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AIR FORCE SYSTEMS COMMAND

QUESTIONS OF ATMOSPHERIC DIFFUSION AND AIR POLLUTION (SELECTED ARTICLES)

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EDITED MACHINE TRANSLATION

QUESTIONS OF ATMOSPHERIC DIFFUSION AND AIR POLLUTION
(SELECTED ARTICLES)

English pages: 79

SOURCE: Leningrad. Glavnaya Geofizicheskaya Observatoriya. Trudy. Voprosy Atmosfery Diffuzi i Zagryazneniya Vozdukha. (Leningrad. Main Geophysical Observatory. Transactions. Questions of Atmospheric Diffusion and Air Pollution), 1965, No. 172, pp. 23-34, 42-47 and 74-78.

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ITIS INDEX CONTROL FORM

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Transliterated Title REZUL'TATY ANALIZA EKSPERIMENTAL'NYKH DANNYKH, KHARAKTERIZUYUSHCHIKH RASPREDELENIYE ATMOSFERNYKH ZAGRYAZNENIY VBLIZI TEPLOVYKH*

09 English Title RESULTS OF ANALYSIS OF EXPERIMENTAL DATA CHARACTERIZING THE DISTRIBUTION OF ATMOSPHERIC POLLUTIONS NEAR THE THERMAL ELECTRIC POWER STATIONS

43 Source LENINGRAD. GLAVNAYA GEOFIZICHESKAYA OBSERVATORIYA. TRUDY. VOPROSY ATMOSFERY DIFFUZI I ZAGRYAZNENIYA VOZDUKHA(RUSSIAN)

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16 Co-Author	**47 Subject Codes**
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RIKHTER, B. V.	sulfurous acid, air pollution, meteorology
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ABSTRACT: The method of analysis of experimental data on surface concentrations of sulfurous gas and ashes is expounded, permitting the determination of the quantity of dangerous speed u_M and maximum concentration q_M. A comparison is made of experimental results characterizing pollution near a number of large thermal electric power stations, with data of the calculation by theoretical formulas. A satisfactory agreement is noted. Data characterizing the dependence of the rise of the torch of chimneys on the speed of wind are reduced, which also will agree with theoretical results obtained in a previous work on this subject. English Translation: 14 pages.

*Transliterated Title - cont. - ELEKTROSTANTSIY

ITIS INDEX CONTROL FORM

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09 English Title ANALYSIS OF DISPERSION OF HORIZONTAL OSCILLATIONS OF THE WIND DIRECTION

43 Source LENINGRAD. GLAVNAYA GEOFIZICHESKAYA OBSERVATORIYA. TRUDY. VOPROSY ATMOSFERY DIFFUZI I ZAGRYAZNENIYA VOZDUKHA(RUSSIAN)

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16 Co-Author	**47 Subject Codes**
GRACHEVA, V. P.	04, 08
16 Co-Author	**39 Topic Tags:**
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16 Co-Author	
NONE	
16 Co-Author	
NONE	

ABSTRACT: In an analysis of continuous records of meteorological elements (such as wind direction or wind velocity), it is necessary to consider the mean values of these elements for short intervals and later analyze these values for some quite long period. In such a process, both the very small and very large frequencies are cut off from the frequency spectrum. This paper is an analysis of the dependence of the dispersion of meteorological values on the internal and external averaging intervals on the basis of theoretical considerations. The averaging method used by F. B. Smith (J. Roy. met. soc., Vol. 88, 376, 1962, 177) is summarized and applied by the authors: the work of J. Ogura (J. meteorol. 14, 1957, 9-17) in this field is also taken into account. The results obtained are in general agreement with an earlier paper by V. P. Gracheva and V. P. Lozhkina on the stability of wind direction in the surface layer of the atmosphere (Tr. GGO, No. 158, 1964). For example, in Fig. 1 of the Enclosure, the value of the parameter $\Delta T/u_1^2$, characterizing atmospheric stability in the lower layer of the atmosphere, has been plotted along the x-axis and the mean value of σ (dispersion) for the summer or winter season has been plotted (in degrees) along the y-axis for a 20-minute averaging period. With an increase of instability when $\Delta T/u_1^2 > 0$ (temperature decrease with height) the values of σ increase in summer from 2 to [illegible]°, whereas in winter they are almost constant and equal to 3-5°. When there is an inversion ($\Delta T/u_1^2 < 0$) in both winter and summer the average values of σ change insignificantly, approximately from 6-7 to 2-3°; the winter and summer values of σ are almost equal, in contrast to unstable states when σ in summer is several times greater than the winter values. The figures alongside the vertical lines denote the number of 20-minute periods used in constructing the

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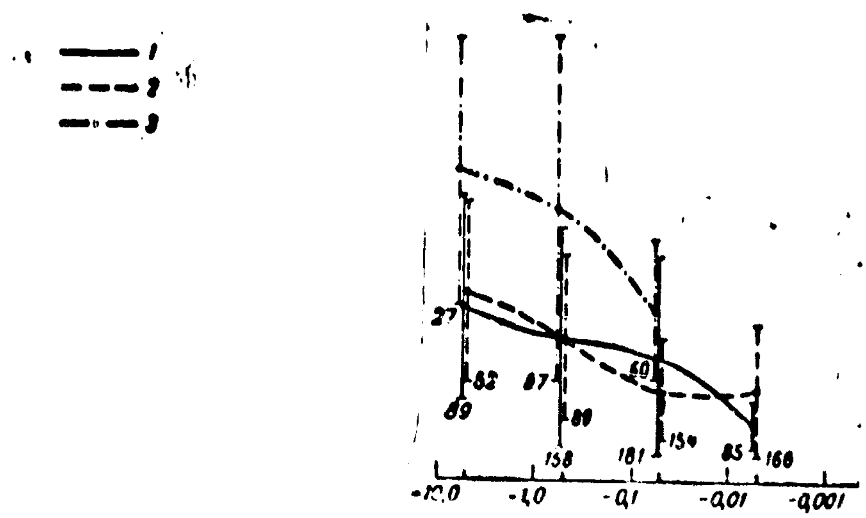
curve for each interval of values $\Delta T/u_1^2$; the length of the vertical lines is a measure of the scattering of individual σ values from their mean value for the considered (winter or summer) seasons. With an increase in wind velocity to approximately 5-6 m/sec the σ values for all ΔT usually decrease, except in the case of winter inversions. With an increase of wind velocity above 6 m/sec, σ in both winter and summer changes very little (about 2°), except in unstable weather in summer when mean $\sigma = 3.5^{\circ}$. Fig. 2 of the Enclosure shows the dependence of σ in summer, averaged for 2-hour time intervals, on the averaging period for different stability conditions. It is shown that with a change in the external averaging period from 20 to 40 minutes the values of σ increase by 20% on the average under unstable conditions and by 35% under stable conditions; with a change in the averaging period from 40 to 60 min. the values increase by 15 and 25%, respectively. Orig. art. has: 11 formulas, 3 figures and 1 table. English Translation: 8 pages.



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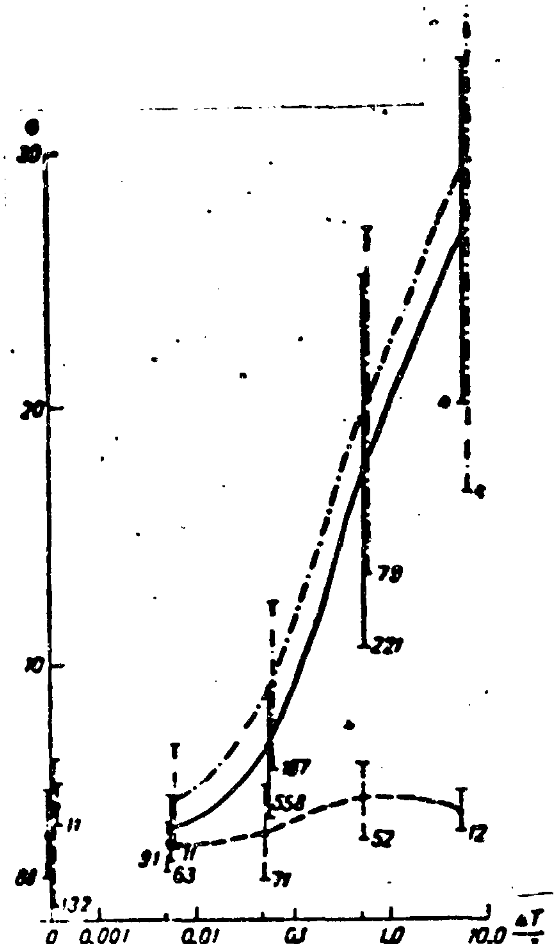

Fig. 1. Dependence of σ on stability: 1) 20-minute averaging period, summer data; 2) same, winter data; 3) 40-minute averaging period, summer data.

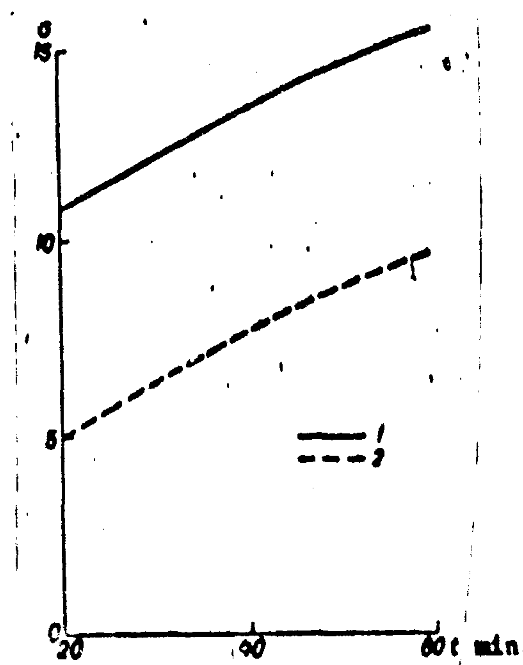

Fig. 2. Dependence of σ on averaging period: 1) unstable conditions; 2) stable conditions.

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09 English Title THE QUESTION OF HORIZONTAL SCATTERING OF IMPURITY IN THE ATMOSPHERE

43 Source LENINGRAD. GLAVNAYA GEOFIZICHESKAYA OBSERVATORIYA. TRUDY. VOPROSY ATMOSFERY DIFFUZI I ZAGRYAZNENIYA VOZDUKHA(RUSSIAN)

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ABSTRACT: This paper reviews the method for determining the horizontal component of the exchange coefficient on the basis of the apparent configuration of a smoke plume from a factory chimney proposed by M. Ye. Berlyand (Meteorologiya i Gidrologiya, No. [illegible], 19[illegible]1). The method is applied to investigations made in 19[illegible]2-19[illegible]3 in the neighborhood of the Shchekino GRES. These studies of atmospheric contamination from an aircraft were made to determine the geometrical parameters of the smoke plume at various distances from the source. The horizontal flights were made to a distance where the plume apparently ended. a point where the concentration for all practical purposes was considered equal to zero. A total of [illegible]0 flights were made. It was found that the key parameter φ_0 (mean dispersion in the time T) varies from 0.1 to 0.[illegible] (depending on weather conditions), but its absolute value remains constant to a distance of 30-40 km from the source. The determined characteristics of φ_0 are compared with data obtained on the basis of Sutton's theory; φ_0 is recalculated to the parameters used in othter studies. Using data from these other studies (E. W. Bierly and E. W. Hewson, J. appl. met., No. [illegible], 19[illegible]; Norman F. Islitzer, J. met., Vol. 1[illegible], No. 4, 19[illegible]1; I. Euqvay and C. Simpson, J. appl. met., Vol. [illegible], No. 1, 19[illegible]2) the value of φ_0 is 0.1 to 1[illegible] km from the source and on the average φ_0 = 0.1 to a distance of [illegible] km from the source. Orig. art. has: 1[illegible] formulas, 1 figure and 2 tables. English Translation: 7 pages.

TABLE OF CONTENTS

U. S. BOARD ON GEOGRAPHIC NAMES TRANSLITERATION SYSTEM

Block	Italic	Transliteration	Block	Italic	Transliteration
А а	*А а*	A, a	Р р	*Р р*	R, r
Б б	*Б б*	B, b	С с	*С с*	S, s
В в	*В в*	V, v	Т т	*Т т*	T, t
Г г	*Г г*	G, g	У у	*У у*	U, u
Д д	*Д д*	D, d	Ф ф	*Ф ф*	F, f
Е е	*Е е*	Ye, ye; E, e*	Х х	*Х х*	Kh, kh
Ж ж	*Ж ж*	Zh, zh	Ц ц	*Ц ц*	Ts, ts
З з	*З з*	Z, z	Ч ч	*Ч ч*	Ch, ch
И и	*И и*	I, i	Ш ш	*Ш ш*	Sh, sh
Й й	*Й й*	Y, y	Щ щ	*Щ щ*	Shch, shch
К к	*К к*	K, k	Ъ ъ	*Ъ ъ*	"
Л л	*Л л*	L, l	Ы ы	*Ы ы*	Y, y
М м	*М м*	M, m	Ь ь	*Ь ь*	'
Н н	*Н н*	N, n	Э э	*Э э*	E, e
О о	*О о*	O, o	Ю ю	*Ю ю*	Yu, yu
П п	*П п*	P, p	Я я	*Я я*	Ya, ya

* ye initially, after vowels, and after ъ, ь; e elsewhere. When written as ё in Russian, transliterate as yё or ё. The use of diacritical marks is preferred, but such marks may be omitted when expediency dictates.

FOLLOWING ARE THE CORRESPONDING RUSSIAN AND ENGLISH

DESIGNATIONS OF THE TRIGONOMETRIC FUNCTIONS

Russian	English
sin	sin
cos	cos
tg	tan
ctg	cot
sec	sec
cosec	csc
sh	sinh
ch	cosh
th	tanh
cth	coth
sch	sech
csch	csch
arc sin	$\sin^{-1}$
arc cos	$\cos^{-1}$
arc tg	$\tan^{-1}$
arc ctg	$\cot^{-1}$
arc sec	$\sec^{-1}$
arc cosec	$\csc^{-1}$
arc sh	$\sinh^{-1}$
arc ch	$\cosh^{-1}$
arc th	$\tanh^{-1}$
arc cth	$\coth^{-1}$
arc sch	sech^{-1}
arc csch	csch^{-1}
rot	curl
lg	log

RESULTS OF ANALYSIS OF EXPERIMENTAL DATA CHARACTERIZING THE DISTRIBUTION OF ATMOSPHERIC POLLUTIONS NEAR THE THERMAL ELECTRIC POWER STATIONS

R. I. Onikul, G. A. Panfilov, B. V. Rikhter,
and R. S. Gil'denskiol'd

The method of analysis of experimental data on surface concentrations of sulfurous gas and ashes is expounded, allowing the determination of the quantity of dangerous speed u_M and maximum concentration q_M. A comparison is conducted of experimental results characterizing pollution near a number of large thermal electric power stations, with data of the calculation by theoretical formulas [1]. There is noted their satisfactory agreement. Data characterizing the dependence of the rise of the torch of chimneys on the speed of wind are reduced, which also will agree with theoretical results obtained in [1].

At present there is insufficient volume of experimental data on characteristics of the propagation of harmful impurities ejected by industrial sources into the atmosphere in different seasons and in different climatic and physicogeographic conditions. This is the essential obstacle for use of available theoretical researches on atmospheric diffusion, since it does not permit judging the correctness of initial positions of the theory and used parameters and determining the region of applicability of design equations. In many cases the experimental study of air pollution by industrial enterprises was not accompanied by a determination of all the parameters necessary for a comparison of obtained data with theoretical calculations, or it was conducted without the necessary complex of meteorological observations.

The experimental data existing until recently in the USSR and abroad pertained to sources of comparatively weak power located at low height. Thus, for example, the formulas of Sutton obtaining wide use, essentially, in detail were checked only on the basis of data of experiments at Porton[1] during the carrying out of which concentrations were determined at short distances (of the order of 100 m) from the surface source.

There subsequently appeared many modifications of Sutton's formulas [2, 3, 4] etc., and they were widely applied in the calculation of pollution of atmosphere from chimneys of industrial enterprises. But the results obtained were unsatisfactory, and in certain cases the divergence of theoretical and experimental data by one order and more was noted.

In recent years there has been conducted a number of great researches in the examined question [5, 6, 7], but the methods of the calculation given in them are not confirmed in sufficient degree by experimental data. Geometric heights of chimneys H at large industrial enterprises reach 150-200 m. Streams, of flue gases ejected from the stacks possess an initial speed and overheating with respect to the surrounding air, and depending upon meteorological conditions they rise to a certain height above the opening of the stacks. The rise of the stream as frequently characterized by the quantity $H + \Delta H$, called the effective height of the stacks. Speeds of ejection and overheating are such that ΔH at slight and moderate speeds of wind also attain hundreds of meters.

Dependence of ΔH on meteorological parameters and parameters of ejection is studied experimentally also insufficiently.

Thus at present very great practical importance is obtained by the investigation of atmospheric diffusion from sources whose effective height outside the dependence on meteorological conditions is not less than 200-300 m. At such heights the regularities of the stratification of wind and temperature with height, intensity of turbulent exchange and other meteorological characteristics determining atmospheric diffusion are studied quite inadequately.

In connection with this in the period from 1961 to 1963 the Main Geophysical Observatory im. A. I. Voyeykov (GGO)[2] jointly with the Moscow Scientific-Research Institute of Hygiene im. F. F. Erisman, the All-Union Heat Engineering Institute im. F. E. Dzerzhinskiy (VTI)[3] and the Southern Branch of ORGRES[4]

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[1]This name cannot be verified and is a transliteration from the Russian. [Tr. Ed. note]

[2][GGO] (ГГО) = Main Geophysical Observatory.

[3][VTI] (ВТИ) = All-Union Heat Engineering Institute.

[4][ORGRES] (ОРГРЭС) = State Trust for Organization and Rationalization of Regional Electrical Stations and Networks.

conducted investigations of scattering of sulfurous gas and ashes from stacks of thermal electric power stations. GGO conducted theoretical researches, and a wide complex of meteorological and aerological works. Meteorological observations included gradient and balance measurements. Aerological observations, consisted of aerostat, aircraft and helicopter soundings and pilot balloon observations. Moreover, there was conducted an anemometric survey of the terrain and certain other observations.

Methods of observations and the first results of their analysis are expounded in a number of articles of this collection and in [8, 9, 10].

The F. F. Erisman Institute produced measurement of the concentration of sulfurous gas and ashes under the torch of GRES[1] and fractional composition of ashes. The method of these observations is discussed in [11].

VTI and the Southern Branch of ORGRES measured parameters of ejection, namely; the volume of gas-air mixture ejected from stacks, temperature of ejection, quantity of ejected sulfurous gas and ashes and the fractional composition of ejected ashes; these parameters were determined by the conventional method.

In this article data of four expeditions are analyzed jointly (September-October 1961, March 1962, July-September 1962, and February-March 1963). The conducted complex of experimental works is one of the most complete researches in the study of diffusion of impurity from industrial sources.

On the basis of the conducted theoretical researches, there were developed formulas of the calculation of pollution of the atmosphere by ejections from chimneys of electric power stations [1].

Below are given certain results of analysis of data obtained in expeditions by surface concentrations of sulfurous gas and ashes. Essential difficulties in the use of data available in literature on experimental determination of surface concentrations of harmful substances, about which it was already mentioned above, are connected with the fact that different authors applied essentially differing methods of investigation: the duration of the sampling of air varied, various methods of chemical analysis were used, the quantity of points of sampling of air and distribution of them with respect to the source of ejection were also unequal. It is especially necessary to note that the data given in literature on pollution of atmospheric air, as a rule, were not accompanied by synchronous measurements of parameters of ejection (temperature, volume, weight ejection).

During the study of pollution of the surface air from local source, which is the Shchekino, GRES, the method examined in detail

[1][GRES] (ГРЭС) = State Regional Electric Power Station.

in [11] was used. It consists in the fact that under a visually defined axis of the torch at different distances from the source (from 1 to 10 km) it is disposed along several points. Usually at a given distance there was placed 3 point, and simultaneously altogether 15-20 points, in which a 20-minute sampling of the air with subsequent analysis on the content of sulfurous gas was produced. The period of sampling is conditioned by the accepted method, and to a certain degree it is close to the optimum. The more short-lived changes of concentration are connected with fluctuations of the flow, and during a long period of intake of samples the probability of departure of the torch is increased, which leads to decreasing of surface concentrations. During a 20-minute period of sampling in many cases the measured concentrations are considerably lower than the axial concentrations, since in certain cases a departure of the torch from the point of measurement was observed. Other causes of understating can be the inaccurate location of points of sampling on the basis of visual determination of the axis of the torch, sharp distinctions in the direction of wind on land and at heights, turbulent pulsations of airflow and the change of their intensity, the irregularity of ejection from stacks and parameters of the smoke stream, etc. In connection with this analysis of the data occurred by a new method proposed by M. Ye. Berlyand. For an analysis of data there were selected separately data on the concentration of sulfurous gas and ashes, which pertain to equal values of ejections from stacks and to conditions with approximately identical characteristics of turbulent exchange. At every distance (for the individual expedition and for all expeditions together) there were plotted on a graph quantities of SO_2 concentration depending upon the wind speed at the height of the wind vane.

Drawn on these graphs was an envelope above which remained only single, sharply jumping points. One can assume that the low values of concentration on these graphs are explained by the departure of the torch and other above mentioned causes, i.e., they are not of interest from the point of view of the contamination of surface layers of air. Sampling points cannot coincide with the axis of torch, and this is explained by the definite spread of points on the graphs. Plotted on Fig. 1 are values of the surface concentration of SO_2 (at a distance of 3 km from GRES stacks) depending upon the wind speed according to the wind vane, and an envelope is drawn.

Analogous graphs for distances 4, 6, 10, 15 km are given respectively on Figs. 2-5. From the graphs given it is clear that envelopes clearly limit the basic mass of maximum single concentrations measured for the whole period of investigations at different distances from GRES stacks.

It is necessary to note also that at all distances the maximum of concentrations is connected with the definite value of wind speed u, which is dependent on the initial speed of outflow of flue gases from the stacks and the quantity of their overheating. At small wind speeds the height of the rise of flue gases is very great; with strong winds the effective height is small, but the flue gases pass far from the source and greatly disperse in the atmosphere. The greatest surface concentrations are observed when $u \approx u_M$. Calculations and experimental data show that when $u < u_M$ with an increase in speed of the wind the surface concentrations rather quickly increase, and when $u > u_M$ with a further increase in speed of the wind (up to 1.5-2 m/s) the change in surface concentrations is very small.

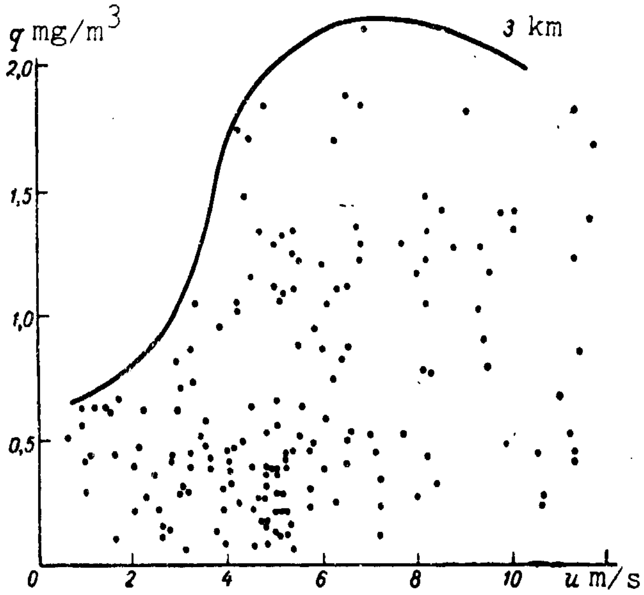

Fig. 1.

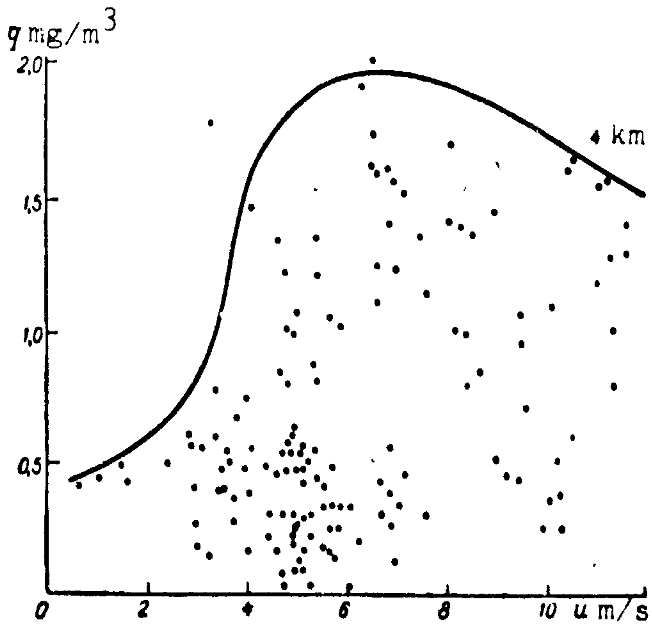

Fig. 2.

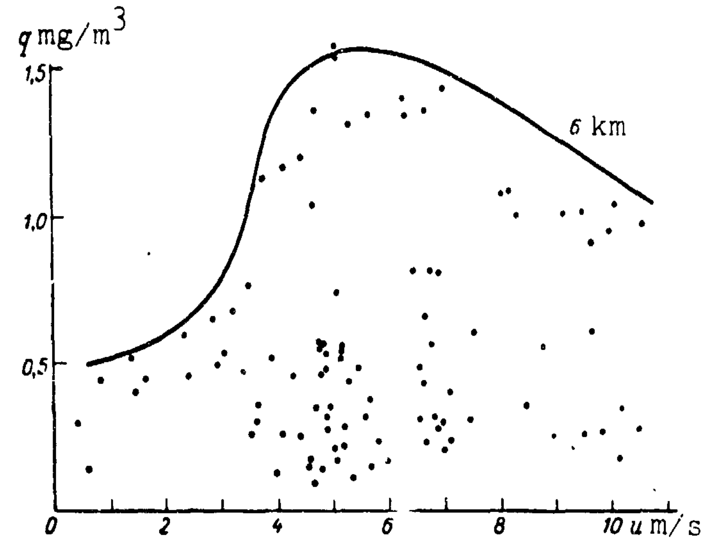

Fig. 3.

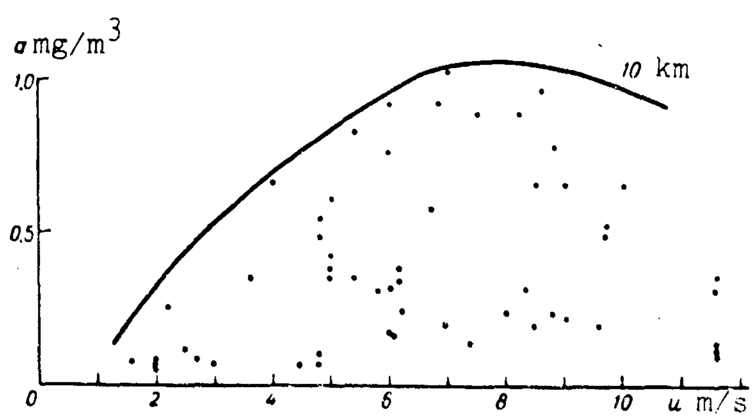

Fig. 4.

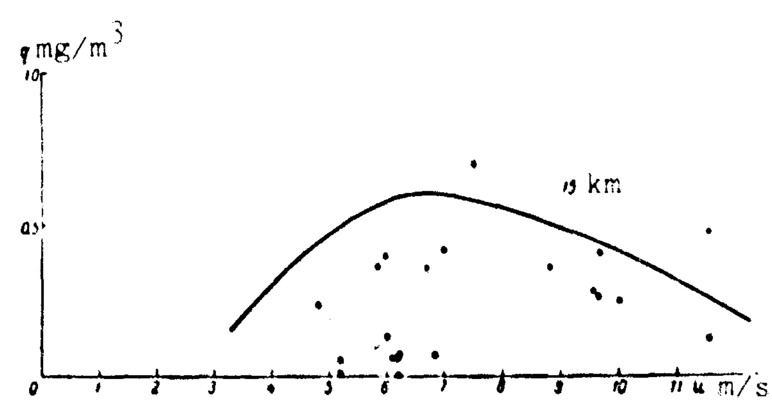

Fig. 5.

The examined method of analysis of data of observations possesses a definite advantage over the usually utilized methods of finding the average concentrations. With calculation of average concentrations there are considered zero and weak concentrations, which are usually connected with the departure of torch from the point of intake of sample or with the low sensitivity of the method of determination of the concentration. Thus mean values of concentrations with the indicated system of sampling are insufficiently defined and depend on random factors. Also depending on random factors is the value of the absolute maximum, which is observed very rarely and in certain cases can be connected with the error of the measurements. The reduced data permit checking formulas in [1] obtained on the basis of theoretical solution for the concentration of impurity:

$$u_м = 0,65 \sqrt[3]{\frac{V \Delta T}{NH}}, \quad (1)$$

$$q_м = \frac{AQFm}{H^2} \sqrt[3]{\frac{N}{V \Delta T}}, \quad (2)$$

$$x_м = 20H. \quad (3)$$

Here A is the measured coefficient depending on the temperature stratification of the atmosphere determining conditions of the vertical and horizontal scattering of impurity in air; V – the total volume of flue gases ejected from all stacks; N – number of stacks; H – geometric height of stacks; Q – quantity of impurity ejected from all stacks; $\Delta T = T_Г - T_B$, where $T_Г$ is the temperature of escaping gases, T_B – temperature of ambient air; m and F – dimensionless correction factors considering the speed of ejection of flue gases and dispersiveness of aerosol particles.

Coefficient A is calculated for conditions when in the surface layer maximum concentrations of contamination are created, i.e., for convection conditions in the summertime. In those cases when the speed of the wind attains dangerous values u_M and the surface concentration attains a maximum value, A takes the following values: 200 for Kazakhstan, Central Asia, central part of Siberia; 160 for the northern and northwestern European territory of the USSR, Urals and Ukraine; 120 for the central part of the European territory of the USSR in regions with similar climatic conditions.

At values of parameters characteristic for the Shchekino GRES, u_M according to calculation data should be about 5 m/s. The fact that the quantity of dangerous speed appears close to 5 m/s is very significant, since similar speeds are observed almost daily, and therefore it is possible by calculating for dangerous speeds not to consider recurrence of the wind according to the speeds.

A comparison of calculations by formulas (1), (2) and (3) with given experimental data showed that calculated maximum concentrations of sulfurous gas q_M and distances x_M corresponding to them will agree with quantities obtained as a result of the application of the above described method of analysis of experimental data. The distinction does not exceed 20-30%.

There is obtained a satisfactory coordination for maximum values of the concentration of SO_2 q_u calculated by formulas given in [1] at different wind speeds u at various distances from the stacks.

Given below are ratios of the largest concentration q_u to q_M at speeds of wind from 3 to 10 m/s according to data of the calculation and observations:

u m/s...........	3	4	5	8	10
q_u calculated.....	0,5	0,8	1,0	0,9	0,8
q_M experimental..	0,7--0,8	0,9	≈1,0	1,0	0,7—0,9

Theoretical and experimental values of ratios of concentrations of SO_2 at distances from 2 to 15 km (when $u = u_M$) to q_M are the following:

x km...........	2	3	4	6	10	10
q_x calculated.......	0,9	1,0	0,9	0,5	0,3	0,2
q_M experimental......	0,8	0,9	0,8	0,6	0,5	0,3

According to data of observations for each distance of the measurement of concentration there was determined the wind speed u at which q at this distance attained the greatest values. It turned out that for distances of 2-6 km u = 5-6 m/s, and for 8-15 km u = 6-7 m/s. According to calculation, these speeds consist of 5-6 m/s. Thus, it is obtained that at all distances from the source the maximum concentration are observed at speeds close to u_M.

By an analogous method a comparison was made of data of calculation and the experiment for surface concentrations of ashes.

Figures 6 and 7 give graphs of the dependence of the concentration of flying ash on the wind speed for a distance of 1 and 3 km and analogous graphs of Fig. 1-5 are for sulfurous gas.

Let us give the ratio $\frac{q_x}{q_M}$ for ashes at a distance from 1 to 6 km:

x km...........	1	2	4	6
q_x calculated.......	0,4	0,9	0,9	0,8
q_M experimental........	0,5	1,0	0,8	0,6

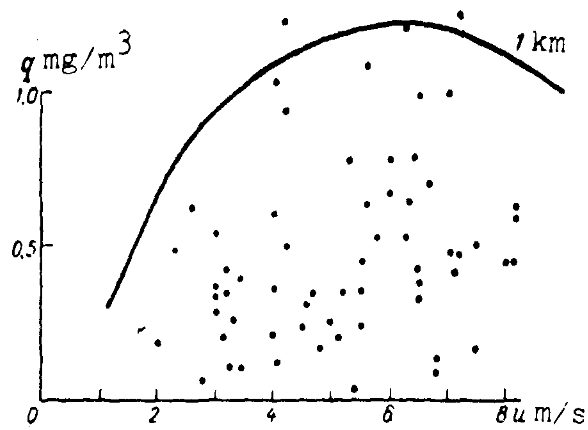

Fig. 6.

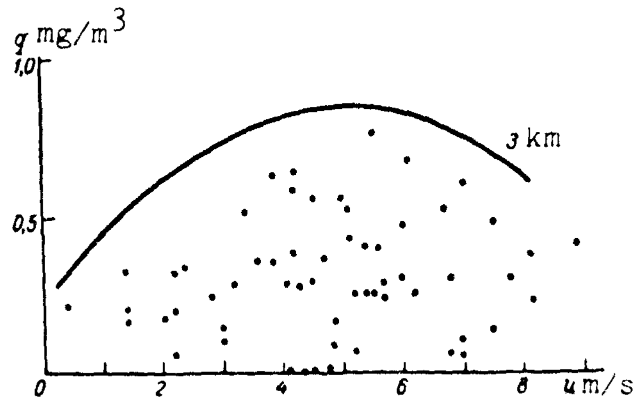

Fig. 7.

Calculations confirmed the satisfactory agreement of theory and experiment and on concentrations of flying ash.

For checking formulas (1)-(3) there was undertaken also the analysis of certain other experimental data on surface concentrations of sulfurous gas and ashes obtained during 1953-1958 by F. F. Erisman Institute in its expeditionary researches in the study of air pollution near a number of large electric power stations.

Data were analyzed at seven thermal electric stations operating on different carbon and peat with a range of heights of the stacks from 40 to 150 m ; . the number of pipes varied from 1 to 18.

In those cases when some of the parameters of ejection were absent, they were calculated according to the power of the station and caloricity of fuel with the help of a formula well-known in technology. If it was not possible to construct graphs analogous to those shown in Figs. 1-5, then quantity q_M was defined as the half-sum of the quantity of the absolute maximum of concentration and the average quantity of all positive samples. Coordination was very good both with respect to sulfurous gas and also ashes.

Table 1 gives experimental and calculated values of maximum concentrations of sulfurous gas and ashes referred to the corresponding consumption Q.

Table 1

TPES	Height H, m	$\frac{q_M}{Q} \cdot 10^3$			
		sulfurous gas		ashes	
		experimental	calculated	experimental	calculated
Kashira	150	0,29	0,31	0,18	0,32
Cherepovets	120	0,28	0,25	0,62	0,50
South-Ural	120	0,09	0,25	0,39	0,50
South-Kuzbass	105	0,63	0,30	0,64	0,74
Nesvetay	70	1,6	1,1	1,1	2,3
Ivanovo	40—60	5,2	3,3	5,3	6,2
Shatura	40	5,1	6,0	6,8	12,2

Figures 8 and 9 shows in logarithmic scale the dependence of the ratio $\frac{q_M}{Q}$ on H according to Table 1 for sulfurous gas and ashes. The obtained results permit making a conclusion about the satisfactory coordination of data of the calculation (1) and experiments (2). It is confirmed that the dependence of maximum concentration on height of the stack from data of experiments is close to that obtained theoretically.

Quantity q_M is the basic quantity characterizing surface contaminations, since it is considered with the designing of industrial enterprises. As was said above, the quantity of the surface concentration of impurities depend on the effective height of the source H + ΔH. At a fixed temperature of ejection quantity ΔH depends on the speed of the wind at the height of the source, which on the average is closely connected with the speed of the wind at the height of the wind vane.

Good coordination of the theory and experiment for surface concentrations of sulfurous gas and dust, relationships of concentrations at different distances from the source, quantities of dangerous speed, etc., indicate the fact that the conducted calculation of the rise in a smoke torch should be confirmed sufficiently well by experimental data.

For a direct investigation of the dependence ΔH on parameters of ejection and meteorological parameters and also for checking of the theoretical formula given in [1], in all expeditions photographing of the smoke torch and processing of the photographs were produced.

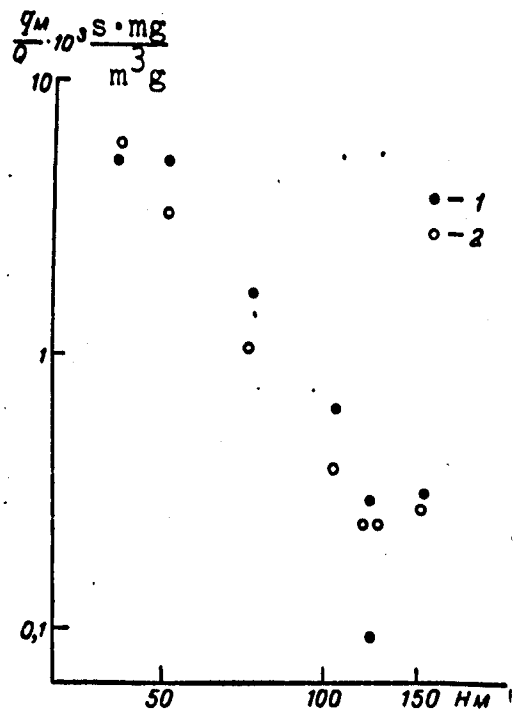

Fig. 8.

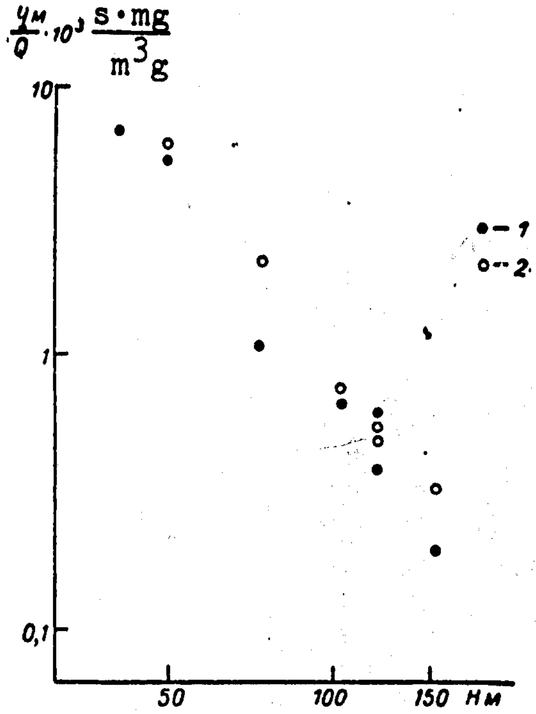

Fig. 9.

Photographing was produced in daylight under different meteorological conditions from the side approximately at a distance of 1 km along the perpendicular to the axis of the torch on an average of every 15 minutes and at moments when the form of the torch was sharply changed. For an illustration Figs. 10 and 11 give photographs of the torch at small and moderate speeds of the wind.

The clear photographs were subjected to treatment. The treatment and analysis of the photographs was performed by G. A. Fedorov and photographing of the smoke torch was conducted by A. M. Tsarev. Quantity ΔH was determined by the height above the mouth of the stacks on which the monotonous rise of the axis of the smoke torch was ceased.

The height of the stacks and distance between balconies available on the stacks were used as a scale in the determination of the photographs of ΔH.

Figure 12 gives the dependence of quantities ΔH, determined by photographs on the speed of wind u at the height of the wind vane (under conditions with approximately an identical quantity of air ejected from the stacks) according to data of three expeditions 1962-1963. The smooth curve on this figure characterizes the dependence of mean values of ΔH (in the interval of wind speeds ± 0.5 m/s) on u at the height of the wind vane.

Upward and downward from every averaged point the standard duration ΔH is plotted.

Fig. 10. Photograph of a smoke torch during slight wind.

Fig. 11. Photograph of a smoke torch during strong wind.

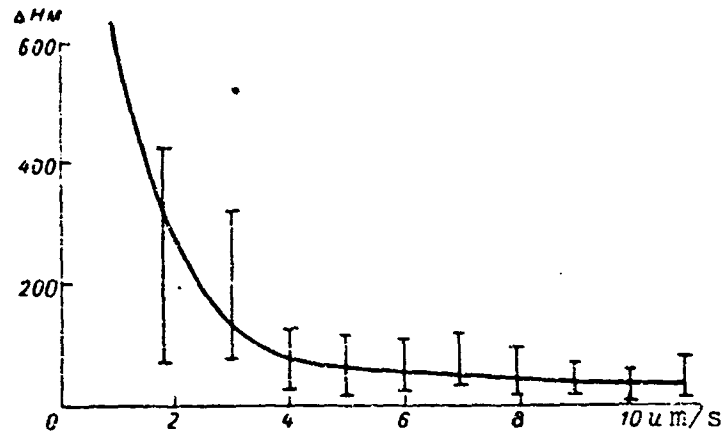

Fig. 12.

The spread of points can be explained by both oscillations of parameters of ejection and a whole series of other factors (distinctions in stratification, ..rbulent pulsations of airflow, etc.).

For calculation of quantity ΔH there was recommended the following interpolation expression:

$$\Delta H = \frac{1{,}5 w_0 R_0}{u}\left(2{,}5 + \frac{3{,}3 g R_0 \Delta T}{T_в u^2}\right). \quad (4)$$

where u – speed of wind at the height of the wind vane, w_0 – average speed of outflow of gases from the stacks, and R_0 – the radius of the stack.

Formula (4) will satisfactorily agree with the experimental data. A comparison of calculated and experimental values of ΔH on the whole material of observations showed that the divergence on the average is about 15-20 m. Somewhat larger distinctions are noted at small wind speed, but the relative error was found to be small, since quantities of ΔH are very great.

In conclusion let us note that the analysis conducted in this article of experimental researches on propagation in the atmosphere of impurities ejected from stacks of thermal electric power stations showed that the application to calculations of atmospheric diffusion of the theory expounded in [1, 12, 13] gives sufficiently good results.

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ANALYSIS OF DISPERSION OF HORIZONTAL OSCILLATIONS OF THE WIND DIRECTION

Ye. L. Genikhovich and V. P. Gracheva

There is examined the dependence of dispersion of meteorological quantities on internal and external intervals of averaging on the basis of theoretical considerations.

As a result of the analysis of experimental data absolute quantities of dispersion of wind direction and also their dependence on meteorological conditions and on the period averaging are obtained.

With the analysis of continuous recordings of meteorological measurements (such quantities, for example, as direction or speed of wind) it is necessary to examine the mean values of measured quantities for small time intervals s (although in order to exclude inertia of the instrument). The obtained values are analyzed for a certain, in general, sufficiently great period of time T. With this, obviously, from the spectrum of turbulence there will be eliminated the region of both very small and very great frequencies. The influence of such a procedure of averaging was investigated in a number of works (for example, [4-8]).

The most clear reasoning on the dispersion of wind speed is conducted by Smith [3], using the following scheme of averaging. Let us assume that V(t) is the continuously recorded wind speed. Let us calculate for it the mean value on the small interval $(t - s/2, t + s/2)$ of length s. The obtained function of the moment of time t is averaged with respect to the great interval of time $(\tau - T/2, \tau + T/2)$ by duration T, and we calculate the dispersion of the average on the interval by duration s (as a function of t) relative to the average on interval T. Th[illegible]ined dispersion is found to be the function of the moment of t[illegible], i.e., depends on the position in time of our interval T.

Averaging with respect to all τ from the interval $(-\Lambda, \Lambda)$ when $\Lambda \to \infty$ (which is equivalent in this case to the statistical averaging with respect to the ensemble), it is easy to obtain searched dependence

$$\sigma^2_{T,s} = \sigma^2_{\infty,0} \int_0^\infty F(n) \left[1 - \frac{\sin^2 \pi n T}{(\pi n T)^2}\right] \frac{\sin^2 \pi n s}{(\pi n s)^2} dn, \quad (1)$$

where F(n) is the spectral function connected with the correlation function r(t) by formula

$$r(t) = \int_0^\infty F(n) \cos \pi n t \, dn. \quad (2)$$

From (1) it is easy to obtain

$$\sigma^2_{T,s} = \sigma^2_{T,0} - \sigma^2_{s,0} + \sigma^2_{s,T}, \quad (3)$$

where there is designated

$$\sigma^2_{T,0} = \sigma^2_{\infty,0} \int_0^\infty F(n) \left[1 - \frac{\sin^2 \pi n T}{(\pi n T)^2}\right] dn. \quad (4)$$

In work Ogura [6] it is shown that

$$\frac{\sigma^2_{T,0}}{\sigma^2_{\infty,0}} = 1 - \frac{2}{T^2} \int_0^T (T - x) r(x) dx \quad (5)$$

(this formula is equivalent to the equation of Taylor in the form of Fourier). Thus it is easy to obtain the expression for the first two components in (3). But the expression for the third component in terms of the correlation function was not obtained. When $s \ll T$ the smallness of this component followed from physical considerations and was confirmed by Smith for the particular case when the spectral function was assigned by equation $nF(n) = \text{const}$.

A more thorough analysis shows that for the last component in (3) the simple expression in terms of the correlation function can be obtained. For this (1) is divided into two components, and the obtained integrals are calculated by differentiation with respect to parameter s (with the calculations it is necessary to remember that $s < T$). The final result has the following form:

$$\frac{\sigma^2_{T,s}}{\sigma^2_{\infty,0}} = \frac{2}{s^2} \int_0^s (s - x) r(x) dx - \frac{2}{T^2} \int_0^T (T - x) r(x) dx +$$
$$+ \frac{1}{3s^2T^2} \int_0^s (s - x)^3 [2r(x) - r(T + x) - r(T - x)] dx; \quad (6)$$

comparing (6) with (3) and (5), we obtain

$$\frac{\sigma^2_{s,T}}{\sigma^2_{\infty,0}} = \frac{1}{3s^2T^2}\int\limits_0^s (s-x)^3\,[2r(x) - r(T+x) - r(T-x)]\,dx. \qquad (7)$$

If one considers that

$$0 \leqslant |r(x)| \leqslant r(0) = 1, \qquad (8)$$

then it is easy to obtain the estimate

$$\frac{\sigma^2_{s,T}}{\sigma^2_{\infty,0}} \leqslant \frac{s^2}{3T^2}, \qquad (9)$$

not dependent on the form of correlation of function r(t).

If one assigns the concrete form of correlation function, then formula (6) permits obtaining the exact expression for $\sigma^2_{T,s}$, since for the majority of approximations of the correlation function of the quadrature in (6) lead to elementary functions or the simplest special functions. Thus, for example, if one assumes that

$$r(t) = e^{-\alpha|t|}, \qquad (10)$$

then it is easy to obtain

$$\frac{\sigma^2_{T,s}}{\sigma^2_{\infty,0}} = \frac{2}{\alpha^2 s^2}\left(\alpha s - 1 + e^{-\alpha s}\right) - \frac{2}{\alpha^2T^2}\left(\alpha T - 1 + e^{-\alpha T}\right) + \frac{2s}{3\alpha T^2} + \frac{4}{\alpha^4 s^2 T^2}\left(\alpha s - 1 + e^{-\alpha s}\right) - \frac{2}{\alpha^2 T^2}\left(1 - e^{-\alpha T}\right) - \frac{8e^{-\alpha T}}{\alpha^4 s^2 T^2}\,sh^2\frac{\alpha s}{2}. \qquad (11)$$

The first two terms in this formula correspond to $\sigma^2_{T,0} - \sigma^2_{s,0}$, and all the remaining components appear in $\sigma^2_{s,T}$.

With the help of formula (11) it is possible to calculate error obtained with rejecting in (3) of the last component. Results of calculations of the quantity $\delta = \dfrac{\sigma^2_{s,T}}{\sigma^2_{T,s}}$ are given in the following table:

αT	120	12	1	1
αs	18	1,8	0,1	0,01
δ%	25	7,9	7,7	2,4

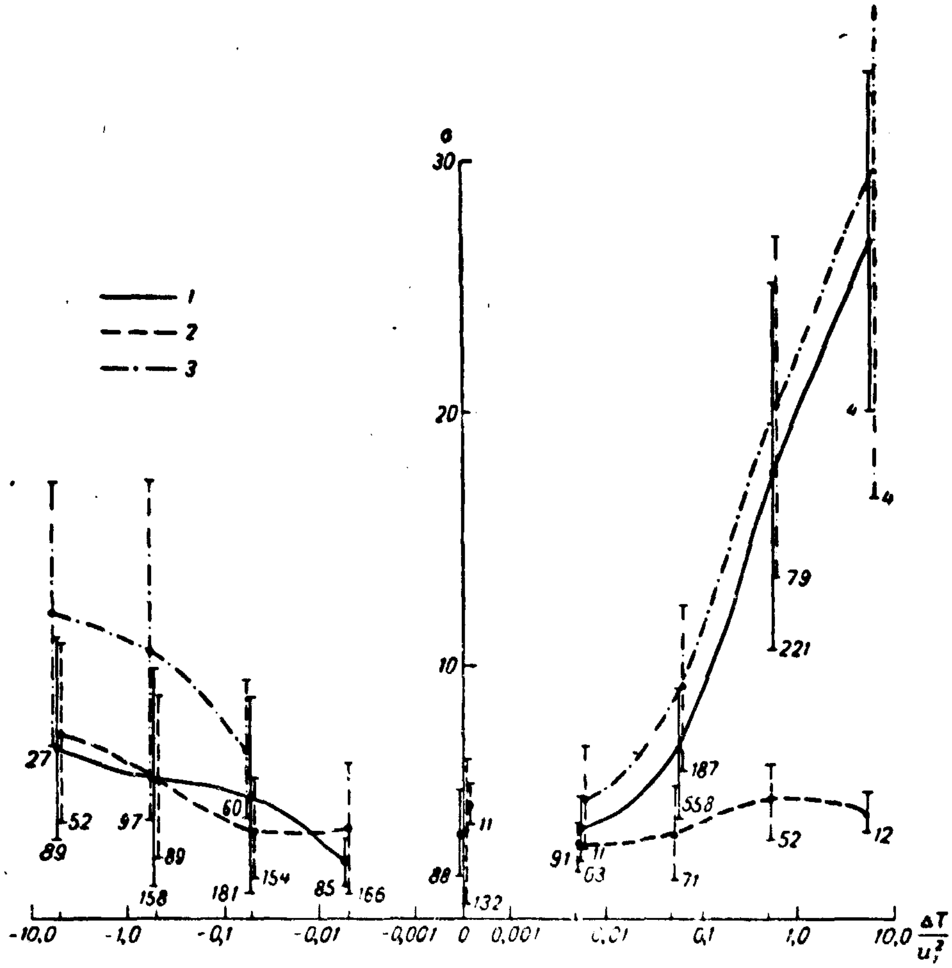

Fig. 1. Dependence of σ on stability. 1 – 20-minute period of averaging, summer data; 2 – the same, winter data; 3 – 40-minute period averaging, summer data.

As was shown in [4], formula (1), and this means and formula (6), takes place also when by σ^2 we understand dispersion not of the quantity but of wind direction.

Analysis of experimental data [2] shows, for example, for the case of great instability quantity α is approximately $0.5 \cdot 10^{-3}$ s^{-1}, which agrees well with results of [1]. From formula (11) it is easy to obtain that with such α and the selection of the internal and external intervals of averaging equal respectively to 150 and 1200 s, quantity δ does not exceed 8%. Then in (3) the last component can be disregarded, where the dependence of dispersion of the direction of wind on intervals of averaging is determined by the first two terms of (11).

Absolute quantities of dispersions of the wind direction and also their dependence on meteorological conditions can be obtained as a result of analysis of experimental data. The method of corresponding observations and analysis is discussed in [2]. In this article in the supplement to the earlier published work [2] there is examined data of observations at the Shchekino GRES[1] for March and July-August of 1963, during which there were obtained and analyzed recordings of the M-45 recorder approximately for 700 h. As before, there was determined the average direction of wind and standard deviation σ. The quantity of the internal period of averaging was 2.5 m and of external period of averaging, 20 m (200 h were analyzed also on 40-minute and hour external periods of averaging).

Dependences σ on the stability and wind speed were sought separately during the summer (July-August 1963) and winter (March 1963) periods, where in the summer data there are included also observations of August, 1962.

The obtained results confirm those earlier published in [2], somewhat definitizing them. From graph given in Fig. 1, where plotted along the axis of the abscissas in logarithmic scale is the value of parameter $\frac{\Delta T}{u_1^2}$, which characterizes the stability of the atmosphere in the lower layer and along the axis of the ordinates there is plotted the average (for the examined summer or winter period) value of σ in degrees during a 20-minute period of averaging, it is clear that with an increase in instability when $\frac{\Delta T}{u_1^2} > 0$ (decrease in temperature with height) values of σ in the summer increase from 2° to 25° and in winter almost do not change and are equal to 3-5°. During an inversion state ($\frac{\Delta T}{u_1^2} < 0$) both in winter and summer values of σ on the average change insignificantly, approximately from 6-7° to 2-3°, the summer and winter values of σ almost being equal in value, in contrast to unstable states when values of σ in summer exceed winter values several times. Figures at the vertical segments of the straight lines indicate the number of 20-minute periods used in the plotting of the graph in every defined interval of values of $\frac{\Delta T}{u_1^2}$; the quantity of the vertical segments of the straight lines characterizes the measure of scattering of separate values of σ from their mean value for the examined period (summer or winter). The scale for the measure of scattering is the same as for σ.

The dependence of values of the standard deviation on speed of the wind was examined, just as in work [2], separately for $\Delta T > 0$, $\Delta T = 0$ and $\Delta T < 0$, where ΔT is the difference in temperatures between levels 0.5 and 2.0 m.

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[1][GRES] (ГРЭС) = State Regional Electric Power Station.

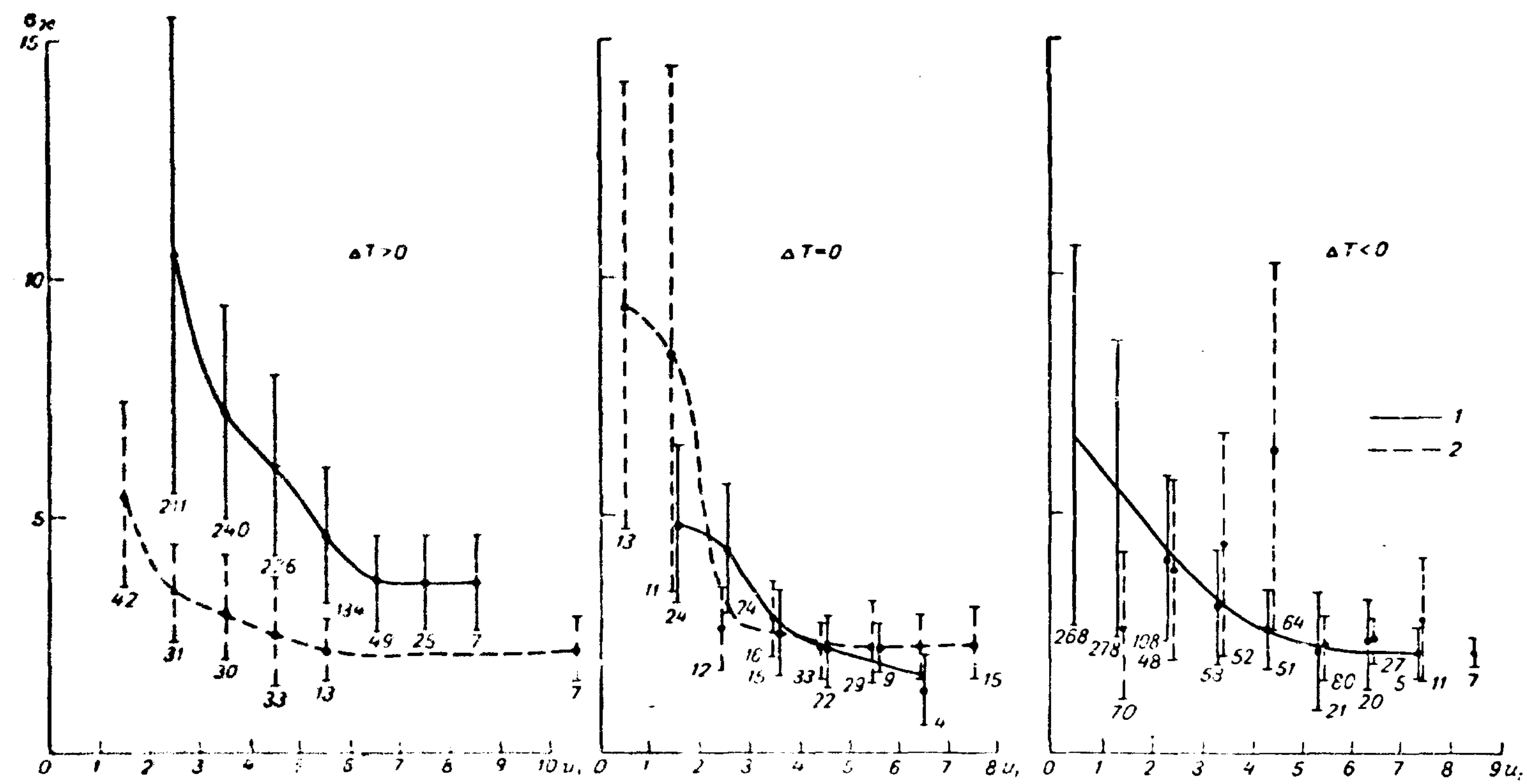

Fig. 2. Dependence of σ on wind speed. 1 – summer data; 2 – winter data.

With an increase in the wind speed approximately up to 5-6 m/s the σ values with all ΔT, take rule, decrease, except for inversion states in the winter. This can be seen from Fig. 2, where plotted along the axis of the ordinates are mean values of σ for the examined periods during a 20-minute period of averaging and along the axis of the abscissas, the wind speed at a height of 1 m.

With an increase in the wind speed above 6 m/s the values of σ both in the summer and winter periods are changed very little and equal to approximately 2°, except for unstable states in the summer when the mean values of σ reach 3.5°.

Figure 3 gives the dependence of σ values averaged for two-hour time intervals according to data of summer recordings (approximately 300 h) on the period of averaging for different conditions of stability.

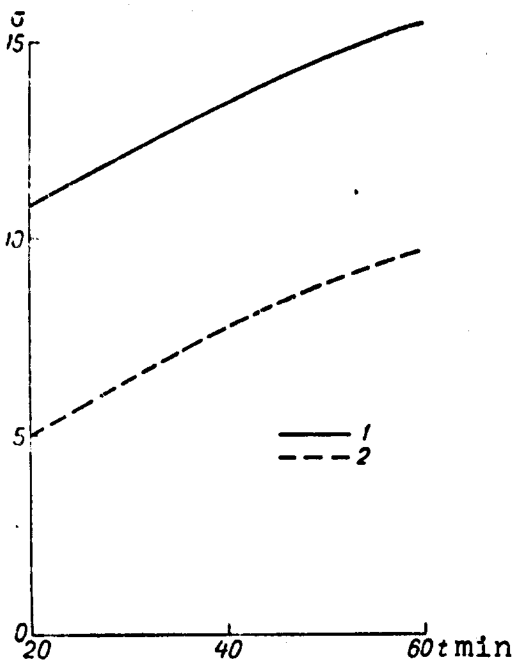

Fig. 3. Dependence of σ on the period of averaging. 1 – unstable conditions; 2 – stable.

From the represented data it follows that with a change in the external period of averaging from 20 to 40 min the values of σ increases on an average of 20% during unstable and 35% during stable states, and with a change in the period of averaging from 40 to 60 min 15 and 25% respectively, which will agree with results of the calculation by the formula (11).

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THE QUESTION OF HORIZONTAL SCATTERING OF IMPURITY IN THE ATMOSPHERE

V. S. Yeliseyev

Discussed here is the method of the determination of the coefficient of horizontal diffusion according to a visible outline of smoke from industrial smoke stacks, and results are given of the calculation and analysis of parameters characterizing horizontal diffusion according to data of aircraft observations of the smoke torch of the Shchekino GRES.[1] A comparison is made of obtained data with characteristics of horizontal diffusion by Sutton.

The question of horizontal scattering of particles in the atmosphere plays a very large role in the number of applied and theoretical problems of meteorology. It is necessary to note that the question of the vertical component of the coefficient of turbulent exchange was the subject of numerous investigations both in the Soviet Union and abroad, and the magnitude of it dependent on the wind speed, stratification of air and roughness of the underlying surface in the first approximation is well-known. It is a more complicated matter with the horizontal component of the exchange coefficient. A number of works on the horizontal diffusion of particles [6-9 and others] is well-known, in which the coefficient of horizontal diffusion is determined on the basis of meteorological parameters or data on diffusion of particles in the atmosphere. One of the natural methods of determining the horizontal exchange coefficient is the study of the behavior of smoke torches from industrial stacks, which are sensitive indicators of atmospheric turbulence.

Upon getting out of the source the smoke gets into the environment and is transferred by airstreams, coloring them,

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[1] [GRES] (ГРЭС) = State Regional Electric Power Station.

moreover, in colors visible to the human eye. The method of determination of the horizontal component of the exchange coefficient by a visible outline of smoke torch is proposed by M. Ye. Berlyand [1]. The essence of this method consists in the following. We consider the equation of turbulent diffusion characterizing the propagation of smoke torches in the atmosphere,

$$u\frac{\partial q}{\partial x}=\frac{\partial}{\partial z}k_z\frac{\partial q}{\partial z}+k_y\frac{\partial^2 q}{\partial y^2}. \tag{1}$$

Here q is the concentration of impurity, and k_z, and k_y are vertical and horizontal components of the exchange coefficient.

The initial condition with this formulation depends on the type of the examined source. Taken as boundary conditions is the absence of the flow of smoke on the surface of land and the limitedness of solution on infinity. It is assumed that changes of coefficient of horizontal diffusion with height are approximately proportional to a change with height of the wind speed, i.e., $k_y = k_0 u$.

The solution for q is then in the form

$$q=q_1(x,y)M(x,y), \tag{2}$$

where

$$M=\frac{1}{2\sqrt{\pi k_0 x}}\exp\left(-\frac{y^2}{4k_0 x}\right). \tag{3}$$

Quantity q_1 is the solution of the differential equation

$$u\frac{\partial q_1}{\partial x}=\frac{\partial}{\partial z}k_z\frac{\partial q_1}{\partial z}. \tag{4}$$

After integrating equation (4) with respect to the vertical from 0 to ∞, we will obtain the relation characterizing the condition of preservation of the impurity in the atmosphere,

$$\int_0^\infty uq_1\,dz=Q. \tag{5}$$

From (2), (3), (5) with the taking out of the mean value of wind speed $\bar{u}$ beyond the integral sign it follows

$$\int_0^\infty q\,dz=\frac{QM}{\bar{u}}=V_*, \tag{6}$$

where V_* is the weight of the smoke in the column of unit section.

When $V_* > N$, where N is the defined number, the cloud is not examined; when $V_* < N$ the cloud is transparent. Equality $V_* = N$ determines the visible contour of the smoke stream.

Observing the smoke torch from above or from below, considering with this (3) and (6), one can determine parameter k_0 characterizing the horizontal scattering of the particles. The obtained results pertain to comparatively short distances from the source. As was shown in works [3, 4], as a result of the instability of the average direction of the wind, distribution of concentration depends on the utilized period of the intake of samples.

In the period of observation $T > \tau$ the probability of recurrence of the wind direction, averaged on period τ, is described by the normal Gauss law

$$\omega(\varphi) = \frac{1}{\varphi_0 \sqrt{2\pi}} \exp\left(-\frac{\varphi_0^2}{2\varphi_0^2}\right), \quad (7)$$

where ϕ_0 is the average dispersion during the time T.

In this case the mean value of concentration can be obtained from the solution of the equation of turbulent diffusion, if in it we replace parameter k_0 by some effective coefficient $\tilde{k}_0 = k_0 + \frac{x\phi_0^2}{2}$. At great distances from the source

$$\tilde{k}_0 = \frac{x\phi_0^2}{2}. \quad (8)$$

Quantity ϕ_0 can be determined on the basis of analysis of pulsations of the wind vector, as was done in work [5].

At the same time it is possible to offer another independent method of determination of parameter ϕ_0. In particular, by replacing in (3) k_0 by $\tilde{k}_0$, according to (8), and by knowing that equality $V_* = N$ determines the visible contour of the smoke cloud, it is possible to write approximately

$$\frac{Q}{2\bar{u}\sqrt{\frac{\pi x^2\varphi_0^2}{2}}} \exp\left(-\frac{y^2}{2x^2\varphi_0^2}\right) = N. \quad (9)$$

When y = 0, x = L, satisfying equation (9), this presents the total visible length of the torch.

Then

$$\frac{Q}{2\bar{u}\sqrt{\frac{\pi x L \varphi_0^2}{2}}} = N. \qquad (10)$$

Equating (9) to (10) and replacing 2y = d (where d is the width of the smoke stream at a fixed distance from the source), we obtain

$$\varphi_0 = \frac{d}{2x\sqrt{\ln\frac{L}{x}}}, \qquad (11)$$

where d – the width of the torch at the fixed distance, x – distance from the source, L – length of visible contour of the cloud.

Since the parameter ϕ_0 practically depends little on distance, then for the calculation of it it is possible to propose another formula excluding the visible end of the torch.

Determining the width of the torch at two different distances from the source, we will obtain the appropriate formulas:

$$\varphi_0^2 = \frac{d_1^2}{4x_1^2 \ln\frac{L}{x_1}};$$

$$\varphi_0^2 = \frac{d_2^2}{4x_2^2 \ln\frac{L}{x_2}},$$

whence, excluding L, we obtain

$$\varphi_0 = \frac{d_1}{2x_1\sqrt{\frac{d_1^2 x_2^2 \ln\frac{x_2}{x_1}}{d_1^2 x_2^2 - d_2^2 x_1^2}}}. \qquad (12)$$

Thus we can determine ϕ_0 by the width of the torch at two distances from the source. During 1962-1963 in the region of the Shchekino GRES there were conducted combined researches in the pollution of atmospheric air. In these investigations, with the help of aircraft there were determined geometric parameters of the smoke stream at fixed distances from the source. Flights along the horizontal were conducted up to a distance where the visible end of the torch was finished, and it was considered that beyond the visible border of the smoke stream the concentration of impurity is practically absent. A diagram of the flight in the horizontal plane is shown on Fig. 1. There were conducted a total of

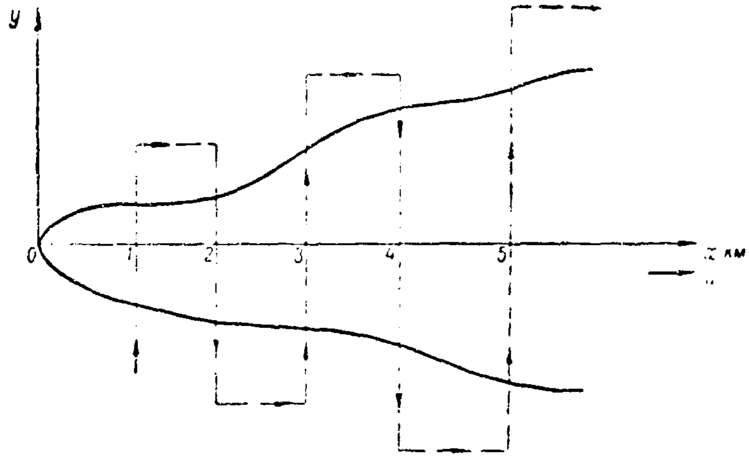

Fig. 1. Diagram of the flight of an aircraft through a smoke torch in a horizontal plane.

20 flights. From an analysis of data we obtained that the parameter ϕ_0 on an average varies from 0.1 to 0.2 (depending upon annual conditions), but the absolute magnitude of it does not change with distance up to 30-40 km from the source.

In Tables 1 and 2 data on geometric parameters of a smoke torch on separate days are reduced.

Table 1. 31 August 1962, L = 17.5 km

x км	d м	φ_0	x км	d м	φ_0
1	[illegible]	[illegible]	7	[illegible]	0,10
2	660	0,11	8	[illegible]	0,11
3	1010	0,12	9	[illegible]	0,09
4	1120	0,10	10	1610	0,11
5	1530	[illegible]	15	[illegible]	0,17
6	1450	0,11			

Table 2. 5 September 1962, L = 42.5 km

x км	d м	φ_0	x км	d м	φ_0
5	1990	[illegible]	25	3990	0,11
10	3330	[illegible]	30	4220	0,11
15	2660	0,09	35	3990	0,13
20	3990	0,11			

The approximately obtained characteristics of ϕ_0 can be compared with data obtained on the basis of the theory of Sutton [7].

According to this theory, ratio I of ground concentration at point (x, y) to the value concentration of impurity at point (x, 0) is determined by the formula

$$\frac{\bar{q}\,(x,\,y)}{\bar{q}\,(x,\,0)} = \exp\left(-\frac{y^2}{c_y^2 x^{2-n}}\right), \qquad (13)$$

where n - parameter of stability of the atmosphere, and c_y - virtual coefficient of horizontal diffusion. Value c_y is connected with σ_y - variance of distribution of concentration across the wind direction in a horizontal direction y - in the following way:

$$c_y = \sqrt{2}\,\frac{\sigma_y}{x^{\frac{2-n}{2}}}. \qquad (14)$$

From the theoretical scheme (3), examined in accordance with the replacement of k_0 by $\tilde{k}_0$ with calculation of the instability of the wind direction it is possible to write approximately

$$\frac{\bar{q}\,(x,\,y)}{\bar{q}\,(x,\,0)} = \exp\left(-\frac{y^2}{2\varphi_0^2 x^2}\right). \qquad (15)$$

Then by comparing formulas (13) and (15), we will obtain the approximate relation

$$\varphi_0 \simeq \frac{c_y}{\sqrt{2x^n}}. \qquad (16)$$

The given transition from c_y to ϕ_0 has meaning to use in connection with the fact that in literature there is comparatively much data on quantity c_y and its connection with weather conditions.

Recalculation of ϕ_0 according to work [10] showed that ϕ_0 does not change with distance from the source up to 16 km, and equals approximately 0.1 (when $\bar{n}$ = 0.23).

Using values of σ_y, given in works [11, 12], it is possible to show that in the medium ϕ_0 = 0.1, up to 25 km from the source.

Further investigations should be connected with taking into account the nature of the horizontal diffusion of particles depending upon meteorological conditions.

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