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PARTICULATE MATTER IN THE EZCURRA INLET: CONCENTRATION AND SIZE DISTRIBUTIONS*

1. INTRODUCTION

This paper summarizes the preliminary results of an experimental study of concentration and size distributions of suspended particles in an Antarctic fiord, the Ezcurra Inlet, on King George Island belonging to the South Shetland Islands.

This research was a part of complex oceanographic programme of the 2nd Antarctic Expedition of the Polish Academy of Sciences which operated there from 20 XII 1977 to 10 III 1978.

The aims of the programme as well as the description of the general oceanographic conditions in the area are given elsewhere [1].

2. METHODS

All the samples for analyses were taken from on board the vessel anchored in the middle of the Ezcurra Inlet at a depth of about 80 m. Sampling depth ranged from 1 to 80 m, with the greatest depth depending on the actual bottom depth. Plastic 10 l Nansen bottle was used to sample the water, which was subsequently stored in 10 l plastic containers. All the analyses were completed not later than 4 hours after collecting the samples.

2.1. CONCENTRATION BY MASS OF PARTICULATE MATTER

Dry mass of particulate matter related to 1 l of seawater was measured using filtering technique. „Sartorius" membrane filters 5 cm in diameter, with pore size of 0.45 μm were used to filter up to 5 l of seawater. Plastic filter holders and a vacuum filtering system with reduced pressures down to 0.5 atm were used. Dry filters were weighted on an analy-

tical balance with 0.1 mg accuracy in a shore-based laboratory. The increments of mass of the dry filter after filtering varied from 0.4 to 13 mg. The total error of mass concentration determination, including moisture and loss of mass during filtration corrections, can be estimated at 0.1 mg/l on average.

2.2. CONCENTRATION BY NUMBER AND SIZE DISTRIBUTION OF SUSPENDED PARTICLES

Cumulative particle size distributions $CD(D)$ were measured using a Coulter Counter model ZBI with 100 µm orifice. It enables the counting of particles with an equivalent spherical diameter in the range of 2—40 µm, however for the present study the upper limit was set at 32 µm, because of the very low concentration of such large particles The equivalent spherical diameter of a particle means the diameter of a sphere with a volume equal to that of the particle. Cumulative particle size distribution $CD(D)$ will be referred to as psd and it is here, as usual, a function of particle diameter D with values equal to numbers of particles with diameter $\geqslant D$. Measurements of $CD(D)$ yield also total measured concentration by number of particles i.e. number of particles $\geqslant 2$ µm in 1 cm³ of seawater which will be referred to as TC. The error of measurements of concentration by number of particles depends mainly on the number of particles counted [5]. Tests of variations of the number of particles counted prove that in the case of percentage error this dependence can be summarized by an equation:

$$\text{relative standard deviation} \cong \frac{CD(D)^{-0,5}}{\sqrt{n}}$$

where $CD(D)$ is a cumulative size distribution value at a diameter D, i.e. concentration of particles $\geqslant D$ and n is the number of independent counts. This number ranged up to 5 for the smallest concentrations of particles, which were encountered for the largest particles in order to diminish errors of $CD(D)$ determinations.

The volume V of suspended particles in the measured range was then computed from psd. It was ultimately used to compute an apparent density ϱ of suspended particles as follows:

$$\frac{\wedge}{P_{\text{w}}} = \delta$$

The salinity of seawater was measured by Eng. Z. Lauer using a laboratory salinometer [3].

3. RESULTS AND DISCUSSION

The Ezcurra Inlet is an area with substantial variations of hydrometeo-
rological conditions, with winds ranging up to 30 m/s and efficient sup-
plies of suspended matter during the Antarctic summer [1]. The sources
of suspended matter in the area are:
— streams produced by melting ice in icefields on the seashore;
— floating growlers of land origin followed frequently by well vi-
sible, high particle concentration tracks produced by mineral particles
released during melting of ice in the seawater;
— dust from shore transported by strong winds;
— biological production.
The detailed chemical analysis of the composition of the particulate
matter has not yet been completed, however, a brief examination of the
suspended particles using an optical microscope, as well as the high
apparent density of particles equal to 1.46 g/cm^3 and small concentra-
tion of dissolved organic matter, i.e. yellow substances which are pro-
ducts of degradation of suspended biological material, suggested by op-
tical measurements [4], indicates that the majority of suspended parti-
cles is of inorganic origin.
Concentration by mass and by number of particles suspended in
seawater were measured throughout the whole period. Both parameters
vary strongly with time and space. Typical examples are shown in
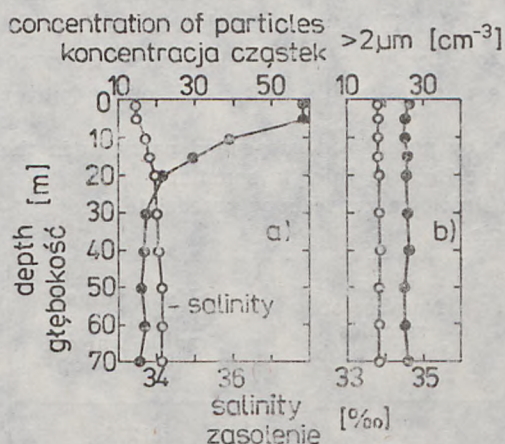Fig. 1. These variations considerably hinder comparison of individual

Fig. 1. Typical vertical profiles of concentration by number of suspended par-
ticles $\geqslant 2\mu$m related to 1 cm^3 of seawater in Ezcurra Inlet as compared with si-
multaneous salinity profiles
Rys. 1. Typowe profile pionowe koncentracji ilościowej zawiesin $\geqslant 2\mu$m od-
niesionej do 1 cm^3 wody morskiej we fiordzie Ezcurra porównywane z jednoczes-
nymi profilami zasolenia wody

samples from different depths taken at one station, i.e. within about
40 mins, especially when they were associated with those caused by ship
movements around the anchoring site. For this reason it was not always
possible to take a very accurate vertical profile of a parameter, which
forced us to use statistical techniques to examine variations of measured
parameters as well as relations between them.

Mass concentration examination (summarized in Table 1) indicate
the tendency for concentration of particulate matter to decrease with
depth, which is connected with the surface character of the sources of
suspensions in the area.

Table 1. Concentration by mass of particulate matter in the Ezcurra Inlet at three
          levels during summer
Tab. 1. Koncentracja zawiesin we fiordzie Ezcurra na trzech głębokościach podczas
          lata

Depth Głębokość m	Number of samples Liczba prób	Mean value Średnia wartość mg/l	Standard deviation Odchylenie standardowe mg/l
10	25	1.66	0.60
30	25	1.03	0.23
50	26	1.00	0.33

Concentration by mass and concentration by number of suspended
particles (Table 2) show quite a high correlation, with the coefficient of
correlation equal to 0.86. This indicate the relative stability of the shape
of psd. Concentration by number of particles, however, presents more
complete set of data and only this will be discussed later.

Table 2. Concentration by number of suspended particles in the diameter range of
          2—32 µm in the Ezcurra Inlet in summer
Tab. 2. Koncentracja ilościowa zawiesin w przedziale średnic 2—32 µm we fiordzie
          Ezcurra w lecie

Depth Głębokość m	Number of samples Liczba prób	Mean value particles/cm³ Średnia wartość zawiesin/cm³	Standard deviation particles/cm³ Odchylenie standardowe zawiesin/cm³
10	58	31230	8600
30	30	22790	6340
50	50	18950	5350

The range of variations of concentration by number of suspended
particles is shown in Fig. 2. It has been found that the probability di-

stribution of this parameter can well be described by a gamma distribution of probability density [2]:

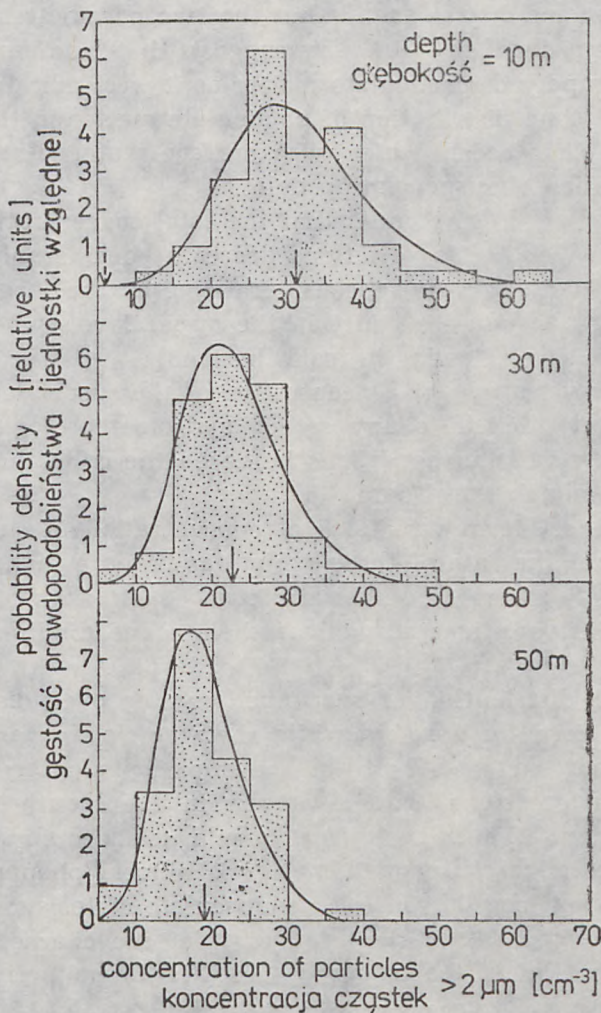$$p(TC) = \frac{\beta^{\alpha}}{\Gamma(\alpha)} \, TC^{\alpha-1} e^{-\beta TC}.$$

Fig. 2. Probability distributions of concentration by number of suspended partiules $\geqslant 2\mu m$ related to 1 cm³ of seawater at three levels in the Ezcurra Inlet during the Antarctic summer 1978
Mean concentrations are indicated by solid arrows. Typical concentration of suspended particles in the Bransfield Strait at a depth equal to 6 m is shown by dotted arrow in the 10 m diagram for comparison.

Rys. 2. Rozkłady prawdopodobieństwa koncentracji ilościowej zawiesin $\geqslant 2\mu m$ odniesionej do 1 cm³ wody morskiej na trzech głębokościach we fiordzie Ezcurra podczas antarktycznego lata 1978
Średnie koncentracje są pokazane przez pełne strzałki. Typowa koncentracja zawiesin w Cieśninie Bransfielda na głębokości 6 m jest pokazana na wykresie dla 10 m strzałką przerywaną.

where α and β are constans connected with variance and mean concentration, $\Gamma(\alpha)$ is Euler's gamma function value at α and TC is concentration of particles $\geqslant 2$ μm related to 1 cm^3 of seawater.

As can be seen from Fig. 1 high concentration of particulate matter tends to be associated with low salinities. This tendency was tested for all the samples and it was found that the two parameters had a correlation coefficient equal to —0.8. This suggests that land derived particles are the main supply of particulate matter as it was indicated earlier and that space and time distribution of particulate matter in the inlet is due to mixing of clear ocean water with surface water of the inlet with high concentration of suspended particles.

It follows from Figs. 1 and 2 that the total concentration of suspended matter, as well as its variations decrease considerably with depth. This conforms with the above considerations, as the largest variations of salinity were encountered only in the upper layer, where it was affected by fresh water flowing in from the land.

Long term variations of concentration of the suspended matter cannot be definitely linked to any set of hydrometeorological factors as frequent stormy weather conditions hindered the collecting of systematic and dense enough set of data.

Tests of short term variations of concentration of suspended matter indicate that the rate of these variations is quite high, especially in the upper layer, where TC can vary even fourfold within two hours. The rate of the variations as well as their range diminishes distinctly with depth.

Horizontal distribution of suspended matter over distances larger than those covered by the ship while she was slewing around the anchoring site could not be studied as the ship was anchored in one place only. However occasional samples taken in the mouth of Admiralty Bay encompassing the Ezcurra Inlet would seem to indicate that the high concentration of suspended matter is a local phenomenon linked to enough efficient coastal sources of particulate material.

Suspended particles in the Ezcurra Inlet are characterized by almost pure power-law distribution of sizes (Fig. 3) composed of two segments intersecting on average at 3.7 μm:

$$CD(D) = \begin{cases} k_1 D^{-m_1} & 2\,\mu m \leqslant D < 3.7\,\mu m \\ k_2 D^{-m_2} & 3.7\,\mu m \leqslant D \leqslant 32\,\mu m \end{cases}$$

where k is the concentration factor and m is the slope of psd. Indexes 1 and 2 are related to the first and second segment respectively.
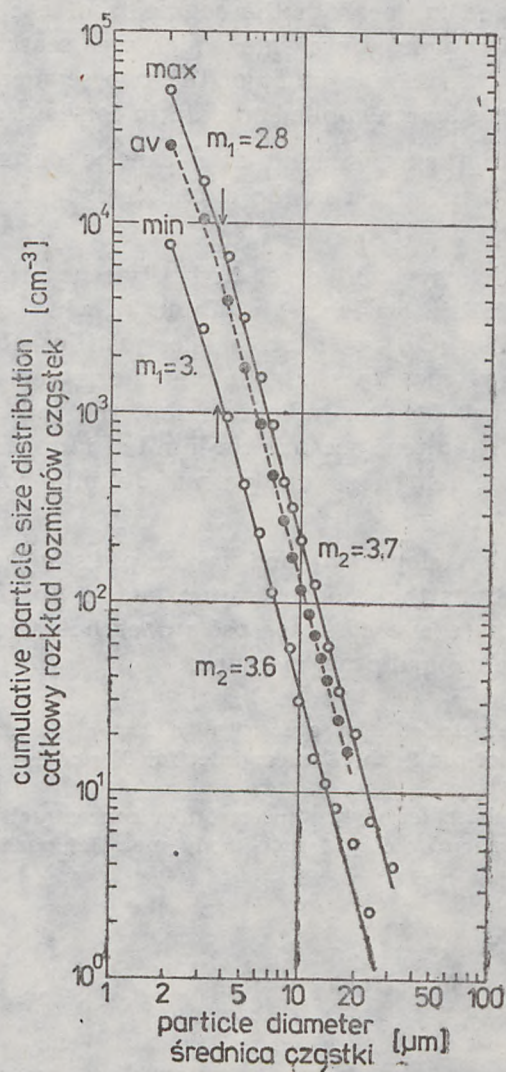
Fig. 3. Cumulative particle size distributions (psd) in the Ezcurra Inlet during the Antarctic summer 1978
av — an avarage psd computed from 83 samples from all the depths.
max, min — psd's corresponding to the greatest (depth = 10 m) and smallest (depth = 60 m) measured concentrations of suspended particles.
Intersections of the two segments of psd are indicated by solid arrows.
Rys. 3. Akumulatywne rozkłady rozmiarów zawiesin (psd) we fiordzie Ezcurra podczas antarktycznego lata 1978
av — średni rozkład rozmiarów obliczony z 83 próbek dla wszystkich głębokości.
max, min — psd odpowiadające największej (głębokość = 10 m) i najmniejszej (głębokość = 60 m) zmierzonej koncentracji zawiesin.
Załamania rozkładu rozmiarów wskazane są przez pełne strzałki.

Coefficients k and m for both the segments of each psd measured were found using a computer program which was searching for k_1, m_1, k_2, m_2 and also the intersection point of the two segments of psd using the criterion of least squares applied to data in log-log scale.

It was found that experimental data can be described especially well by power-law distribution in the diameter range of ~ 3.7—32 µm, i.e. within the limits of the second segment of psd.

This was indicated by high correlation between variables CD and D within this range of D in log-log scale (Table 3), which proved linearity of the dependence $\log (CD) = f(\log D)$, i.e. justifies equation (1). The first segment of a psd encompassing the diameter range of 2— ~ 3.7 µm should rather be treated as an indication that the psd starts to deflect from power-law distribution, because the limited number of points used to construct this segment does not permit definite conclusions to be drawn.

It was found that slopes m_1 and m_2 of psd's measured exhibited much smaller variations then concentration factors do. This is also suggested by Fig. 3 where averaging of psd's does not affect the slope as compared with the extremal psd's measured.

Table 3. Statistical characteristics of concentration factor k and slope m of both the segments of psd in the Ezcurra Inlet for 83 samples taken in February and March 1978

Tab. 3. Statystyczne charakterystyki współczynnika koncentracji k i nachylenia m rozkładów rozmiarów dla 83 prób wody morskiej pochodzących z lutego i marca 1978

Particle diameter range Zakres średnic µm	Parameter Parametr	Mean value Średnia wartość	Relative standard deviation Względne odchylenie standardowe %
2—~ 3.7	k_1 (particles/cm³) (zawiesin/cm³)	189 500	34
	m_1	2.8	10
~ 3.7—32	k_2 (particles/cm³) (zawiesin/cm³)	760 700	193
	m_2	3.6	9
	correlation between CD and D in log-log scale korrelacja pomiędzy CD i D w skali log-log	—0.995	0.003

4. CONCLUSIONS

The Ezcurra Inlet is an area with strong variations of concentration of suspended particles in the sea in time and space.

These particles are mainly of inorganic origin and are supplied by coastal sources of particulate material.

The concentration of suspended particles is highly and negatively correlated with the salinity of seawater, which indicates that its variations are due to the circulation pattern of the inlet which mixes clear deep water of high salinity with the surface water enriched by land--derived particles carried from the shore by fresh water. The concentration of suspended matter decreases distinctly with depth, on average, which supports this conclusion.

Cumulative particle size distributions (psd) of the suspended particles can be described by power-law distribution with high accuracy in the diameter of the particle range $\sim$3.7—32 µm, but not so good in the 2— $\sim$3.7 µm range.

Slopes of both the segments are close to each other and vary only slightly as compared with the concentration factors for different psd's measured. This indicates that the psd characteristic for the area in the Antarctic summer have a constant shape in the diameter range of 2—32 µm, which is supported by the high correlation between concentration by number and concentration by mass of suspended particles.

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ZAWIESINY WE FIORDZIE EZCURRA: KONCENTRACJA I ROZ-KŁADY ROZMIARÓW

Streszczenie

W pracy przedstawiono wstępne wyniki badań eksperymentalnych koncentracji i rozkładów rozmiarów zawiesin morskich w zakresie średnic 2—32 µm w typowym antarktycznym fiordzie Ezcurra na Wyspie Króla Ierzego.

Pomiary koncentracji masowej zawiesin wykonywano metodą filtrowania wody morskiej przez sączki membranowe o średnicy porów 0.45 μm, natomiast koncentrację ilościową i rozkłady rozmiarów mierzono licznikiem Coultera z dyszą o średnicy 100 μm.

Stwierdzono dużą zmienność koncentracji zawiesin morskich w czasie i przestrzeni (tab. 1 i 2, rys. 1 i 2). Większość zawiesin to zawiesiny mineralne, pochodzące z brzegów fiordu.

Koncentracja zawiesin wykazała dużą i ujemną korelację z zasoleniem wody morskiej, ze współczynnikiem korelacji równym —0.8, co wskazuje, że zmiany koncentracji zawiesin są związane z prądami i turbulencją w zatoce, które mieszają czystą oceaniczną wodę o dużym zasoleniu z wodą o mniejszym zasoleniu z powierzchni zatoki, zawierającą dużą ilość zawiesin wnoszonych przez słodką wodę spływającą z lądu.

Rozkłady rozmiarów zawiesin morskich (psd) we fiordzie Ezcurra dają się opisać przez funkcję kD^{-m} z dużą dokładnością w zakresie średnic $D \sim 3.7—32$ μm i gorzej w zakresie $D \sim 2—3.7$ μm. (rys. 3).

Zakres $\sim 2—3.7$ μm należy traktować przy tym raczej jako przejściowy do innego rozkładu rozmiarów dla $D \geq 2$ μm, którego typ i parametry nie mogły być dokładnie oszacowane z powodu małej liczby punktów pomiarowych w tym zakresie średnic zawiesin.

Współczynniki nachylenia m obu części rozkładów rozmiarów zmieniały się w zakresie znacznie mniejszym niż współczynniki koncentracji k (tab. 3), co świadczy o stabilności kształtu rozkładów rozmiarów zawiesin morskich w badanym akwenie w zakresie rozmiarów 2—32 μm.

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