer	Sasakura (J)	19.0
	SIDEM (fr)	9.5
	Ionics (USA)	3.6
Geography	Arabian peninsula (Saudi Arabia 50%)	60.0
	USA	17.0
	Libya	5.4
	Iran	3.1
	USSR	2.5
Plant size	< 0.01 mgd: MSF	44.0
	RO	43.0
	> 1.0 mgd: MSF	84.5
	RO	11.2

Source: L. Liberti, R. Passino, M. Santori, and G. Boardi, Second World Congress on Desalination and Water Reuse, Bermuda, Nov. 17, 1985.

Pollutants from Desalination Plants

Pollution can be defined as the presence in the biosphere of one or more contaminants for such a duration as may be injurious to human, plant or animal life or property or may unreasonably interfere with enjoyment of life or property. The biosphere consists of atmosphere, hydrosphere and lithosphere. So air pollution, water pollution and solid liquid wastes are defined in accordance with the corresponding parts of the biosphere.

In desalination plants, these types of pollution occur according to the desalination process used and the location of the plant. In coastal plants, water pollution is the main problem. In inland plants, attention must be paid to disposal of the rejected concentrated brine. If those plants are of the MSF type, air pollution problems arise. In MSF plants, large amounts of fuel are burned to generate the necessary energy for desalting.

Air pollutants are of the fuel combustion type, such as carbon monoxide, nitrogen oxides, unburned hydrocarbons and sulphur oxides. Desalination burners and power stations are the main source of sulphur oxides as high sulphur content fuels are usually used.

TABLE II

Major Saudi desalination plants

(A) Plants in operation Plant	Startup date (Hegira)*	Installed Water, mgd	Capacity Power, MW
1. Al-Wajh I	1389	0.060	-
2. Duba I	1389	0.060	-
3. Jeddah I	1390	5.000	50.0
4. Ummlugg I	1395	0.150	-
5. Jeddah II	1398	11.400	84.0
7. Duba II	1399	0.150	-
9. Al-Wajh II	1399	0.150	-
10. Farasan Island I	1399	0.132	2.30
11. Hagl I	1400	0.233	-
12. Madina/Yanbu I	1401	28.500	250.0
13. Jeddah IV	1401	58.100	600.0
14. Tabigh I	1401	0.340	-
15. Al-Birk I	1403	0.340	-
16. Al-Khafji I	1393	0.145	-
17. Al-Khobar I	1394	0.330	-
19. Al-Jubail I	1401	36.300	360.0
20. Al-Jubail II	1403	253.500	1295.0
21. Al-Khobar II	1403	51.500	600.0
(B) Plants under construction			
22. Makkah-Taif	Under construction	48.000	320.0
23. Assir I	"	24.000	128.0
24. Ummlugg II	"	1.000	-
25. Duba III	"	1.000	-
26. Hagl II	"	1.740	-
27. Al-Khafji II	"	6.100	-
(C) Projects in planning			
28. Leith	In planning	0.150	-
29. Madina/Yanbu II	"	20.000	50.0
30. Tabuk	"	30.000	to be determined
31. Kunfuda	"	1.000	-
32. Al-Khobar III	"	60.000	600.0
(D) Projects under study			
33. Jeddah II	Under study	50.000	to be determined
34. Al-Wajh III	"	1.00	-
35. Thul/Al-Kadima	"	0.50	-
36. Mastura	"	0.50	-
37. Farasan Island II	"	0.50	-

SWCC Project in Bahrain, a reverse osmosis plant of 10 mgd

* Year 1389 in Hegira corresponds to 1968.

Source: '*Saline Water Conversion*', published by Saline Water Conversion Cooperation (SWCC) Riyadh, Saudi Arabia.

TABLE III

Rating of various desalination processes [3]

Effect	RO	MSF	ED
Noise	H	M	L
Waste effluent	M	H	M
Product water impurity:			
* Micro-elements	L	H	L
* Toxic material	M	H	M
Air pollution	L	H	M
Industrial risk	L	H	M
Total score	10	17	10

Water pollution of desalination plants is caused by the disposal of the hot brine. The world's oceans receive 3.86×10^{7} kcal (1.53×10^{8} Btu) and 4.5×10^{16} tons of minerals from desalination plants daily [2]. The rejected brine affects the sea's salinity and turbidity, it increases its temperature and causes water currents. Besides this thermal and saline pollution of the rejected brine, toxic effects are also caused by the use of different chemicals in the desalination pre and post treatment processes.

Sabri *et al.* [3] evaluated the safety, health and environment (SHE) considerations for RO, MSF and ED using value impact analysis techniques. They utilized a pseudo-quantitative scale where high (H=3), medium (M=2) and low (L=1). RO and ED seem preferable to MSF from the SHE viewpoint. Their results are shown in Table III.

Gaseous pollutants from desalination stacks have serious effects on human health. Carbon monoxide, CO, is a poisonous gas which deprives the body tissues of essential oxygen. It combines with haemoglobin and forms carboxy haemoglobin, COHb. This reduces the oxygen carrying capacity of the blood significantly since haemoglobin has an affinity for CO of 210 times its affinity for oxygen. Evidence indicates that exposure for 8 or more to a concentration of 30 ppm (35 mg m^{-3}) of CO cuases impaired performance in certain psychomotor tests [4]. At 100 ppm, most people experience dizziness, headaches and lassitude. CO exposure may cause death at high concentrations of >750 ppm. Air quality standards for CO are; 9 ppm (10 mg m^{-3}) for 8; 35 ppm (40 mg m^{-3}) for 1 hr.

Nitric oxide, NO, and nitrogen dioxide, NO_2, are the most important forms of nitrogen oxides emitted from fuel combustion in desalination plants. Nitrogen dioxide acts as an acute irritant and is more harmful than NO. Both of them react with unburned hydrocarbons in the presence of sunlight to form photochemical smog. The main products of these photochemical reactions are ozone, peroxyacetyl nitrate (PAN) and peroxybenzoyl (PBN). These photochemical oxidants are harmful to humans, plants and materials. Nitrogen oxides also contribute to the formation of acid rain which is seriously affecting soil and natural water resources. The primary air quality standard for nitrogen oxides is 0.05 ppm (100 μg m^{-3}) as an annual average.

Sulphur dioxide, SO_2, acts as a pungent, suffocating and irritant gas. Its effect under moderate exposure is on the upper respiratory tract. Table IV summarizes the effect of

TABLE IV

Effect of SO_2 at various concentrations [4])

Concentration	Effect
0.03 ppm, annual average	1974 air quality standard, chromic plant injury.
0.037-0.092 ppm, annual mean	Accompanied by smoke at a concentration of 185 $\mu g\ m^{-3}$, increased frequency of respiratory symptoms and lung disease may occur.
0.11-0.19 ppm, 24 h mean	With low particulate level, increased hospital admission of older persons for respiratory diseases may occur. Increased metal corrosion rate.
0.19 ppm, 24 h mean	With low particulate level, increased mortality may occur.
0.25 pp, 24 h mean	Accompanied by smoke at a concentration of 750 g m^{-3}, increased daily death rate may occur (British data); a sharp rise in illness rates.
0.3 ppm, 8 h	Some trees show damage.
0.52 ppm, 24 h average	Accompanied by particulate, increased mortality may occur.

Source: Summarized from data presented in National Air Pollution Control Administration, Air Quality Criteria for Sulfur Oxides, AP 50. Washington, D.C.: HEW, 1970.

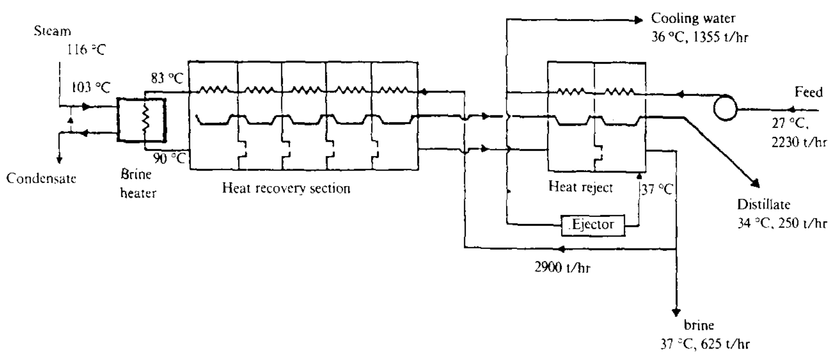

Fig. 1. Heat balance on MSF desalination plant.

SO_2 at various concentrations [4]. Sulphur oxides also react with atmospheric moisture and form acid rain. The air quality standards for SO_2 are 0.5 ppm (1300 $\mu g\ m^{-3}$) for 3 h, 0.14 ppm (365 $\mu g\ m^{-3}$) for 24 h and 0.03 ppm (80 $\mu g\ m^{-3}$) as an annual average.

The thermal pollution of a 1.59 mgd (6000 $m^3\ day^{-1}$) MSF desalination plant is illustrated in the thermal balance of Figure 1. The temperature rise is about 9 °C. The total discharge brine is 1980 t h^{-1} (0.55 $m^3\ s^{-1}$) with an approximate salinity rise of 12.6%.

Pollution at Jeddah Desalination Plant

The total desalting capacity in Jeddah is 100.9 mgd (382 000 $m^3\ day^{-1}$) plus the projected 50 mgd (190 250 $m^3\ day^{-1}$) plant which is still at the study phase. These plants require an intake of about 810 mgd (3.07 $mm^3\ day^{-1}$). Approximately 700 mgd (2.65 $mm^3\ day^{-1}$ - 36.8 $m^3\ s^{-1}$) are used as coolant and rejected at the intake concentration of 39%. Salinity of the rejected brine is always higher than the intake concentration. The average concentration of the total rejected seawater is 47.5% which represents an increase of 21.8% in salt concentration. The total salts added to the sea are then to the order of 266 kg s^{-1} (8.3×10^9 kg y^{-1}). The total salt content in the Red Sea (where the Jeddah desalination plant is located) is 8.4×10^{15} kg with an exchange rate of 13.5×10^6 kg s^{-1} at Bab El-Mandab, the southern entrance of the Red Sea.

With regard to air pollution, the Saudi Meteorology and Environmental Protection Administration, MEPA, studied the effect of the Jeddah desalination plant on nearby housing, Air Defense Base Housing, from January 1 until March 31, 1986 [5]. About 76 violations in sulphur dioxide concentration were recorded above the one hour average MEPA standard of 0.28 ppm during the study period. Figures 2, 3 and 4 show the maximum one hour average concentrations of sulphur dioxide for January, February and March respectively. During this period, the maximum one hour concentration of sulphur dioxide was 0.757 ppm on February 14, 1986 at a direction of 297 and wind speed of 4.8 m s^{-1}. Most violations were observed in the period between noon and 4:00 pm. No violation of the 24-h maximum average concentration of sulphur dioxide was observed. However, the maximum average 24-h concentration of sulphur dioxide was 0.13 ppm, close to the 0.14 MEPA standard.

There were six violations in the nitrogen oxides concentration as listed in Table V. The maximum one hour concentration was 0.528 ppm which was recorded on February 9, 1986. The MEPA standard for one hour nitrogen oxides concentration is 0.35 ppm.

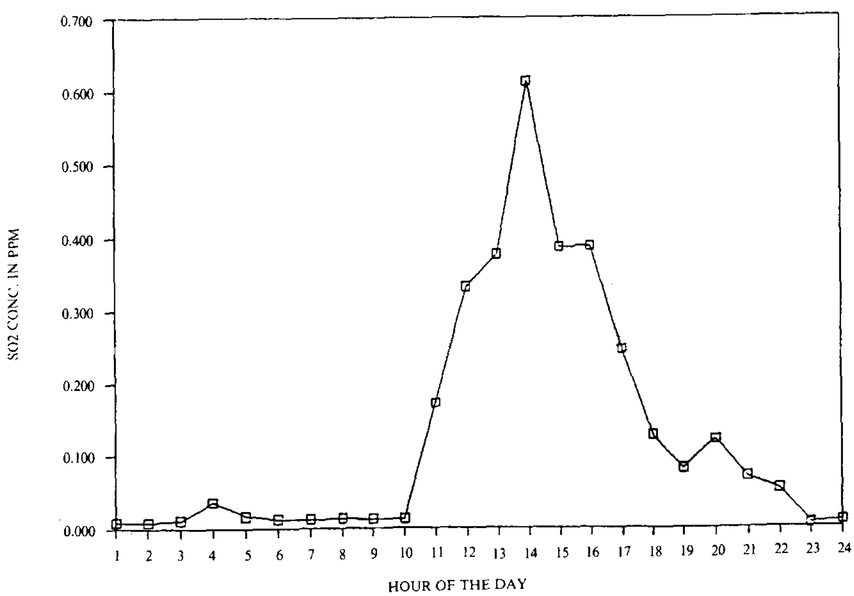

Fig. 2. Average maximum 1-h SO_2 conc. in the vicinity of Jeddah desalination plant, January 86 (5).

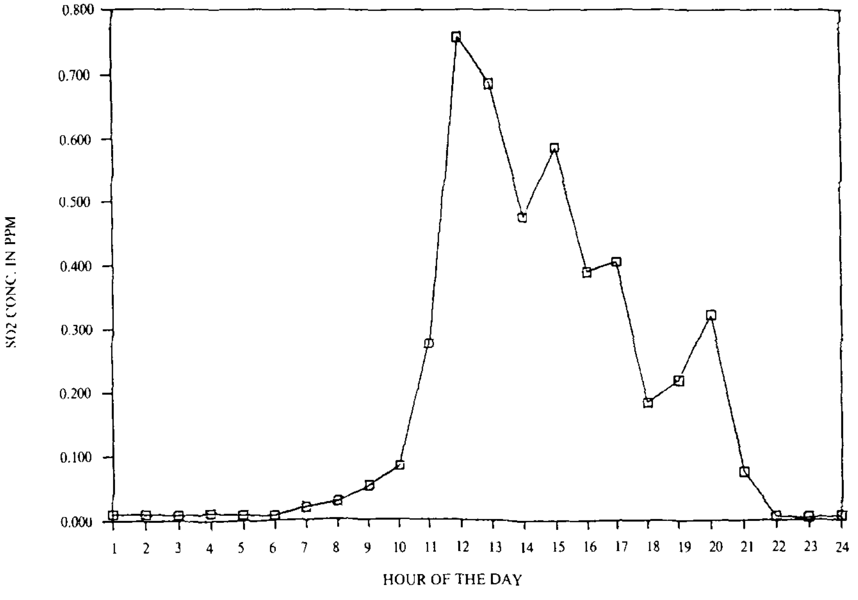

Fig. 3. Average maximum 1-h SO_2 conc. in the vicinity of Jeddah desalination plant, February, 86 (5).

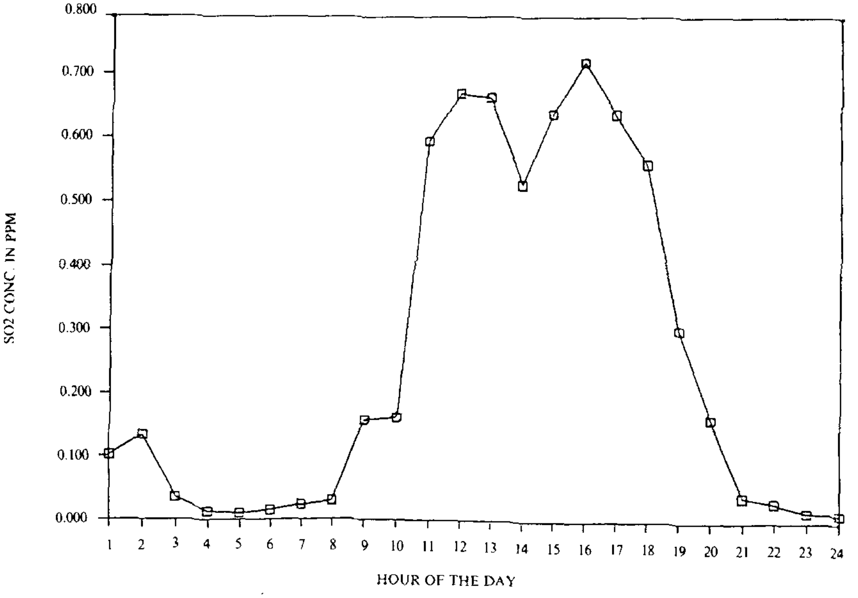

Fig. 4. Average maximum 1-h SO_2 conc. in the vicinity of Jeddah desalination plant, March, 86 (5).

TABLE V

Violation in nitrogen oxides concentration in the vicinity of Jeddah desalination plant [4]

Date	Hour	N ox. conc. ppm	Wind direc. deg	Wind speed m s^{-1}
2-03-86	24:00	0.405	351	4.0
2-04-86	9:00	0.528	-	6.0
2-21-86	4:00	0.363	343	3.1
2-21-86	8:00	0.351	36	2.1
3-09-86	8:00	0.392	321	9.0
3-09-86	9:00	0.369	210	4.0

Ozone and carbon monoxide were found to be well below the permitted MEPA standard [5], so the high concentration of sulphur dioxide emitted from the desalination plant is the only air pollution problem. This is due to the high sulphur content of the fuel used in the 13 boilers of the Jeddah desalination plant, which is about 3.5 weight percent. Boiler stacks are between 92.5 and 150 meters in height and electrostatic precipitators are used to control the emission of particulates Yet there are no means of controlling air pollution. About 259 950 tons of fuel were combusted during January, 1986. This led to the formation of the following amounts of pollutants:

- Sulphur dioxide 287.0 ton day^{-1},
- Sulphur trioxide 4.0 ton day^{-1},
- Carbon monoxide 2.7 ton day^{-1},
- Nitrogen oxides 27.0 ton day^{-1}.

The MEPA standard for sulphur is 1 $\mu g\ J^{-1}$ (2.3 lb $MBtu^{-1}$) which is equivalent to 2.1 to 2.3% by weight of sulphur in the fuel. This is considered less stringent in comparison to the recent US EPA standard of 0.8 lb $MBtu^{-1}$. Table VI shows the standards for sulphur in fuel oil in some other countries.

Most of the crude oil in Saudi Arabia has a sulphur content in excess of 3.2%. However, desulphurization of heavy crude oil is difficult; it requires huge energy consumption and is very expensive. A plant producing 2.5 million ton y^{-1} of desulphurized products would need 340 million dollars of capital investment.

It would appear that the regulatory authorities have done little to alleviate the serious impact of desalination plants on the environment. No regulations have yet been formulated to conserve marine life in the desalination discharge vicinity. Environmental protection agencies are usually concerned with minimizing the emissions from the desalination stacks, yet the thermal and saline pollution caused by desalination plants is of comparable importance. It has serious repercussions on both the desalination intake facilities and the marine environment.

TABLE VI

Standards for sulphur content in fuel oil

Country	Sulphur content, %
Canada	1.5
Denmark	2.5
England	1.0
France (Paris)	2.0
(Nord)	2.0
(Rhone)	1.0
Japan	1.5
Netherlands	2.5
Norway	1.2
Saudi Arabia	2.3
Spain	2.0
Sweden	2.5
USA	0.8
West Germany	1.8

Conclusions

Desalination plants cause thermal and saline pollution and these environmental problems have localized effects. They cause damage to marine life in the desalination intake/disposal vicinities. Disposal of desalination effluents are a particular problem for inland plants.

Desalination boilers are sources of air pollution. Either modification of the combustion process or flue gas desulphurization is required to minimize the environmental damage caused by these boilers [6]. Flue gas desulphurization of stack exhaust gases is a fairly well-developed technique for medium-sized oil fired boilers.

To reduce environmental damage by desalination plants temperature differences should be minimized, by cooling for example. Excessive dispersion of the rejected brine is required. Seawater pretreatment processes may be adapted with the withdrawal of the minimum amount of chemicals. Complete combustion in the fuel burner is needed as well as the use of low sulphur fuels.

References

[1] Libertt, L., Passino, R., Santori, M. and Boari, G.: 1985, 'Technical and Economical Trends of Seawater Desalting in the 90's', Second World Congress on Desalination and Water Reuse, Bermuda, Nov. 17-22.

[2] Al-Mutaz, I. S.: 1987, 'By-Product Recovery from Saudi Deslination Plants', Third World Congress on Desalination and Water Reuse, Cannes, France, Sept. 14-17.

[3] Sabri, Z. A., McLagan, G. P. and Hagensonh, R. L.: 1980, 'Safety and Environmental Impact of Fossil Fueled Desalination Plants', Processing of the 7th International Symposium on Fresh Water from the Sea, Vol. 1, 99 pp.

[4] Wark, K. and Warner, C. F.: 1981, 'Air Pollution: Its Origin and Control', 2nd ed., Harper & Row Pub., New York.

[5] Saudi Meteorology and Environmental Protection Administration: 1986 'Monitoring Air Quality in Jeddah Air Defense Base', MEPA, Jeddah, October.
[6] Al-Mutaz, I. S.: 1987 'Power Station and the Environment', Kuwait Environmental Protection Society, Environmental Issue No. 29, February.