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STUDY ON OXYGEN AND PHOSPHATE IN THE WATERS OF THE SOUTHERN ARABIAN GULF AND THE GULF OF OMAN

IZUČAVANJE KISIKA I FOSFATA U VODAMA JUŽNOG DIJELA ARAPSKOG ZALJEVA I ZALJEVA OMAN

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Sea water samples were collected from 35 stations in the southern Arabian Gulf and the Gulf of Oman during winter of 1987. In the southern Arabian Gulf dissolved oxygen shows an increase in an offshore direction at a rate of 1.3—5.7 $\times 10^{-3}$ ml. 1^{-1}. km^{-1} as ell as strong correlation exists (r = —0.71) between oxygen and temperature. The presence of detectable phosphate in surface waters at vitually all stations both in the southern Arabian Gulf (0.12—0.84 μmoles 1^{-1}) and the Gulf of Oman (0.18—1.65 μmoles. 1^{-1}) may indicate that phosphate if not a limiting factor.

The presence of a shallow oxygen minimum (0.23—0.79 ml. 1^{-1} & 4.2—15.9%) that coincides with the layer of maximum phosphate (1.06—2.64 μmoles. 1^{-1}) at a depth of 100—200 meters results from the mineralization of organic matter. The identification of water mass of Arabian Gulf origin that exhibits higher levels of temperature (20.10—21.54°C), salinity (37.06—38.11‰) and oxygen (1.40—2.09 ml. 1^{-1}) at a depth of 200—350 meters was performed.

The estimated ratio of AOU: Po_4 in the Omani water is found to be 250 compared with 167 in the southern Arabian Gulf which represent about 40% less than the theoretical value of Redfield.

The excess of oxygen remaining after the oxidation of all organic matter in the layer of minimum oxygen is found to be 30% of saturation. Of this amount, 20% is consumed in processes other than oxidation of organic matter.

The phosphate budget in the Arabian Gulf is evaluated as 375×10^2 tonnes $year^{-1}$ which represent the net gain to the Gulf water.

INTRODUCTION

The importance of dissolved oxygen and inorganic phosphate in the sea as an index of potential fertility of waters and for identifying different water masses as tracers has long been recognized. While considerable information is available on such elements in the sea, very little published work is known on hydrochemical conditions of the Gulf region (Kuronuma 1974, Grasshoff 1976, Brewer & Dyrssen 1985, Emara *et al.* 1985, El-Samra 1988).

In this paper, the results of oxygen and inorganic phosphate during the winter season of 1987 in the southern Arabian Gulf and the gulf of Oman are discussed.

MATERIALS AND METHODS

Sea water samples were collected from 35 stations in the southern Arabian Gulf and the Gulf of Oman (Fig. 1) during the period between February 16th and March 3d 1987 using the R/V Muktabar Al-Behar. The samples were collected at the standard depths from the surface down to 400 meter depth.

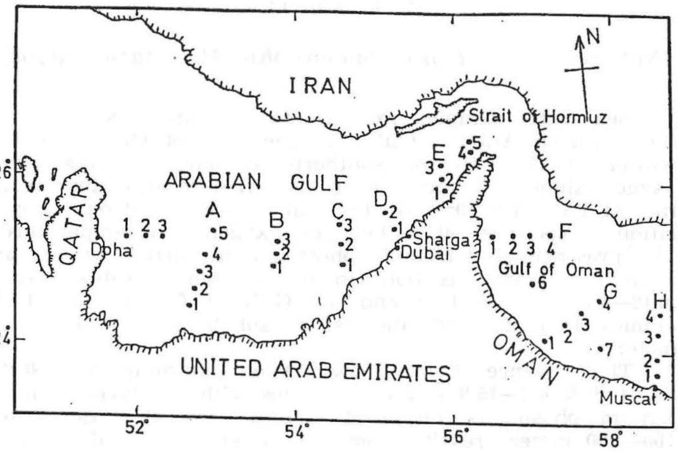

Fig. 1. Study area

Dissolved oxygen and inorganic phosphate were determined according to the methods described by Strickland and Parsons (1968). The oxygen percentage saturation was calculated on the basis of the International Oceanographic Tables (Unesco, 1973).

RESULTS AND DISCUSSION

The concentration of dissolved oxygen at the surface varies from 3.85 ml. 1^{-1} (79.7%) to 5.00 ml. 1^{-1} (100.4%). In the southern Arabian Gulf, dissolved oxygen shows a definite trend, an increase in an offshore direction at a rate of 1.3—5.7 $\times 10^{-3}$ ml. 1^{-1}, km^{-1}, while in the Gulf of Oman this trend is not obvious (Fig. 2). Dissolved oxygen is strongly correlated with temperature (r = — 0.71) in the southern Arabian Gulf, however this relationship does not hold for the Gulf of Oman.

At subsurface levels (Fig. 3) the oxygen values show a more or less homogeneous distribution in the water column in the upper 30 meters due to vertical mixing of the winter season. An oxygen maximum (93—108%) could occasionally be observed at St. No. F_4, G_3, and G_2 within this layer. It can be attributed to a maximum in primary production (Qasim, 1977). Below this depth, a sharp fall in dissolved oxygen occurs at a rate of $2.0—4.48 \times 10^{-2}$ ml. 1^{-1}. m^{-1} (1.78—3.99 μmoles. 1^{-1}. m^{-1}). In the Gulf of Oman, Brewer

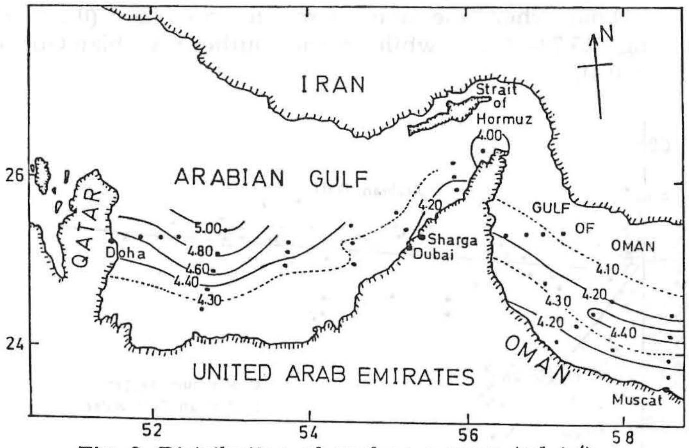

Fig. 2. Distribution of surface oxygen (ml 1^{-1})

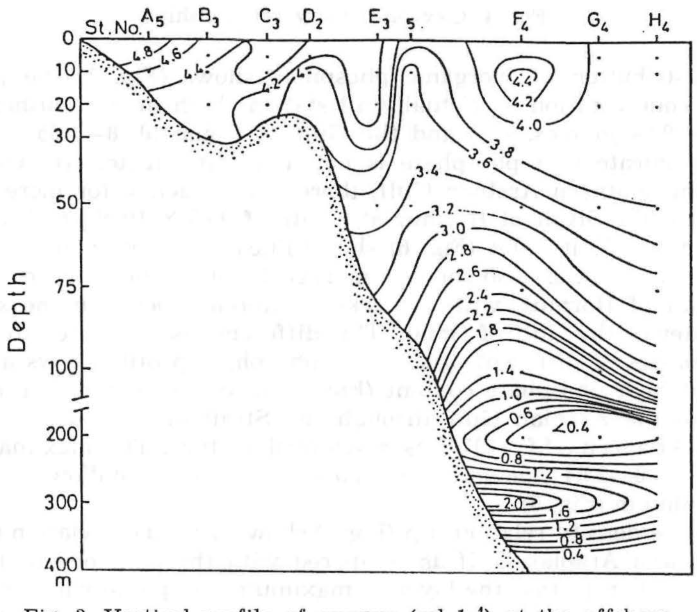

Fig. 3. Vertical profile of oxygen (ml 1^{-1}) at the offshore stations

and Dyrssen (1985) recorded an oxygen gradient of 3 μmoles. 1^{-1}. m$-^{1}$). This oxygen minimum is caused by the biochemical consumption (Sen Gupta and Naqvi, 1984). Below the depth of oxygen minimum, the concentration increases again due to the penetration of water mass of relatively high oxygen content (1.40—2.09 ml. 1^{-1}), higher salinity (37.06—38.11‰), and higher temperature (20.10—21.54°C) flowing from the Arabian Gulf to the Gulf of Oman at a depth of 200—350 meter.

Oxygen-density relationship (Fig. 4) showed good correlation (r = — 0.76) for the Gulf of Oman where the layer of minimum oxygen (0.23—0.79 ml. 1^{-1}) occurs at σt range 25.73—27.07, while in the southern Arabian Gulf the relation is marginal (r = 0.4).

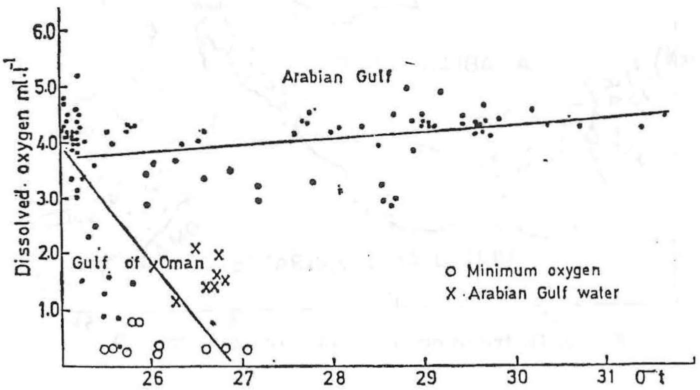

Fig. 4. Oxygen-density relationship

The distribution of inorganic phosphate shows (Fig. 5) the presence of detectable concentration at virtually all stations both in the southern Arabian Gulf (0.12—0.84 μmoles. 1^{-1}) and the Gulf of Oman (0.18—1.65 μmoles. 1^{-1}). This may indicate that phosphate is not a limiting factor (Emara *et al.*, 1985). In the southern Arabian Gulf, there is a tendency for increasing phosphate toward the Strait of Hormuz at a rate of 0.85×10^{-3} μmoles. 1^{-1} km$-^{1}$. The phosphate-salinity plot (Fig. 6) shows linear correlation (r = — 0.60) for both gulfs. The relation also shows a marked break at the entrance of the Gulf in the Strait of Hormuz, with a marked difference between the surface and bottom water of the Gulf of Oman. This difference is attributed to the mixing of water masses of different origin. The phosphate profile shows an intrusion of water of high phosphate content (Fig. 7) at 10 meter depth from the Gulf of Oman to the Arabian Gulf through the Strait of Hormuz. This is considered by Grasshoff (1976) as a seasonal feature. The maximal values of phosphate (1.06—2.64 μmoles. 1^{-1}) occurs at the same shallow depths as the oxygen minimum (Fig. 8).

Phosphate-density relationship (Fig. 9) chows a good correlation (r = —0.62) in the southern Arabian Gulf as compared with the poor one in the Gulf of Oman. In addition to that the layer of maximum phosphate which results from the mineralization of organic matter occurs at σt range 25.5—26.65 which nearly coincides with the layer of minimum oxygen content.

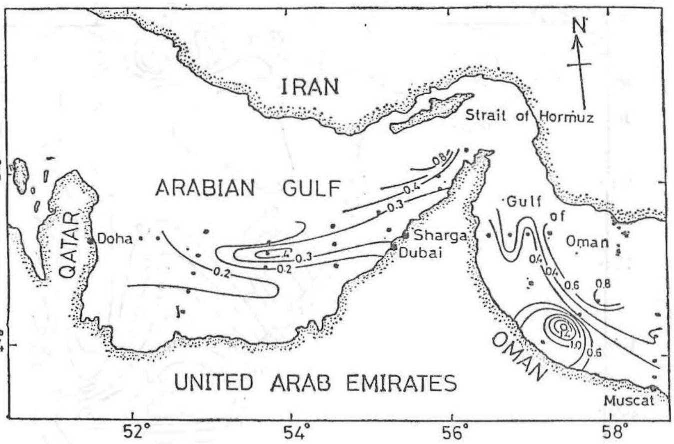

Fig. 5. Distribution of surfade phosphate (μ mol 1^{-1})

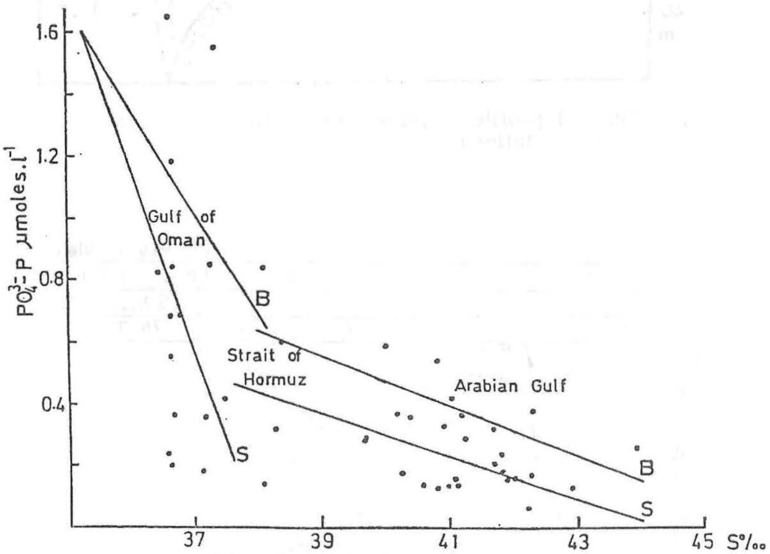

Fig. 6. Phosphate-salinity diagram for surface »S« and bottom »B« waters

The relationship of the apparent oxygen utilization (AOU) with phosphate (Fig. 10) is linear and strong (r = 0.75) in the Omani waters, and the ratio of 250 obtained is similar in the Arabian Sea, the Bay of Bengal, the Laccadive and the Andaman Seas (Table 1). By contrast, the southern Arabian Gulf shows bad correlation with an atom ratio of 167. These ratios obtained are lower than the theoretical value of 276 (Redfield *et al.*, 1963) by 9.4% and 39.5% for the Gulf of Oman and the Arabian Gulf waters.

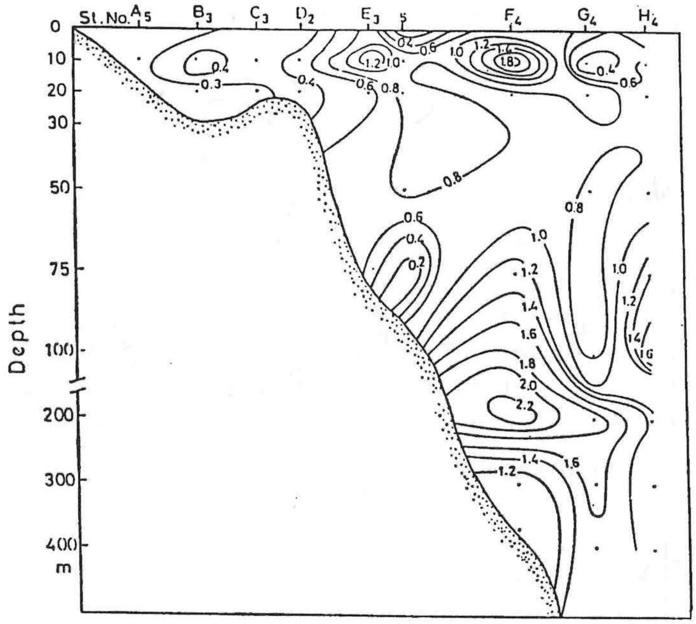

Fig. 7. Vertical profile of phosphate (u mol 1-1) at the offshore stations

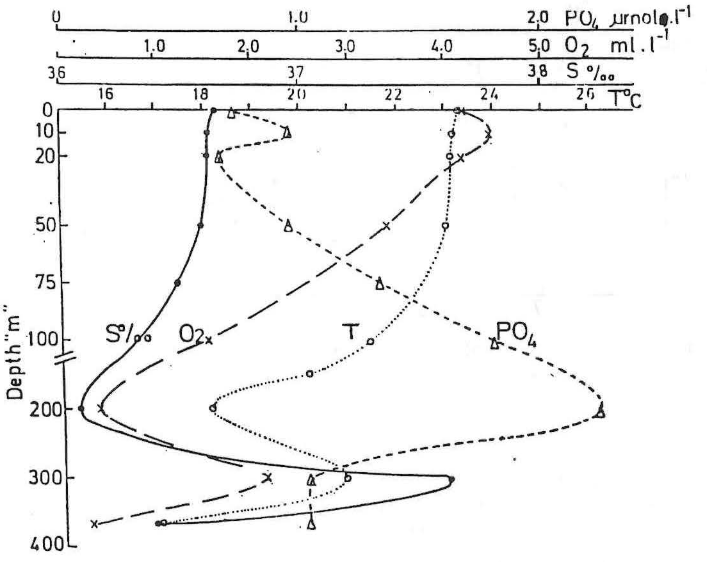

Fig. 8. Vertical profile of temperature, salinity, oxygen and phosphate at St. F_4 in the Gulf of Oman

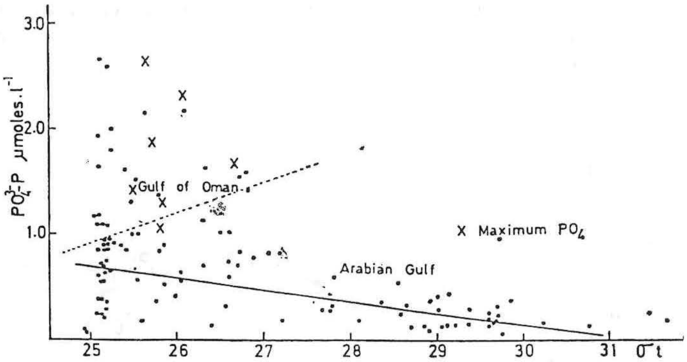

Fig. 9. Phosphate-density relationship

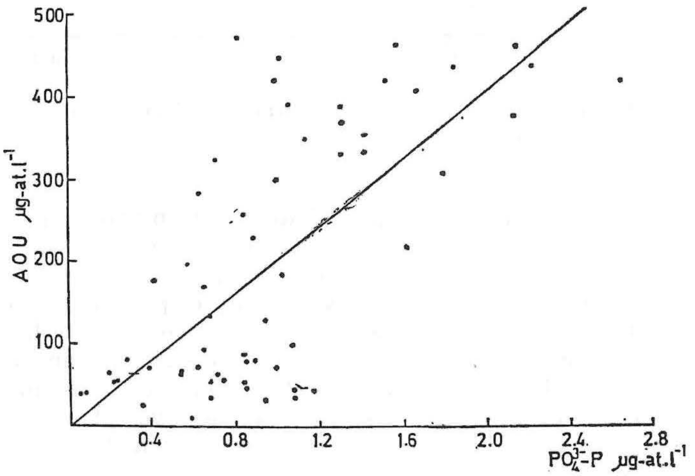

Fig. 10. Apparent oxygen utilisation AOU-phosphate relationship in the Gulf of Oman

Table 1. Relationships between the apparent oxygen utilisation (AOU) and phosphate--phosphorus in some parts of the North Indian Ocean (Sen Gupta & Nagvi, 1983): 1. Northern Arabian sea, 2. Northwestern Indian Ocean, 3. Western Bay of Bengal, 4. Laccadive Sea, 5. Andaman Sea, 6. Arabian Sea, 7. Gulf of Oman (present study), 8. Southern Arabian Gulf (present study).

	1	2	3	4	5	6	7	8
AOU : PO_4	270	280	260	249	252	248	250	167

Variation in the portions of both preformed phosphate P_p and phosphate from oxidative origin P_{ox} in the Gulf of Oman are given in Fig. 11, with the P_{ox} amounting to 46.6—87 per cent of the inorganic phosphate. This suggests the possibility that a good part of the phosphate in the Gulf of Oman is not readily returnable to a fully oxidized form in the upper layers but requires more prolonged oxidation.

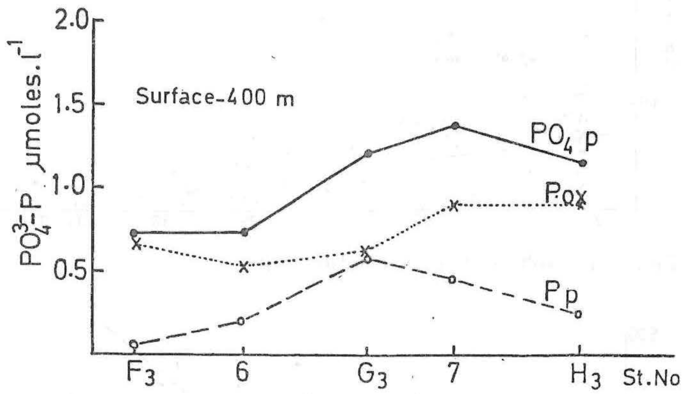

Fig. 11. Distribution of phosphate fractions Pox, Pp in the Gulf of Oman

Comparison of the excess oxygen available in deep water of the oceans is given in Table 2 (Redfield *et al.*, 1963). The upper part of this table shows the excess of oxygen (30%) remaining after the oxidation of all organic matter which would be formed from the limiting quantity of phosphate present in the layer of minimum oxygen. The avergage oxygen content in the layer of minimum oxygen is found to be 10%. Thus 20% of oxygen is consumed in processes other than oxidation of organic matter. On the basis of preformed phosphate, the lower part of table 2 shows that the layer of minimum oxygen would contain 43% of its original oxygen content which is similar to the deep water of the North Pacific Ocean.

Table 2. Comparison of the excess oxygen available in deep water of the oceans Redfield *et al*, 1963) and in the layer of minimum oxygen in the Gulf of Oman (present study). Values are expressed as μg-at. 1^{-1}

		North Atlantic	North Pacific	Gulf of Oman
Phosphorus	PO_4 P	1.25	.00	1.86
Equivalent O_2 utilization	276 x PO_4 P	345	828	513
O_2 saturation value	100% O_2	735	735	735
Excess O_2 100%	O_2 — 276 x PO_4 P	390	—93	222
O_2 saturation		53%	—13%	30%
Preformed Phosphorus	Pp	0.75	1.50	0.35
Phosphorus of oxidative origin	Pox = PO_4 P-Pp	0.50	1.50	1.51
Equivalent O_2 utilization	276 x Pox	138	414	417
Excess O_2	100% O_2 — 276 x Pox	597	321	318
O_2 saturation		81%	44%	43%

The volume of inflowing and outflowing water through the Strait of Hormuz was given by Hartmann *et al.* (1971) as 3365 $km^3 \cdot yr^{-1}$ and 3110 $km^3 \cdot yr^{-1}$ respectively. The average phosphate content in these waters was found to be 0.74 and 0.41 $\mu moles \cdot l^{-1}$. These data-sets make it possible to evaluate a first order phosphate budget for the Arabian Gulf. It was found to represent 375×10^2 tonnes $\cdot yr^{-1}$ as a net gain to the Arabian Gulf (Table 3).

Table 3. Phosphate budget (tonnes. $year^{-1}$) in the Arabian Gulf water.

Type of water	Volume of water km^3 $year^{-1}$	Concentration PO_4 μmoles. 1	Amount of PO transported (tonnes. y^{-1})
Inflowing water	3365	0.74	77056
Outflowing water	3110	0.41	39490
Net gain	255	0.33	37566

CONCLUSION

The concentration of oxygen shows more or less homogeneous distribution in the upper thirty meter of both gulfs. The phosphate is present at all surface locations and the concentration in the Omani water is twice that of the southern Arabian Gulf.

The presence of an intermediate or shallow oxygen minimum that coincides with the layer of maximum phosphate as a result of mineralization of organic matter is shown.

An intermediate layer flowing from the Arabian Gulf to the Gulf of Oman below the shallow oxygen minimum, that exhibits relatively higher levels of temperature, salinity and dissolved oxygen is identified.

The relatinship AOU : PO_4 is linear and high for the Omani water, and the ratio obtained is similar to some parts of the North Indian Ocean. The southern Arabian Gulf shows low correlation with an atom ratio less than the theoretical value by 40%.

In the Gulf of Oman a considerable part of the phosphorus (Pox) is not readily returnable to a fully oxidized form in the upper layers but requires more prolonged oxidation.

The excess of oxygen remaining after oxidation of all organic matter in the layer of minimum oxygen is estimated as 30% of which 20% is consumed in processes other than oxidation of organic matter. On the basis of preformed phosphate, the layer of minimum oxygen would contain 43% of its original oxygen content.

The phosphate budget in the Arabian Gulf is estimated as 375×10^2 tonnes $year^{-1}$ which represent the net gain to the Arabian Gulf waters.

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IZUČAVANJE KISIKA I FOSFATA U VODAMA JUŽNOG DIJELA ARAPSKOG ZALJEVA I ZALJEVA OMAN

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KRATKI SADRŽAJ

Uzorci morske vode sakupljani su na 35 postaja južnog dijela Arapskog zaljeva i zaljeva Oman tijekom zime 1987. U južnom dijelu Arapskog zaljeva otopljeni kisik je pokazao porast vrijednosti udaljavanjem od obale, i to od 1,3—5,7 $\times 10^{-3}$ ml 1^{-1} km^{-1}. Pokazalo se također da postoji jako izražena korelacija između kisika i temperature (r = —0.71). Prisustvo fosfata nađenih u površinskom sloju mora na gotovo svim postajama kako u južnom dijelu

Arapskog zaljeva (0,12—0,84 μmoles 1^{-1}) tako i u zaljevu Oman (0,18—1,65 μmoles 1^{-1}) ukazuje na to da fosfati nisu limitirajući faktor.

Minimum kisika (0,23—0,79 ml 1^{-1} i 4,2—15,9%) koji se nalazi u sloju u kojem su fosfati na vrhuncu (1,06—2,64 μmoles 1^{-1}) na 100—200 m dubine posljedica je mineralizacije organske tvari. Izvršena je i identifikacija porijekla vodene mase Arapskog zaljeva koja pokazuje više vrijednosti temperature (20,10—21,54°C), slanosti (37,06—38,11‰) i kisika (1,40—2,09 ml 1^{-1}) na dubini od 200—350 m.

Određen je i AOU omjer: PO_4 u vodama Omana iznosio je 250 naspram 167 u južnom dijelu Arapskog zaljeva što je otprilike za 40% manje od teoretske vrijednosti prema Redfield-u.

Višak kisika koji preostaje nakon oksidacije organske tvari u sloju s minimumom kisika iznosio je 30% od zasićenja. Od ove vrijednosti 20% otpada na procese koji nisu oksidacija organske tvari.

Količina fosfata u Arapskom zaljevu procijenjena je na 375×10^2 tona godišnje i to je ustvari neto prinos u vodama zaljeva.