Wat. Res. Vol. 26, No. 4, pp. 435–441, 1992
Printed in Great Britain. 

0043-1354/92 $5.00 + 0.00


# IMPACT OF A DESALINATION PLANT ON THE PHYSICAL AND CHEMICAL PROPERTIES OF SEAWATER, BAHRAIN

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*(First received April 1990; accepted in revised form October 1991)*

**Abstract**—The impact of effluent from the Sitra power and desalination plant (SPDP), Bahrain, on the physical and chemical properties of the receiving water was investigated. Two distinguished zones of the receiving water were recognized. These zones resulted from the presence of the jetty. The length of the first zone is about the same length as the jetty, 70 m. The length of the second zone extends to about 150 m. Seventy five case stations were selected on the receiving water. On the intake side, fifteen stations were considered as control stations. The SPDP effluent significantly changed the temperature and salinity of the receiving water of the first zone. The dissolved oxygen levels vary slightly from the control stations. The jetty was found to restrict the water circulation of the first zone. This restriction caused a delay in the temperature, salinity and dissolved oxygen dispersion. Beyond the first zone, this restriction is removed and the dispersion processes affected the control stations.

*Key words*—thermal pollution, power plants, desalination plants, dissolved oxygen, salinity, Arabian Gulf, Bahrain

## INTRODUCTION

The problems of thermal discharge are becoming more and more critical as the demand for electricity and desalinated water is increasing in the Arabian Gulf countries. Thermal discharge may cause three major changes in the natural ecosystems. The first change is the thermal enrichment of the receiving water; secondly, alteration of the chemical make-up of the water may be detected; and thirdly, the biotic structure may be modified (GESAMP, 1984).

The magnitude of the effects of the thermal discharge varies with the temperature of the effluents, the topography of the system and the dispersion rate of the receiving water. Signs of thermal effects on the marine ecosystem could be seen through the alteration in the water quality, marine organisms and habitats (Jensen *et al.*, 1969; Coutant, 1970; Davies and Jensen, 1974).

The most obvious chemical alteration may include an increase in the salinity and a decrease in the dissolved oxygen (Winters *et al.*, 1979). The effects of these changes on the marine ecosystem may depend upon the rate of dispersion of the effluent (Winters *et al.*, 1979; Eloranta, 1983). As the rate of dispersion increased, the effects of the effluent are decreased.

This work was designed to study the physical and chemical effects of the thermal discharge from the Sitra power and desalination plant (SPDP), Bahrain is the Arabian Gulf. The near- and far-field effects were investigated. The effects of the jetty on the dispersion rate of the effluent were also considered.

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### *The study site*

The investigated site is located at the north side of Sitra Island, Bahrain (Fig. 1). More details on the State of Bahrain are given elsewhere (Madany and Danish, 1988). The island is surrounded by a shallow bay. The average depth of the bay is 1 m. The SPDP is a thermal plant located on the island and produces about 28 Mgal/day of desalinated water and 125 MW of electric power.

The plant has four cooling water conduits. These conduits are located on the north side of the plant. The seawater inlet flow has an average rate of 66,000 $m^3/h$. There are four effluent outlets, three from the distillers and one from the condenser (Fig. 1). The hot effluent is discharged at an average rate of about 12,000 $m^3/h$.

To prevent the spill-over of warm effluent into the intake surface water, a rocky jetty has been constructed. The length and width of the jetty are 70 and 2 m, respectively (Fig. 1). The water temperatures of the site range from 10 to 20°C in winter months, December–February (Price *et al.*, 1984; Al-Alawi, 1983) and may reach 40°C during summer months, May–September. Coastal air temperatures during winter months normally drop to 12°C and regularly exceed 40°C in summer months (Issa, 1989; Vousden, 1988). During the winter months, the salinity of the surface water of the site may drop to about 37 ppt, and may reach 45 ppt during the summer months (Vousen, 1988; Al-Alawi, 1983). The dissolved

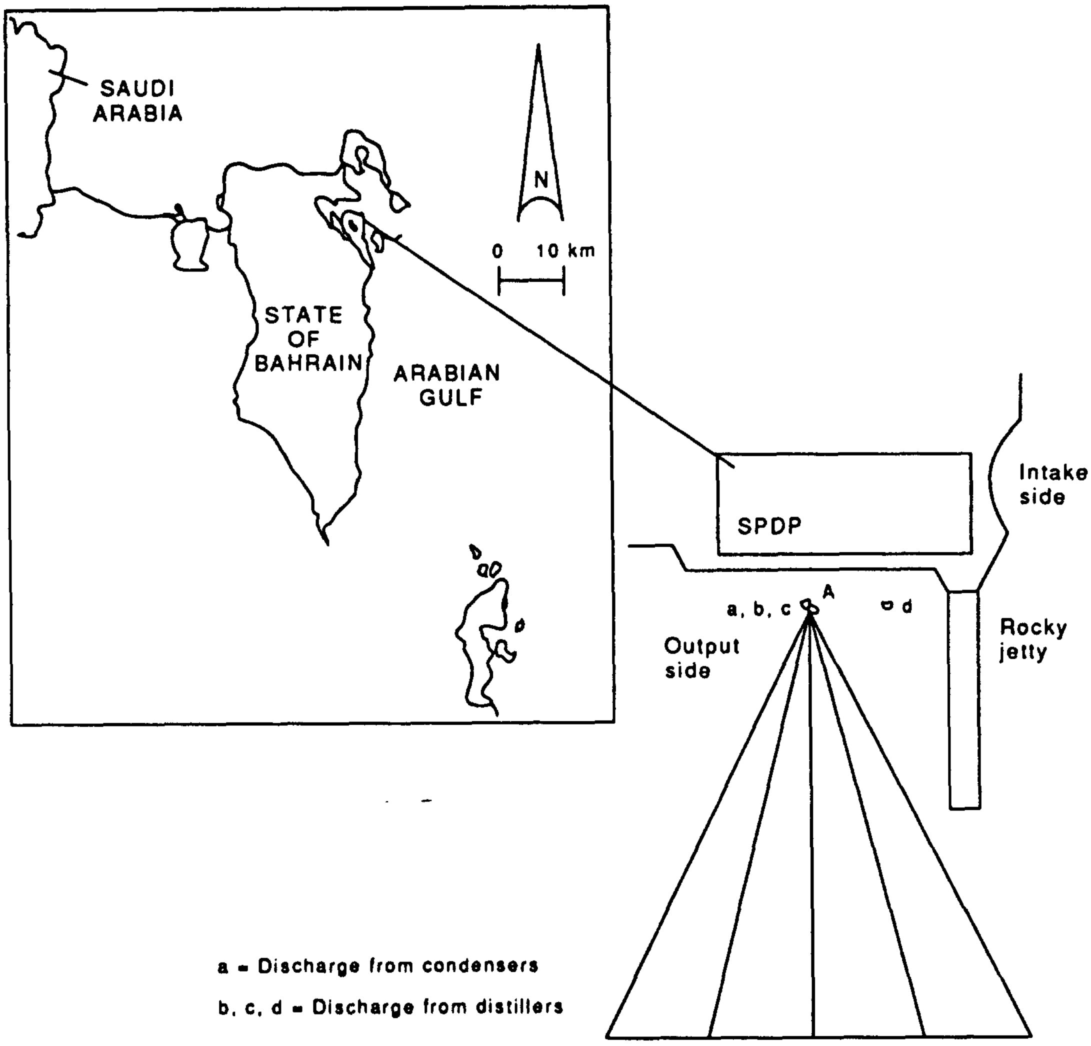


Fig. 1. The location of the investigated site and the discharges from the Sitra power and desalination plant (SPDP). Fifteen stations are distributed on each line of AC, AE, AB, AF and AD.

oxygen levels of the surface water range from 6.0 to about 4.0 mg/l during the winter and summer months, respectively (Al-Alawi, 1983).

*The field study*

The effects of thermal discharge from the SPDP on the surface water temperature, salinity, dissolved oxygen and pH were monitored. An electric thermometer (Digi-Sense, Cole–Pamer Instrument Co., U.S.A.) was used to measure the water temperature. A refractometer (Reichert, Model 10419, Reichert Scientific Instruments, U.S.A.) was used to determine the salinity. Dissolved oxygen levels were determined by a portable oxygen meter (Surveyer 2, Hydrolab Corp., Austin, Tex., U.S.A.). An electronic pH meter was utilized to measure the pH levels.

Measurements were conducted twice a week for a period of 2 months (February and March). These 2 months are a transition period between the winter and summer months. The measurements were conducted at 90 stations. The distribution of these stations is presented in Fig. 2. Fifteen stations were located on the inlet side. These were considered as the reference points of this study. Seventy five stations were selected randomly on the outlet side. The first station was selected near the concrete wall of the outlets. These stations covered an area of approx. 1500 $m^2$.

The NCSS (1987) statistical package was used to analyze the data. The size of the mixing zone was estimated according to the method of the U.S. Atomic Energy Commission (1971). The contour maps were produced by Surfer (1987).

## RESULTS

The results are presented in Tables 1–3 and Figs 2–7. Two zones of the receiving water were distinguished. The first zone extends from the discharge points to 70 m seaward. This zone falls within the

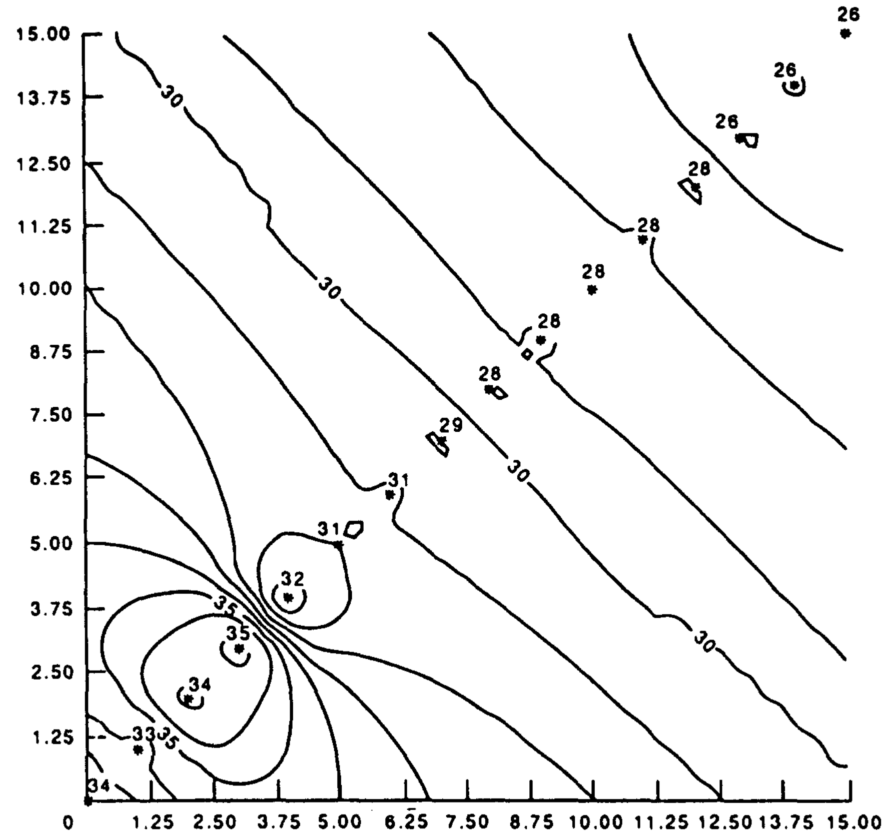

Fig. 2. The pattern of the temperature dispersion of the thermal discharges from the SPDP. The contours represent the mean temperature (°C) of 75 stations. The units of the $x$ and $y$ axes are distance from the discharge ( × 10 m).

protection limit of the jetty (hereinafter called the protected zone). The second zone extends beyond the protected zone to about 150 m seaward.

No significant changes were noted in the pH values of the various stations (the pH value was 8.3), therefore, data about the pH were not included.

The effluent of the SPDP had various effects on the receiving winter. The temperature and salinity of the stations of the protected zone were significantly higher than those of the control stations (Tables 1 and 2). The dissolved oxygen levels of the protected zone were slightly lower than those of the control stations (Table 3).

Beyond the protected zone limit there were various responses. The significant differences in water temperature between the receiving and control stations continued, but significant differences in the water salinity of the receiving and control stations were also

Table 1. The mean temperature (°C) of 75 stations of receiving water distributed on five lines (AC, AE, AB, AF and AD) and 15 control stations

| Station number | Receiving water stations | | | | | Control station |
|---|---|---|---|---|---|---|
| | AC | AE | AB | AF | AD | |
| 1 | 32 | 32 | 32 | 35 | 35 | 22 |
| 2 | 25 | 34 | 34 | 35 | 35 | 22 |
| 3 | 26 | 37 | 36 | 36 | 35 | 22 |
| 4 | 27 | 37 | 37 | 36 | 34 | 22 |
| 5 | 25 | 30 | 35 | 34 | 34 | 22 |
| 6 | 25 | 31 | 33 | 33 | 30 | 22 |
| 7 | 25 | 31 | 33 | 33 | 29 | 22 |
| 8 | 25 | 31 | 33 | 28 | 27 | 22 |
| 9 | 25 | 29 | 30 | 28 | 27 | 22 |
| 10 | 25 | 29 | 30 | 28 | 27 | 22 |
| 11 | 25 | 28 | 30 | 28 | 25 | 23 |
| 12 | 25 | 28 | 30 | 28 | 23 | 23 |
| 13 | 23 | 28 | 29 | 28 | 23 | 23 |
| 14 | 23 | 28 | 29 | 25 | 25 | 25 |
| 15 | 23 | 26 | 29 | 25 | 25 | 25 |

Table 2. The mean salinity (ppt) of 75 stations of receiving water distributed on five straight lines (AC, AE, AB, AF and AD) and 15 control stations

| Station number | Receiving water stations | | | | | Control station |
|---|---|---|---|---|---|---|
| | AC | AE | AB | AF | AD | |
| 1 | 45 | 45 | 45 | 45 | 49 | 45 |
| 2 | 48 | 48 | 48 | 48 | 49 | 45 |
| 3 | 48 | 48 | 48 | 48 | 49 | 46 |
| 4 | 48 | 54 | 55 | 48 | 51 | 46 |
| 5 | 48 | 53 | 49 | 48 | 46 | 46 |
| 6 | 46 | 51 | 49 | 48 | 46 | 46 |
| 7 | 46 | 51 | 48 | 48 | 46 | 46 |
| 8 | 46 | 50 | 48 | 46 | 48 | 46 |
| 9 | 46 | 50 | 48 | 46 | 49 | 46 |
| 10 | 46 | 46 | 48 | 46 | 44 | 46 |
| 11 | 46 | 46 | 46 | 46 | 46 | 46 |
| 12 | 46 | 46 | 46 | 46 | 46 | 46 |
| 13 | 46 | 46 | 46 | 46 | 46 | 46 |
| 14 | 46 | 46 | 46 | 46 | 46 | 46 |
| 15 | 46 | 46 | 46 | 46 | 46 | 46 |

Table 3. The mean dissolved oxygen (mg/l) of 75 stations of receiving water distributed on five straight lines (AC, AE, AB, AF and AD) and 15 control stations

| Station number | Receiving water stations AC | AE | AB | AF | AD | Control station |
|---|---|---|---|---|---|---|
| 1 | 5.0 | 5.0 | 5.0 | 5.0 | 4.7 | 6.5 |
| 2 | 5.0 | 5.0 | 5.0 | 5.0 | 4.7 | 6.4 |
| 3 | 5.5 | 5.7 | 5.5 | 5.0 | 5.0 | 6.3 |
| 4 | 5.8 | 5.8 | 5.7 | 5.3 | 5.0 | 6.4 |
| 5 | 5.5 | 5.7 | 5.5 | 5.7 | 5.8 | 6.4 |
| 6 | 5.5 | 5.5 | 5.6 | 5.6 | 5.8 | 6.4 |
| 7 | 5.5 | 6.0 | 5.6 | 5.2 | 5.6 | 6.5 |
| 8 | 5.5 | 6.0 | 5.6 | 5.2 | 5.5 | 6.5 |
| 9 | 5.5 | 5.8 | 5.6 | 5.3 | 5.6 | 6.3 |
| 10 | 5.5 | 5.8 | 5.6 | 5.3 | 5.6 | 6.5 |
| 11 | 5.6 | 5.8 | 5.8 | 5.3 | 5.6 | 6.5 |
| 12 | 5.6 | 5.8 | 5.8 | 5.8 | 5.5 | 6.0 |
| 13 | 5.8 | 5.8 | 5.8 | 5.8 | 5.5 | 6.0 |
| 14 | 5.8 | 5.8 | 5.8 | 5.8 | 5.5 | 6.0 |
| 15 | 6.0 | 5.8 | 5.8 | 5.8 | 5.5 | 6.0 |

observed (Tables 1 and 2). A slight difference in the dissolved oxygen was recorded between the receiving and control stations (Table 3).

Heated water dispersion is strongly affected by the presence of the jetty. The jetty restricts water currents and circulation within the protected zone. Within the protected zone, the dispersion of the heated effluent was strongly restricted and depressed. The dispersion of temperature in the protected zone was also affected by the jetty, whereas, the dispersion of temperature returned to normal beyond the jetty. At about 30 m beyond the protected zone, and where the jetty effect is lifted, the control stations were affected by the change of water temperature of the receiving water (Fig. 4). Similar pictures to that of the protected zone were obtained regarding the salinity and dissolved oxygen (Figs 5–8).

The size of the mixing zone was estimated as 160 m. This distance exceeds the protection limit of the jetty by about 90 m.

## DISCUSSION

The rate of heat dissipation is a direct function of the amount by which the effluent temperature is above ambient water temperature. The average temperature increase of the cooling water of the SPDP deducted is 7.5°C. Effluent water is directly discharged into the shallow coastline water body at a temperature of 10–15°C above the naturally occurring equilibrium water temperature during winter and summer months. The water discharged into the natural water body from the SPDP caused the effluent to spread over the surface and avoid excessive mixing. The warmed water is directly exposed to the atmosphere for heat dissipation. This type of dissipation relies on the rate at which warmed water moves to the surface.

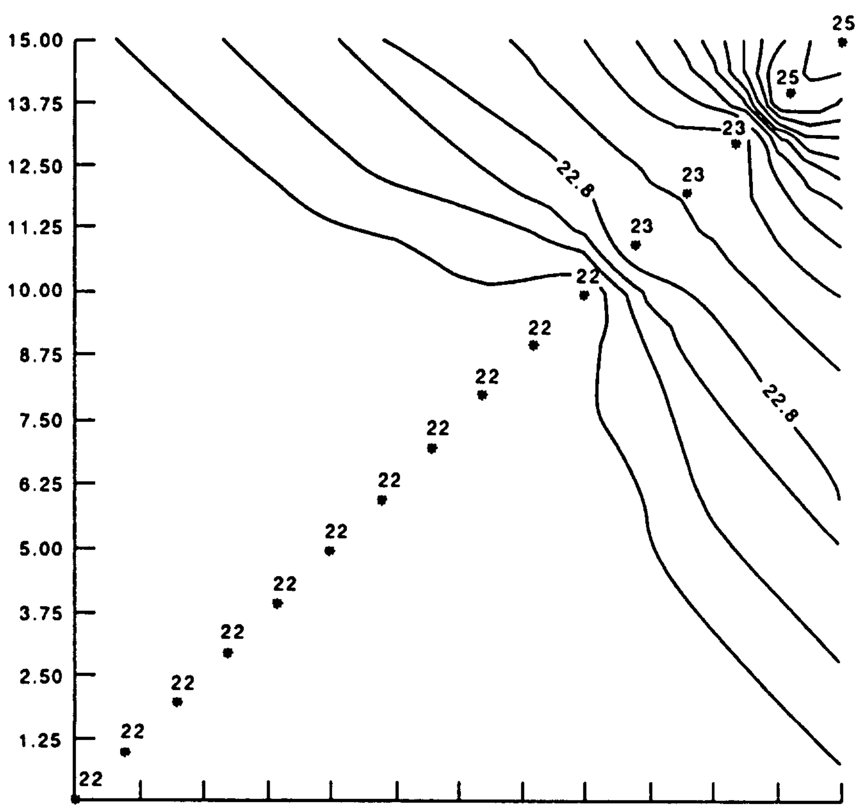


Fig. 3. The pattern of the temperature dispersion of the control stations of the SPDP. The contours represent the mean temperature (°C) of 15 stations. The units of the $x$ and $y$ axes are $\times$ 10 m.

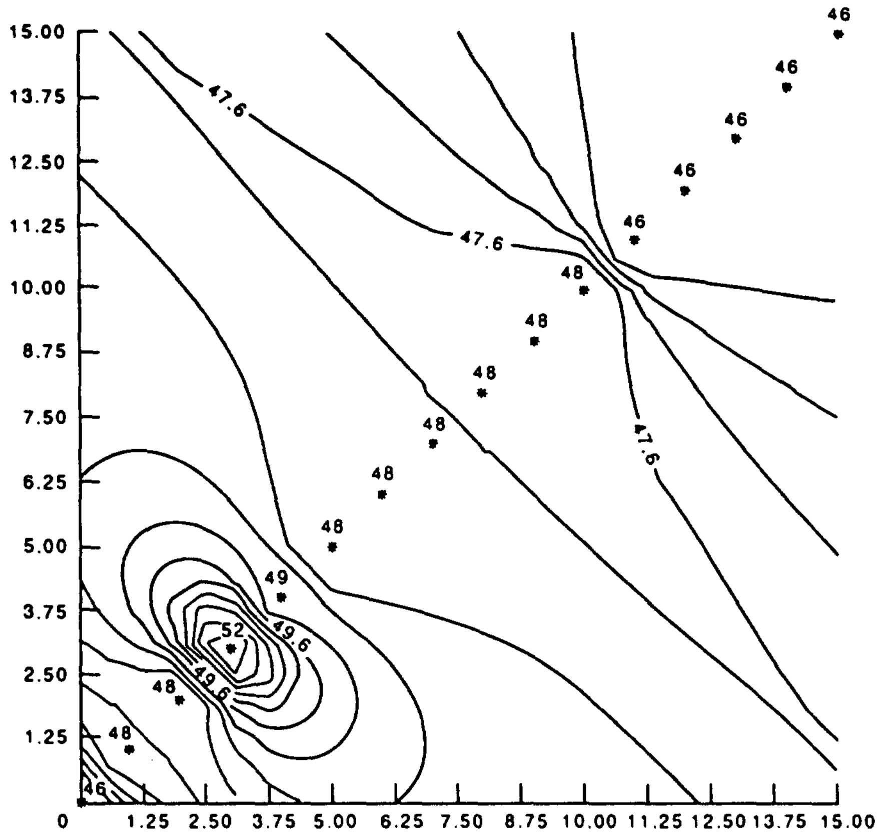


Fig. 4. The pattern of the salinity dispersion of the thermal discharges from the SPDP. The contours represent the mean salinity (ppt) of the 75 case stations. The units of the $x$ and $y$ axes are distance from the discharge ( × 10 m).

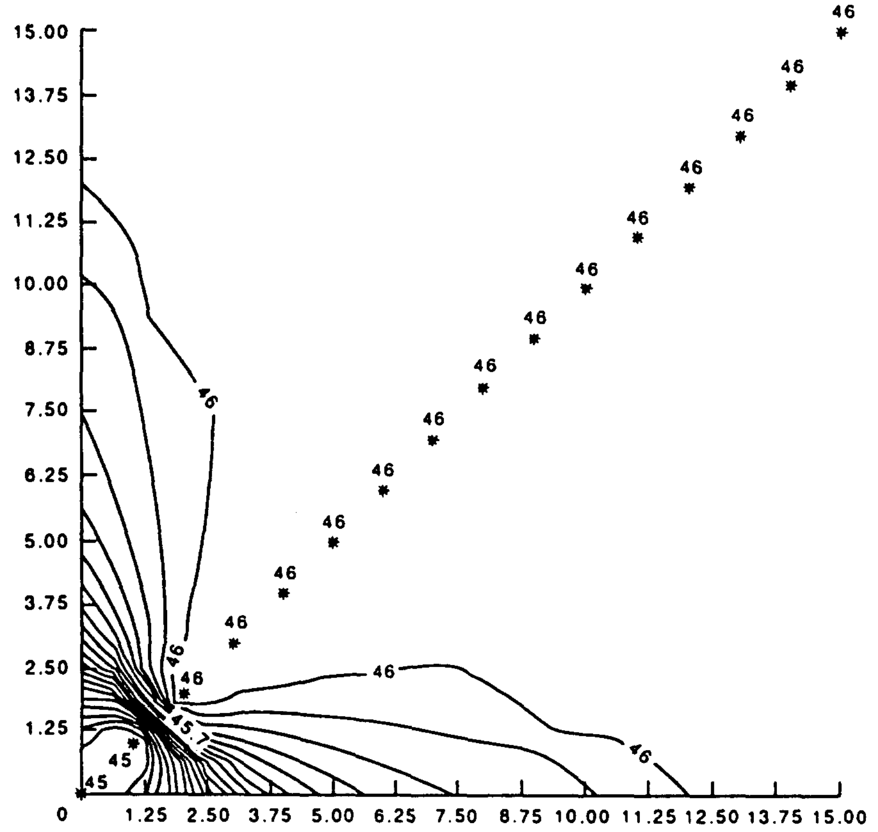


Fig. 5. The pattern of the salinity dispersion of the control stations of the SPDP. The contours represent the mean salinity (ppt) of the 15 stations. The units of the $x$ and $y$ axes are × 10 m.

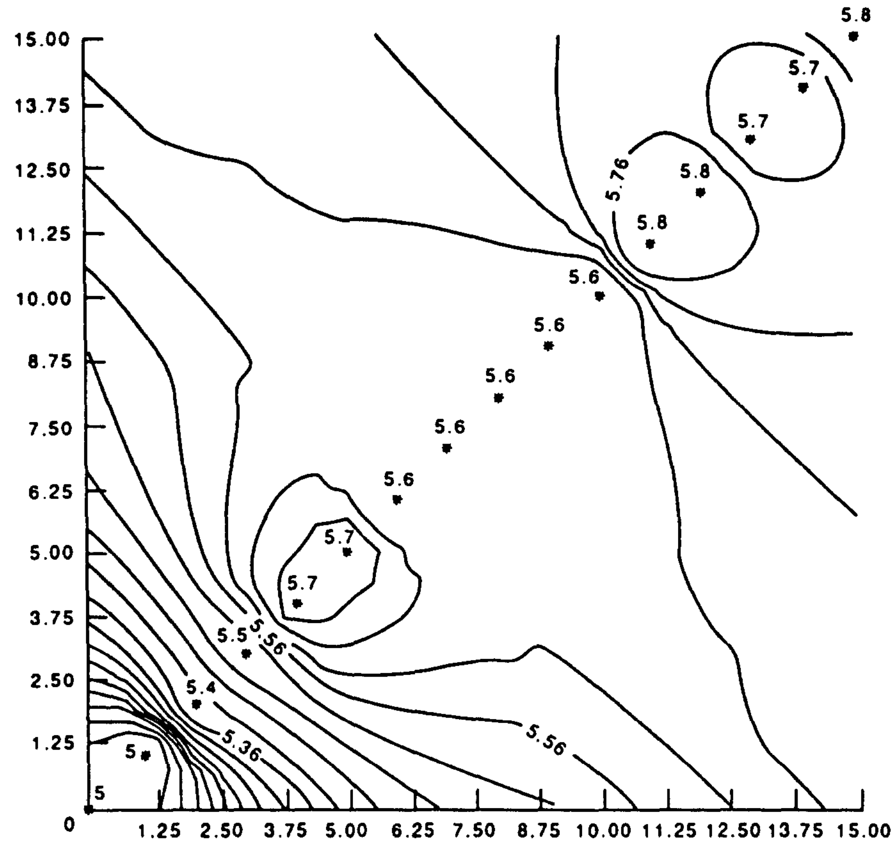


Fig. 6. The pattern of the dissolved oxygen dispersion of the thermal discharges from the SPDP. The contours represent the mean dissolved oxygen (mg/l) of the 75 stations. The units of the *x* and *y* axes are distance from the discharge ( × 10 m).

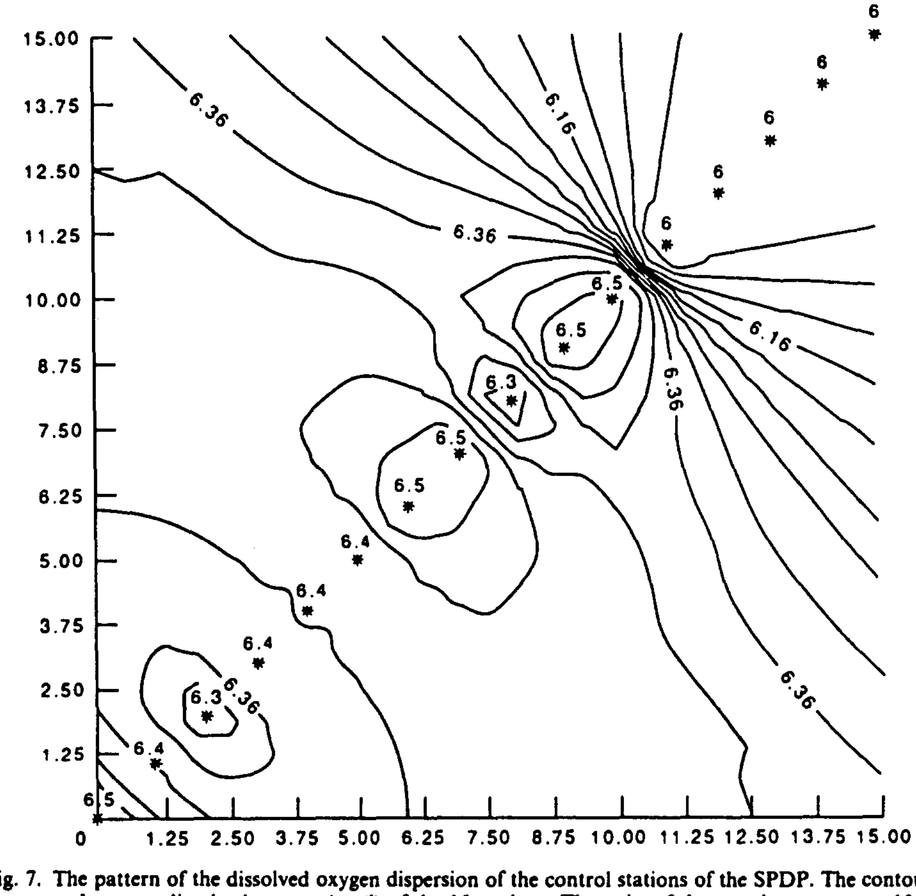


Fig. 7. The pattern of the dissolved oxygen dispersion of the control stations of the SPDP. The contours represent the mean dissolved oxygen (mg/l) of the 15 stations. The units of the *x* and *y* axes are × 10 m.

It appears that the jetty is not working in the way in which it was designed. The effluent was detected to cause changes in the water temperature and salinity beyond the jetty area. It also appears that within the jetty area, water circulation was affected. These effects were reflected in the increasing levels of temperature and salinity in the receiving water and the limited mixing efficiency of the water.

The mixing zone of the receiving water was extended to approx. 160 m from the outlet points. This distance is between 50 and 60 m beyond the effective designed limit of the jetty and exceeds the limit recommended by the U.S. Atomic Energy Commission (1971). The mixing zone size, according to U.S. Atomic Commission recommendations, should not exceed 90 m for a plant with similar specifications to the SPDP. The jetty is effectively reducing the dissipation of the effluent.

This deficiency may be corrected by extending the intake to deeper water, extending the jetty or by changing the method of discharge of the effluent. The first measure may not be possible due to the heavy traffic of Sulman Port near the SPDP and the restricted depth of the area which makes this alternative unfeasible. Increasing the length of the jetty will cause further water restriction and may not be suitable for decreasing the size of the mixing zone. Underwater effluent discharge may be the best alternative. Sending the SPDP effluent 100 m offshore through underwater pipes will provide enough protection to the intake and reduce the effect of restricted water circulation.

*Acknowledgement*—The authors would like to thank the Bahrain Center for Studies and Research for supporting this work.

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