CZESŁAW GARBALEWSKI
HENRYKA BEREK
ANNA BRZEZIŃSKA
ANNA TRZOSIŃSKA
DANUTA WIELBIŃSKA

Institute of Meteorology and Water Economy
Maritime Branch — Gdynia

A STUDY OF TURBULENT FLUX OF AIRBORNE PARTICULATE MERCURY PASSING FROM THE ATMOSPHERE INTO THE SEA*

1. INTRODUCTION

Only sparse material is to be found in literature so far on the occurrence mercury in the sea and the atmosphere. In particular, there is very little on the question of mercury present in the air above sea water areas. This is one of the aspects concerning the general budget of mercury circulation between the atmosphere and the sea. In this bugdet, apart from the mercury influx into this environment by natural geochemical processes, there is a rising share of pollution components [10] due to the activities of Man.

One can assume that the natural background for the presence of mercury in sea waters, caused by the rock weathering processes, is equal to the mean Hg concentration in the world ocean which is at present about 0.03 μg/l [10]. The data that are of particular interest to us are those on the mercury concentrations obtained by Fitzgerald and Hunt [4] for the north-western Atlantic. These concentrations in the surface layer of the ocean in the Long Island nearshore zone are 0.032 μg/l for the organic and 0.026 μg/l for the inorganic Hg compounds. On an average, mercury concentrations in the atmospheric air above the large industrial centres, such as Osaka and Chicago are 2.2 and 4.8 ng/m^3 respectively [2, 11]. For the agricultural areas the concentrations of mercury in the air, recorded in the USA so far are from 1.4 ng/m^3 in Willamette [14] to 1.9 ng/m^3 in the Chicago area [2].

---

* Preliminary results of this study were presented at the X Scientific Session of Physical Oceanography of the Polish National SCOR and published in "Studia i Materiały Oceanologiczne", No. 14, 1976.

We did not succeed in finding any exact figures on the dry fallout of mercury passing into the sea, in literature. The present study aims at obtaining such data for the Gulf of Gdańsk region, which — similar to the whole of the Baltic — is almost unexplored as yet in this respect. Our knowledge does not go far beyond the statement that the share of aerosol component in the process of exchange of matter between the atmosphere and the sea is quite essential. Its magnitude is confirmed, for instance, by the fact, well known from literature [9], that the amount of strontium 90 passing from the atmosphere directly into the Baltic during the past fifteen years was found to be four time higher than the share of this radioactive element entering the marine environment with the river discharges. In the case of mercury of course, the data can be expected to be different. Therefore the problem requires special studies.

2. THEORY OF TURBULENT FLUX OF ADMIXTURES

If we assume that aerosols are sprayed in the atmosphere up to height H and the self-cleaning process occurs by dry sedimentation only, then assuming their homogeneous concentration, the fallout velocity of particles can be determined from the expression

$$V = \frac{H}{\tau} \tag{1}$$

where τ — is the particle residence time in air. It is the eddy diffusion that decides on the effective fallout velocity of the airborne particulate matter. The intensity of diffusive spreading of the aerosol particles and of the air self-cleaning process due to the transfer of the atmospheric admixtures into the sea can be investigated through the semi-empirical equation of eddy diffusion. Upon this assumption, the formula for the spreading of passive aerosol particles in air under non-stationary conditions, and with the horizontal diffusion component neglected in our considerations, will read

$$\frac{\partial q_a}{\partial t} = K_z \frac{\partial^2 q_a}{\partial z^2} - \Lambda q_a \tag{2}$$

where: q_a — particle concentration in the near-water atmospheric layer, K_z — vertical eddy diffusivity, Λ — self-cleaning constant, z — vertical distance in the atmosphere. Dealing with the process in the near-water atmospheric layer we multiply equation (2) by H, which is the height of the turbulent mixing over the sea surface and has been defined by D.L. Laichtman [12] as

$$H = \frac{c_1 \varkappa G}{2 \omega_z \sqrt{c_1 (q/T_o) (\alpha_T/\omega_z^2) (\gamma_a - \bar{\gamma}) + m/4 c_1^3}} \tag{3}$$

where: c_1 — dimensionless coefficient, equal to 2.3, $\varkappa$ — the Karman constant, G — geostrophic wind velocity, ω_z — vertical component of the Earth's angular velocity T_o — temperature, α_T — the Prandtl number, γ_a and $\overline{\gamma}$ — the dry adiabatic and mean actual vertical temperature gradient, m — constant defined by the energy dissipation rate. The expression thus obtained will describe the vertical flux of airborne particulate matter, in which the mixing height is the parameter defining the development scale of the turbulent exchange process. Hence, the rate of transfer of particulate matter towards the sea surface at the height at which measurements were taken, equal to about 10 m a.s.l., can be given by

$$F_{10} = H\left(\Lambda q_a - K_z \frac{\partial^2 q_a}{\partial z}\right). \tag{4}$$

In order to carry out these calculations we had to assume that the aerosol concentrations were homogeneous in the horizontal plane and that the vertical distribution of q_a was linear. The magnitude of the self-cleaning constant, $\Lambda = \frac{1}{\tau}$, was obtainable from the investigations on the airborne salt nuclei in the near-water atmospheric layer over the Baltic. Such investigations were carried out by one of the authors [5] of the present report. The self-cleaning constant obtained therefrom for the Baltic area is $\Lambda = 1.12 \times 10^{-5} s^{-1}$. This value was determined by two different methods, 1. an analysis of the transistory fluctuations of $\frac{\partial q_a}{\partial t}$ — time dependent changes in salt nuclei concentrations in the near-water atmosphere, and 2. by examining the particle size distribution of the airborne particulate matter The above value for Λ was obtained for the western air circulation conditions over the Baltic. It is somewhat less under the local circulation in the investigated water area ($\Lambda = 0.91 \times 10^{-5} s^{-1}$). Since in the area of measurements the western circulation dominates, it appears reasonable to use the former value, $\Lambda = 1.12 \times 10^{-5} s^{-1}$ instead.

3. THE MIXING HEIGHT

It is only in rare cases that direct measurement results of mixing height in the atmosphere are obtainable. Still, there is a number of methods to determine the mixing height indirectly, either by theory [13] or basing on the practice used in applied meteorology including synoptic practice [7]. The range of applicability for each of the indirect methods will depend on a large extent on the atmospheric and morphological conditions for which this height is determined.

In order to assess the value of mixing height H in the present study, two methods were primarily used. Whenever $\bar{\gamma}_{1000}$ — the mean vertical temperature gradient up to 100 m above the ground did not exceed $\bar{\gamma}_{wa}$ — the wet-adiabatic gradient value — or did so to an insignificant extent only, with high wind velocities occurring at the same time, we generally used the methods basing on formulae of general applicability in dynamic meteorology [6, 12].

In the cases of higher gradients, approximating the dry adiabatic or super — adiabatic ones, the mixing height was determined from aerological diagrams [7]. Certain modifications were also introduced for the conditions not covered by the methods that were used by various authors [7, 12]. This refers, in particular, to the cases when there was a front with a low cloud layer or a continuous precipitation zone in the sampling area. The character of the sampling area was also considered being generally a coastal land or sea region, i.e. very much disturbed with respect to the unhomogeneity of their surface conditions.

The following meteorological data were determined and used as parameters for assessment of H in typical cases:

— vertical stability of air mass, determined from the aerological diagrams of the radio-sounding coastal station in Łeba (taken at 00.00 and 12.00 hours GMT),
— the direction of air mass advection, from the synoptic charts,
— water temperature at sea surface, from shipborne measurements or measured at the Władysławowo coastal station,
— maximal air temperature over land,
— minimal air temperature over land,
— the geostrophic wind velocity, G, according to the synoptic charts, averaged from three hours of observation for the "cool" part of the day (00.00, 03.00 and 06.00 hours GMT) and from four hours of observation for the "warm" one (09.00, 12.00, 15.00 and 18.00 hours GMT),
— value of $\bar{u}$ — wind velocity taken from the radio-sounding data, from Łeba, averaged for 0, 100, 300, 500 and 1000 m above the ground,
— height of the cloud layer and the character of precipitation, if any,
— inversion height wind speed and direction.

It was comparatively cool and windy at the time the investigations were carried out. The thermodynamic equilibrium was fairly highly differentiated, and the mixing height was very unstable. The values obtained for H reach from a few metres in the cases of negative vertical temperature gradients in the lowest air layers at low wind velocities, up to about 2000 m, in cases of unstable conditions. For certain summer seasons having a distinct diurnal temperature course, the diurnal course of H had inversion of extreme H values above the sea regions as compared with the land areas. The results of the analysis as applied to H and F_{10} calculations are listed in Table 1.

4. MEASURING TECHNIQUES

Marine aerosol and surface water samples were taken in the Gulf of Gdańsk (Fig. 1) during the exploratory cruises of the research vessel "Hydromet". Air was filtered by means of a water filter (air washer). Equipment of that type was exposed in conjunction with a one-stage cascade impactor to check the effectiveness of capturing the airborne particulate matter by the air washer. A scheme of the equipment is found in Fig. 2. Air drawn by a pump entered the washer through a glass pipe placed 1—2 cm above the water surface. Immersion of the pipe end in water was avoided to prevent the blowout effect of collected substances that might be passing from the water during the bursting of air bubbles at the water surface.

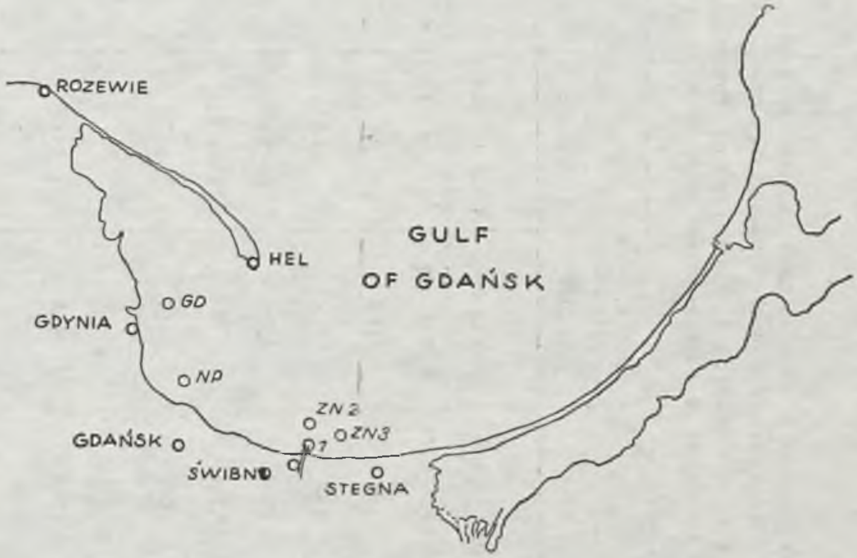

Fig. 1. Hg measurement stations in the Gulf of Gdańsk area
Ryc. 1. Rozmieszczenie stacji pomiarów rtęci na Zatoce Gdańskiej

The portion of the particulate matter that was not captured by water was collected on the surface of a glass plate in the impactor. To achieve this, the glass plate was treated with a vaseline in petroleum solution. After exposure of the plate a Pulfrich photometer was used and the

Table 1
Tabela 1

Height of particle exchange layer and meteorological characteristics used for its assessment in the Gulf of Gdańsk area, during the explorations carried out in 1974

Wysokość warstwy mieszania i wykorzystane do jej oszacowania charakterystyki meteorologiczne dla rejonu Zatoki Gdańskiej w okresie przeprowadzonych badań w 1974 r.

Meteorological Characteristics	Gulf of Gdańsk			Gdynia Coastal Station	
	May	August	October	May	October
γ_{land}, $C^{\circ}/100$ m	0.04 to 1.05	0.50 to 0.94	0.27 to 0.78	— 0.17 to 0.80	0.40 to 0.63
γ_{sea}, $C^{\circ}/100$ m	0.44 to 0.95	0.40 to 0.85	0.27 to 0.85	0.15 to 0.85	0.68 to 0.90
$\bar{u}$, m/s	12.9	10.5	9.4	13.0	10.8
G, m/s	14.1	—	10.9	17.7	11.5
$\bar{h}$ altitude of cloud base, m	unst.	unst.	300—800	100—500	300—700
direction of air flow	W,N,SE	W	SW—SE	NE	SW
$\bar{H}_{land}$, m	697	402	227	351	278
$\bar{H}_{sea}$, m	482	515	282	393	447
$\bar{H}$ — adopted for the sampling area, m	570	445	245	392	326

fraction collected on the glass plate was measured by employing the light dispersion principle. To check the particle capture effectiveness of the air washer, glass plates were exposed afterwards without the use of any water filter. The effectiveness of capturing aerosol particles in the filter was slightly above 90 per cent on the average. The equipment was designed to sample airborn particulate matter from practically unlimited air volumes per sample. An air washer was filled with up to 20 ml bidistilled water and sampling was conducted under strict control of the water level during the exposition. The air washer was made of glass. Even so, the intense water movement during exposure of the equipment, the small surface of the vessel and the relatively short sampling time resulted in Hg losses, due to the absorption possibility of this element on the washer walls, if any, being practically imperceptible. Immediately after exposure water taken with the sample was poured into a polyethylene can with concentrated nitric acid and stored deep frozen in a refrigerator. The sample was thus secured against Hg losses during storage.

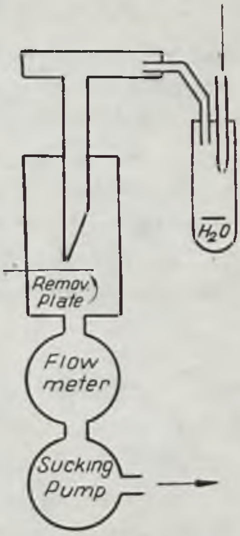

Fig. 2. Scheme of aerosol sampling equipment

Ryc. 2. Schemat urządzenia zastosowanego do pobierania próbek aerozolu z powietrza atmosferycznego

Air filtering took place on the highest deck of the vessel, 6 m high a.s.l. Care was taken that the filtration took place far from the exhaust pipes on the ship, with fresh air passing from the outside. The effect of the vessel on the pollution level of air at the filtration site was actually negligible, as can be inferred from the open sea measurements. In the open Baltic the mercury concentrations in air were frequently found to equal or approximate zero. Parallel with the measurements in the open Gulf area, analogical filtration was carried out in Gdynia, at the point on the Gulf coast, where the described equipment was exposed 12 m above sea level. The sampling, storage procedure, and the capture control were the same as at sea.

Water samples from the sea surface water layer were collected by means of plastic bottles. It was possible to sample water from a layer practically 0.5 m beneath the sea surface. From the very moment of sampling, water samples in polyethylene cans were stored in a refrigerator down to — 20°C. Moreover, to avoid losses during storage samples were treated with a concentrated nitric acid, 10 ml per litre of sampled water.

Mercury concentrations in the samples collected from the atmosphere and the sea water were measured by means of the Beckman (model 448) atomic absorption spectrophotometer. Samples were cold-mineralized with potassium permanganate and potassium persulphate. A flameless technique was used in the measurements and records were made at the 253.4 nm wavelength. The detection limit of about 4 ng was adequate to measure Hg concentrations higher than 0.1 μg/l with a precision of 5 per cent. The coefficient of variations increased up to 50 per cent at low concentrations approximating the detection limit.

5. DISCUSSION OF RESULTS

The applied method enabled us to examine the flux of airborne mercury passing into the sea with other particulate matter suspended in air. The mercury fraction present in the atmosphere (predominantly the gaseous form in methyl or dimethyl mercury), theoretically would dissolve in water until the dinamic equilibrium was achieved. Our measurements have proved that, on the average, the amount of organic mercury compounds present in aerosols and atmospheric precipitations reaches 45 to 95 per cent of their total mercury content, probably depending on the degree of industrial pollution of the atmosphere. It is thus concluded that some organic mercury compounds are not gaseous. Part of them are apparently linked with the aerosols. It must not be excluded that the aerosol particles can act as effective Hg sorbents, among these particularly the carbon particles.

The total mercury concentrations per unit volume measured in the near-water atmospheric layer in the Gulf of Gdańsk are listed in Table 2. These values are compared against the magnitude of Hg flux directed from the air towards the Gulf surface, as calculated on their basis. The values of F_{10} and q_a varied during the measurement period within one order of magnitude, and so did qw — the mercury concentration in the Gulf of Gdańsk surface water layer (Table 2). The mercury concentration in sea water is approximately one million times higher than in the atmosphere.

Table 3 lists separately the mean q_w values for the Gulf of Gdańsk coastal zone in the Three Towns Complex (Gdańsk—Sopot—Gdynia) (Fig. 1, Stations Nos. 1. ZN2, ZN3, NP, GD). The average mercury concentrations at these stations during the measurement period were one and a half times higher than those recorded for the remote stations in the Gulf area. Such a difference in mercury concentrations is even

Table 2
Tabela 2

Total mercury concentration and vertical flux of mercury over the Gulf of Gdańsk
Całkowite stężenie i pionowy strumień rtęci nad Zatoką Gdańską

Data on aerosol sampling (water filter)		Wind velocity, m/s		Measured Hg Concentration in air, ng/m^3		Calculated Flux F_{10} ng/m^2 hour	
Sampling time 1974	Air volume m^3	Gulf of Gdańsk	Gdynia	Open Gulf	Gdynia nearshore area	Open Gulf	Gdynia nearshore area
May	318.7	6.4		0.25 ± 0.02		15.4	
	68.0		7.5		2.13 ± 0.18		31.9
August	38.7	2.9		1.03 ± 0.09		18.5	
October	6.1	8.0		1.09 ± 0.29		10.8	
	59.7		4.8		2.21 ± 0.18		29.0

Table 3
Tabela 3

Total mercury concentration in the surface water layer of the Gulf of Gdańsk and the sedimentation of particulate matter in air and the sea water
Całkowite stężenie rtęci w powierzchniowej warstwie Zatoki Gdańskiej i prędkość sedymentacji cząstek w powietrzu i wodzie

Data on Sea Water sampling		Hg Concentrations, μg/l		Calculated Hg sedimentation velocity, cm/s	
Sampling time 1974	No. of samples	Open Gulf	Nearshore (Three Towns Complex) area	In air	In water
May	3	1.37 ± 0.04		0.65	$0.01.10^{-5}$
	2		1.01 ± 0.04	0.42	$0.09.10^{-5}$
August	3	0.67 ± 0.04		0.50	$0.08.10^{-5}$
	4		1.81 ± 0.05		
October	4	0.05 ± 0.04		0.27	$0.06.10^{-5}$
	4		0.12 ± 0.04	0.37	$0.68.10^{-5}$

more clear from Table 2 for the airborne mercury compounds. The values for Gdynia in this respect are three times higher than the respective data obtained for the open Gulf area. These data might also be indicative of the source of pollution and of the direction in which it is spreading from land towards the sea. Nothing definite however, can be asserted on the share of airborne mercury in its circulation budget in the water area itself. One would have to compare these data with the rate of the mercury passing with river inflow into the Gulf waters while this amount still remains unknown.

The mercury flux into the Gulf of Gdańsk waters with the airborne particulate matter during the measurement period was within 5.4—31.9 ng/m^2 per hour. All the same, even when assessing much higher mercury concentrations in the nearshore atmosphere, one should not rush to the conclusion that air is the main source of water pollution in the Gulf of Gdańsk. As may be inferred from previous investigations [1], the emission of water droplets into the air from the ocean surface is of the order of 100 droplets/cm^2. s. Hence, the mercury emission from water into the atmosphere with the marine aerosols can be quite substantial. On the other hand, the mercury methyl (or dimethyl) volatilization can have quite a different mechanism. The process of particle emission into the atmosphere in general is particularly intense in the surf zone, as explained, for instance, on the example of DDT spreading in the Baltic [13]. This fact is due to the peculiar dynamics of the sea in its nearshore zone, adding to the emission of droplets passing into the air. The mechanism of this emission should be effective, above all, for the components collecting in the surface film of sea water. The concentration distribution of microelements in the sea surface layer, and especially in its film, has not yet been sufficiently explored; one might expect that higher concentrations will be found in that very film.

It will be seen from the data listed in Table 3 that Va — transfer velocity of airborne particulate matter towards the Gulf waters — ranged during the measurement period between 0.3 and 0.7 cm/s on average. This is a velocity comparable with the sedimentantion velocity of, say, smoke particles in windless air, within the radius of the order of 10^{-4} cm [3], i.e. for the giant particle sizes, to which the airborne sea salt nuclei fractions, examined in the study [5], also belong. Still, in our case the velocities obtained do not refer to the sedimentation in calm weather, but rather to the particle transfer under the eddy diffusion conditions. Therefore its magnitude depends on the mixing height and on the self-cleaning constant Λ, determined previously [5] for the turbulent conditions over the Baltic sea. Hence, the values obtained may not be referred to the giant particles only. The air-to-water transfer velocities obtained, for instance, for CO_2 at the average wind speeds of about 5—7 m/s were of the order of $(0.1 \div 0.3) \cdot 10^{-2}$ cm/s [8] and with the wind velocity increase the value for the CO_2 exchange quickly rose These are values by approximately two orders of magnitude lower than the ones obtained by us - being what could be expected. All the same, if we consider the turbulence conditions during the measurement period, by comparing the above values we can also substantiate our conclusions as to the share of submicron particles in the aerosol samples tested.

The extreme F_{10} values for airborne mercury were obtained by open air exposure of polyvinyl trays of 800 cm² collection area, filled with bidistilled water. The exposure was accomplished during the research vessel cruises in the Gulf of Gdańsk and also at the coastal station in Gdynia. To assess the possible losses of Hg due to the adsorption on the tray walls parallel exposure of polyvinyl trays and polythylene cans was effectuated.

Differences in the losses however, escaped any evaluation. An analysis of dry sediment has proved that F_{10} may vary within a wide range of magnitudes (Fig. 3) also covering the scope of calculated values. The considerable deviations of measured values, found to be in excess of the mean ones, can undoubtedly be attributed to the maximum of total mercury concentrations in air in February, coinciding with the measurement period. Apart from these, it should be stressed that experimental methods of dry sediment testing are not devoid of difficulties, and under such circumstances errors occur.

Generally, an equilibrium between the diffusive Hg transfer from the atmosphere into sea and the diffusive Hg sedimentation should exist in water. Otherwise, we could only speak of the tendency of continuous rise or drop in the mercury concentrations in the sea surface layer, as caused by different velocities of mere vertical transfer. If we therefore assume that such an equilibrium does exist, we conclude that

$$F_{10} = F_W$$

i.e. that the vertical turbulent flux of mercury transferred into water from the atmosphere is equal in its magnitude to the Hg flux directed towards the bottom of the sea. Hence on the basis of the values obtained for q_a, q_W and V_a, we can also calculate V_W, being the diffusive sedimentation velocity of particles in the sea water surface layer. This value as shown in Table 3 is on average five to six orders of magnitude lower than V_a, i.e. too low indeed to correspond to the velocities of Hg spreading in the sea, as might be expected upon consideration of the intense turbulent diffusion taking place in the near-surface water layer. This conclusion coincides rather well with the fact that the atmosphere cannot be the only source of mercury pollution in the Gulf of Gdańsk basin. At any rate, there is no doubt about the actual occurrence of sudden change in the vertical transfer velocity at the air-sea interface. If this is so, we arrive at the effect of inertia in the process of Hg transfer through the air-sea interface, and this in turn should considerably obscure the difference between the Hg content fluctuations in the air and

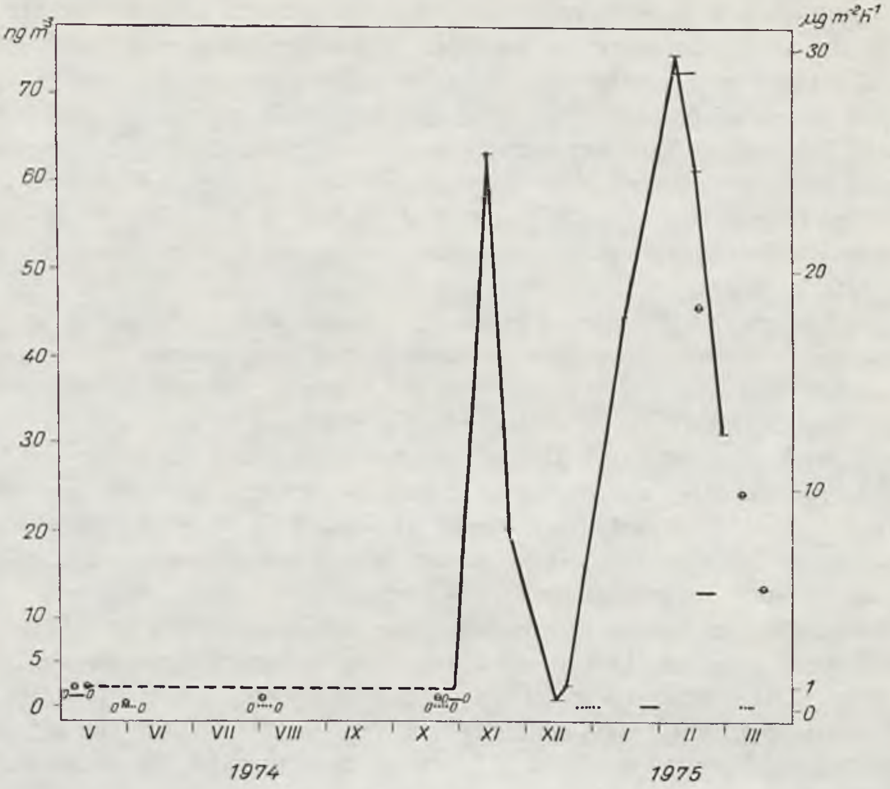

Fig. 3. Variations in total mercury concentration in air, from the measurements in Gdynia (solid line, dashed during the period of longer breaks in measurements) and above the Gulf of Gdańsk (points with a dash, its length corresponding to the number of observation days) and F_{10} values (dashes for Gdynia dotted lines for the Gulf of Gdańsk area; their length corresponding to the number of observation days; dashes with zeros at their ends refer to the calculated F_{10} values)

Ryc. 3. Przebieg czasowy wahań q_a — stężenia całkowitej rtęci w powietrzu według pomiarów w Gdyni (linia ciągła, w okresie z dłuższą przerwą w pomiarach — przerywana) oraz na Zatoce Gdańskiej (punkty z poziomą kreską o długości odpowiadającej liczbie dni obserwacji) a także wielkość F_{10} (kreski ciągłe dla Gdyni, kropkowane — dla Zatoki Gdańskiej; długość kresek odpowiada liczbie dni obserwacji, zera na końcach odnoszą się do obliczonych wartości F_{10})

water respectively. The question of this relationship is complicated and will need further clarification. When investigating the problem, one should rely on the measurements to be taken in the surface film of the sea. Such measurements actually were carried out.

Film water samples were taken to check whether the surface film favours Hg accumulation. The method consisted in vertically immersing a glass plate into the water surface layer; the test plate was 30 by 40 cm, 4 mm thick. When taken out of water, the film sample present on the glass was scraped off with a polyethylene knife. Samples were collected into a polyethylene storage can, and the method to prevent Hg losses was in general as described above. The surface film samples thus collected during the exploration cruises in February 1975 enabled us to determine the total mercury content present there; this was 258 µg/l in the Gulf of Gdańsk. The analysis showed that there were one hundred per cent in organic mercury compounds. By contrasting this value against the data in Table 3 we conclude that the Hg concentration in the surface film is much higher — by two or three orders of magnitude on average — than in the surface water layer. Still, the contribution of the turbulent flux of airborne particulate matter to the mechanism of mercury accumulation in the sea surface film is far from being elucidated and further investigations are necessary to explain its significance.

ACKNOWLEDGEMENT

This research was supported by the U.S. Environmental Protection Agency, project No. PR 05.532-13.

CZESŁAW GARBALEWSKI
HENRYKA BEREK
ANNA BRZEZIŃSKA
ANNA TRZOSIŃSKA
DANUTA WIELBIŃSKA

Instytut Meteorologii i Gospodarki Wodnej
Oddział Morski — Gdynia

BADANIA WIELKOŚCI TURBULENCYJNEGO STRUMIENIA RTĘCI AEROZOLOWEJ PRZENOSZONEJ Z ATMOSFERY DO MORZA

Streszczenie

Turbulencyjny strumień rtęci przenoszonej z cząstkami aerozolu do morza badano na przykładzie Zatoki Gdańskiej. W tym celu zorganizowano pomiary stężenia rtęci w powietrzu przywodnym, na zatoce i na stacjach brzegowych. Korzystając z materiałów aerologicznych i synoptycznych, jednocześnie badano warunki mieszania turbulencyjnego w rejonie pomiarów. Wielkość strumienia obliczano na podstawie oszacowanej wysokości warstwy mieszania i wartości stałej samooczyszczania, określonej z badań nad jądrami kondensacji na Bałtyku. Obliczone wartości porównuje się ze zmierzonymi stężeniami rtęci w powietrzu i powierzchniowej warstwie morza oraz z eksperymentalnymi danymi sedymentacji rtęci aerozolowej w badanym rejonie. Pomiarów dokonano metodą bezpłomieniowej absorpcji atomowej, techniką zimnych par.

W pracy stwierdza się, że wielkość turbulencyjnego przenoszenia rtęci z atmosfery do morza wahała się w okresie maj—październik 1974 roku w granicach jednego rzędu wielkości. Podobnej wielkości fluktuacje obserwowano również w zakresie stężeń rtęci w powietrzu i w powierzchniowej warstwie morza.

Dochodzi się do wniosku, że już tylko występujący na powierzchni rozdziału atmosfery i morza duży skok efektywnej prędkości dyfuzyjnego wypadania rtęci w wodzie i powietrzu w znacznej mierze powinien powodować występowanie maksymalnych stężeń rtęci w błonie powierzchniowej morza. Maksymalne stężenia zostały potwierdzone drogą specjalnych pomiarów.

REFERENCES

LITERATURA

1. Blanchard D.C., *The Oceanic Production Rate of Cloud Nuclei*, J. Rech. Atm., Vol. IV, 1969, No 1, 1—6.
2. Dams R., Robbins J.A., Rahn K.A., Winchester J.W., *Nondestructive Neutron Activation Analysis of Air Pollution Particulates*, Anal. Chem., No 42, 1970, 861.

3. Fett W., *Atmosfiernaja pylj*, Izd. Inn. Lit., Moskwa 1961.
4. Fitzgerald W.F., Hunt C.D., *Distribution of Mercury in Surface Microlayer and in Subsurface Waters of the Northwest Atlantic Ocean*, Int. Symp. Chem. of Sea/Air Partic. Exch. Proc., Bull. de L'Union des Oceanographes de France, No spec., Nice 1973.
5. Garbalewski C., *On the Effect of Air-Sea Interaction on the Diffusion and Removal of Airborne Particulate Matter*, Oceanologia. 1975. No 3.
6. Gandin L.S. i in., *Zadacznik po dinamiczeskoj mietieorologii*, Leningrad 1967.
7. Gross E., *The National Air Pollution Potential Program*, ESSA Technical Memorandum WBTM NMC 47, Washington 1970.
8. Hoover T.E., Berkshire D.C., *Effects of Hydration on Carbon Dioxide Exchange across an Air-Water Interface*, J. Geophys. Res., Vol. 74, 1969, No 2.
9. Iwanowa L.B., Giedieonow L.J., Markiełow W.N., Pietrow J.G., Truzow A.C., Szlapin E.A., *Sodierżanije* Sr^{90} *i* Cs^{137} *w wodach Baltijskogo moria w 1970 g*, Atomn. Energ., t. 33 vyp. 4, 1972, 835—838.
10. Januszkiewicz T., *The Problem of Mercury in a Natural Environment and in One Changed by Man*. Wiad. Ekolog., XX, 3, 1974, 264—285.
11. Kaifer J.W., Wesolowski R., *Trace Element Concentrations in Aerosols from the San Francisco Bay Area*, Atm. Environ., Perg. Press, Vol. 7, 1973, 107.
12. Lajchtman D.L., *Fizika pogranicznogo sloja atmosfiery*, Gidrometizdat, Leningrad 1970.
13. Lundholm B., *Interactions Between Ocean and Terrestrial Ecosystems*, Symp. Glob. Effects of Env. Pollut. (ed. by S.F. Singer) Springer — Verlag, 195—201, New York 1970.
14. Shum Y.S., Loveland W.D., *Atmosperic Trace Element Concentrations Associated with Agricultural Field Burning in the Willamette Valley of Oregon*, Atm. Environ., Perg. Press. Vol. 8, 1974, No 6, 645.