Tellus (1978), 30, 569–572

SHORT CONTRIBUTION

Stability of the shape of particle size distribution in the Baltic

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(Manuscript received August 12, 1977; in final form July 3, 1978)

1. Introduction

This paper deals with experimental evidence of the stability of the shape of particle size distribution in the Baltic considered from the point of view of integral characteristics of particles suspended in sea-water. Some of the investigations, results of which are presented here, were carried out on board the research vessel of GDR *Prof. Albrecht Penck.*

2. Methods

The particle size distributions and related data were collected throughout the whole of 1975 in Gdańsk Bay, in 1976 and 1978 collections were made in Gdańsk Bay and in the open Baltic. Over 200 samples of sea-water taken from different depths (0–145 m) were analysed.

The sea-water for analyses was sampled using 5-litre plastic Nansen bottles, and then stored in plastic containers at a temperature approximately equal to that of the normal environment of the sample.

The particle size distributions were measured, no later than 4 h after collection, using a Coulter Counter Model ZBI with 100 μm orifice tube. This enables counting of particles with diameters in the 2–40 μm range. The diameter of a particle means the diameter of a sphere with a volume equal to that of the particle (Sheldon and Parsons, 1967). In order to obtain the cumulative size distribution $CD(D)$, particles $\geqslant D$ in 1 cm^3 of sea-water were usually counted for about 20 different diameters D in the 2.5 μm–D_{max} range, where D_{max} is the diameter of particles with concentration by number falling below 1 cm^{-3}. For the cases studied D_{max} varies from 16 μm to 37 μm. These counts, i.e. $CD(D)$ values, were then corrected for coincidence (Sheldon and Parsons, 1967) and used to compute the total volume V of particles in the measured size range.

In order to obtain the mass concentration of the suspended matter, the sea-water was filtered through Sartorius membrane filters of 0.1 μm pore diameter, and placed in plastic holders in a vacuum system. Reduced pressures down to 0.4 atm were applied. Subsequently, the filters were rinsed with about 50 cm^3 of distilled water to remove salts and dried in a desiccator to a constant mass. Dry filters were weighed on an analytical balance with 0.1 mg accuracy. Dry mass m_d of particulate matter related to 1 dm^3 of sea-water was obtained as the difference between the dry filter mass before and after filtering divided by the volume of the sea-water filtered.

Scattering of 633 nm light by the sea-water was measured simultaneously during the expeditions on board the *Prof. Albrecht Penck* by Dr H. Prandke from the Institute of Marine Sciences of the Academy of Sciences of GDR using a laboratory scattering meter (Prandke, 1976).

3. Results and discussion

All the integral characteristics of particles suspended in the sea-water, e.g. a mass concentration as well as some optical properties of sea-water, depend strongly on the frequency distribution of particle sizes, i.e. a function of particle diameter D such that $FD(D)dD$ is the number of particles in 1 cm^3 of sea-water with diameters in the range $(D, D + dD)$. This relationship can, in general, be expressed as

$$I[FD(D)] = \int_{D_{\min}}^{D_{max}} FD(D)G(D)dD \qquad (1)$$

where I denotes an integral characteristic of suspended particles and $G(D)$ is an appropriate weight function.

The analysis of the data obtained by the authors, together with the light scattering data, show, however, that excluding the seasons of biological activity much simpler relationships hold, i.e.

$$I \sim CD(D_{\min})$$

where $CD(D_{\min}) = \int_{D_{\min}}^{\infty} FD(D)dD$ is the total measured concentration by the number of particles. Such a linear form was found for the relationship between the total volume V of particles and their total measured concentration by number CD (3 μm), also between the mass concentration m_d and CD (3 μm) and between the scattering function (Jerlov, 1968) β (45°) and CD (3 μm). For these relationships relatively high correlation coefficients were observed, equal to 0.984, 0.937 and 0.955, respectively. Several other authors (e.g. Carder et al., 1974) have found a linear relationship between β (45°) and m_d for other areas, which is an obvious consequence of the above relationships.

One can split $FD(D)$ into

$$FD(D) = CD(D_{\min}) \cdot FD_n(D)$$

where $FD_n(D)$ is the normalized size distribution, i.e. such that

$$\int_{D_{\min}}^{\infty} FD_n(D)\, dD = 1$$

Relation (1) can thus be expressed as

$$I = kCD(D_{\min}) \qquad (2)$$

where

$$k = \int_{D_{\min}}^{D_{max}} FD_n(D) \cdot G(D)dD$$

It is evident that relationship (2) is approximately linear only if k shows small variations as compared with CD $(D_{\min})$. In case of the total volume V of particles with a diameter in the range ($D_{\min}$ = 3 μm, $D_{\max}$), k is fairly constant as can be seen from

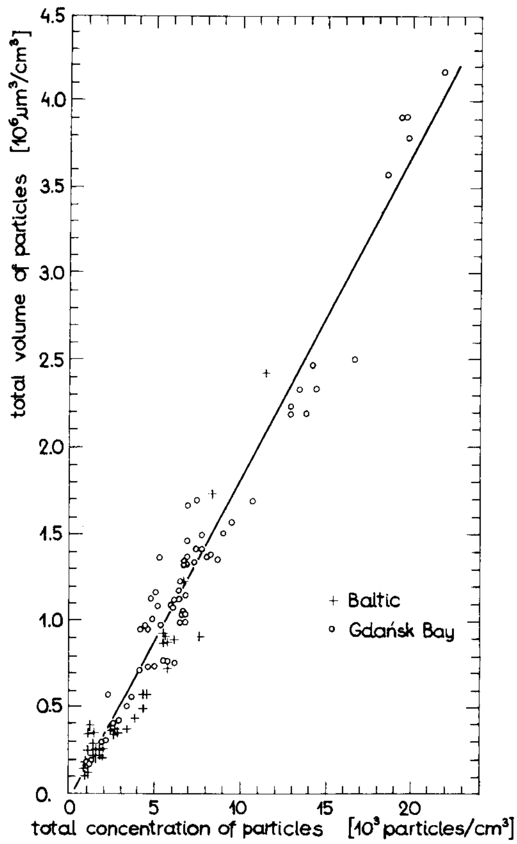

Fig. 1. The relationship between the total volume V of particles with diameter varying from 2.5 μm to about 37 μm and the total concentration by number of particles CD (3 μm), i.e. number of particles $\geqslant$ 3 μm suspended in 1 cm^3 of sea-water, together with the least squares best fit line. Correlation coefficient is equal to 0.984.

Fig. 1, and also from a high value of the correlation coefficient for the relationship presented there. It should be noted that data originating from the seasons of biological activity exhibit quite different behavior and cannot be included in the drawing, having the total volume, e.g. of the order of 5 × 10^6 μm^3/cm^3 against the total concentration by number CD (3 μm) ~ 10^4 cm^{-3}. It indicates that k assumes a quite different value in this case, which is a consequence of an important change of $FD_n(D)$.

Taking into account the fact that the total volume V, in addition to its dependence on the total concentration by number CD $(D_{\min})$, depends only on the shape of the particle size distribution, i.e.

on the function $FD_n(D)$, and not on material properties of particles, the relation

$$V \sim CD\,(3\ \mu\mathrm{m})$$

suggests that $FD_n(D)$ for the cases studied are realizations of the statistical function $FD_n(D)$ with small variance, at least in the range of D which contributes most to the volume of suspended particles.

In order to check this assumption, 127 particle size distributions measured outside the strictly shore zone were used to compute mean values of $FD(D)$ and $FD_n(D)$, in increments of D equal to 1 μm, in the following manner:

$$\widehat{FD}(D_i, D_{i+1}) = CD(D_i) - CD(D_{i+1})$$

$$\widehat{FD}_n(D_i, D_{i+1}) = \widehat{FD}(D_i, D_{i+1})/CD\,(3\ \mu\mathrm{m})$$

The relative standard deviation, i.e. standard deviation divided by a mean, was then computed (Table 1). The mean $\widehat{FD}_n$ is also presented in Table 1.

As can be seen from Table 1 the relative standard deviation of $\widehat{FD}_n$ is an order of magnitude smaller than the relative standard deviation of $\widehat{FD}$ for the smallest diameter D, increasing slowly to the same order of magnitude for the largest one. This increase, however, is mainly due to poorer repeatability of counts of larger particles being present in smaller concentrations and not to variations of the shape of particle size distribution.

Table 1

Particle diameter range (μm)	Relative standard deviation of $\widehat{FD}$	$\widehat{FD}_n$	Mean $\widehat{FD}_n$
3–4	0.70	0.079	0.508
4–5	0.76	0.086	0.227
5–6	0.77	0.078	0.104
6–7	0.86	0.21	0.598×10^{-1}
7–8	0.68	0.23	0.468×10^{-1}
8–9	0.87	0.34	0.226×10^{-1}
9–10	0.89	0.38	0.144×10^{-1}
10–11	0.88	0.49	0.814×10^{-2}
11–12	1.09	0.53	0.537×10^{-2}
12–13	1.04	0.45	0.421×10^{-2}
13–14	0.96	0.55	0.252×10^{-2}
14–15	1.24	0.59	0.184×10^{-2}
15–16	0.98	0.78	0.149×10^{-2}
16–17	1.21	0.76	0.874×10^{-3}
17–18	1.13	0.97	0.486×10^{-3}

Let us define the total variance σ^2_{FD} of the particle size distribution $FD(D)$ as follows

$$\sigma^2_{FD} = \int_{D_{\min}}^{D_{\max}} \sigma^2_{FD(D)}\, dD \tag{3}$$

The σ^2_{FD} can be expanded in a Taylor series (Hudson, 1964) with only terms of the first order being retained

$$\sigma^2_{FD} = [\overline{CD\,(3\ \mu\mathrm{m})}]^2\, \sigma^2_{FD_n} + [\overline{FD}_n]^2\, \sigma^2_{CD\,(3\ \mu\mathrm{m})}$$

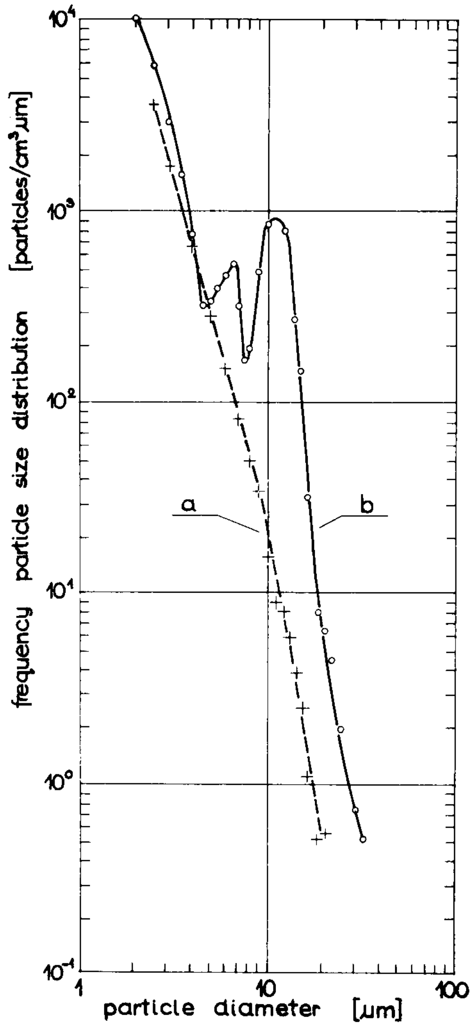

Fig. 2. Examples of the frequency particle size distribution (psd) typical for the Baltic waters, computed from the measured cumulative size distributions:
(a) psd typical for the seasons with no or weak biological activity,
(b) psd typical for the seasons with strong biological activity.

where $\sigma^2_{FD_n}$ is the total variance of the normalized size distribution $FD_n(D)$ defined analogously to σ^2_{FD}, $[\overline{FD_n}]^2$ is defined as $\int_3^{D_{max}} [\overline{FD_n(D)}]^2 dD$, and $\sigma^2_{CD\,(3\,\mu m)}$ is a variance of CD (3 μm).

The variability of CD (3 μm) and the variability of $FD_n(D)$, being the two major components of the total variance (3), contribute to it in a ratio of ~60/1.

The facts presented above suggest that the normalized particle size distribution $FD_n(D)$ for the cases studied can reasonably be replaced by a mean $FD_n(D)$ (Table 1) in the first approximation. Thus, from the point of view of integral characteristics of suspended particles, such as the mass concentration and the scattering function, the particle size distribution, excluding the seasons of biological activity, can be represented by one number, e.g. CD (3 μm), if only the mean $FD_n(D)$ is known.

The analysis of the particle size distributions in terms of characteristic vectors, carried out previously by the authors (Jonasz and Zalewski, 1976), also supports this conclusion.

Examination of the particle size distributions in the Baltic (Jonasz and Zalewski, 1976) shows that all of them contain a hyperbolic component which has a fairly constant shape. Close similarity of this component to stable in shape particle size distribution originating from the seasons with no or weak biological activity suggests that they are identical. Therefore it is probable that this component represents a population of mineral and non-living organic particles produced by a steady set of physical and chemical processes.

In the seasons with strong biological activity another component is added. It has a gaussian form and is probably due to a growth of phytoplankters of definite dimensions.

These two components can produce two basic types of the particle size distributions (psd) observed by the authors (Jonasz and Zalewski, 1976) in the Baltic:

(a) psd containing only the first component (Fig. 2a), typical for the seasons of no or weak biological activity,

(b) psd composed of both components (Fig. 2b), typical for the seasons with strong biological activity.

4. Acknowledgements

The authors express their thanks to Prof. J. Dera and also to Dr J. Olszewski for critical remarks during the preparation of this paper.

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