SEQUENTIAL VENTILATION OF A SERIES OF CHAMBERS WHEN AN ADMIXTURE IS MOMENTARILY EXUDING FROM THE POCKET ENDS

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A one-dimensional problem is formulated concerning turbulent diffusion during a momentary exudation of admixture from the pocket ends of n sequentially ventilated chambers. An expression is obtained for the admixture concentration at the exit from the n-th chamber. The results are compared with experimental data.

The analyzed ventilation system is shown in Fig. 1.

Explosion ocuurs simultaneously in the stopes of n chambers. If the boundary of the zone where the explosion products are spattered coincides with the end of an air duct from a fan, then the distribution of admixture concentration in that plane is described by the relation in [1, 3]:

$$c/c_{01} = \exp\left(-R_1' t\right). \tag{1}$$

In the remaining space of a chamber the concentration is described by the equation of turbulent diffusion:

$$\frac{\partial c}{\partial t} + \mathrm{div}\left(\vec{v}c\right) = D\Delta c. \tag{2}$$

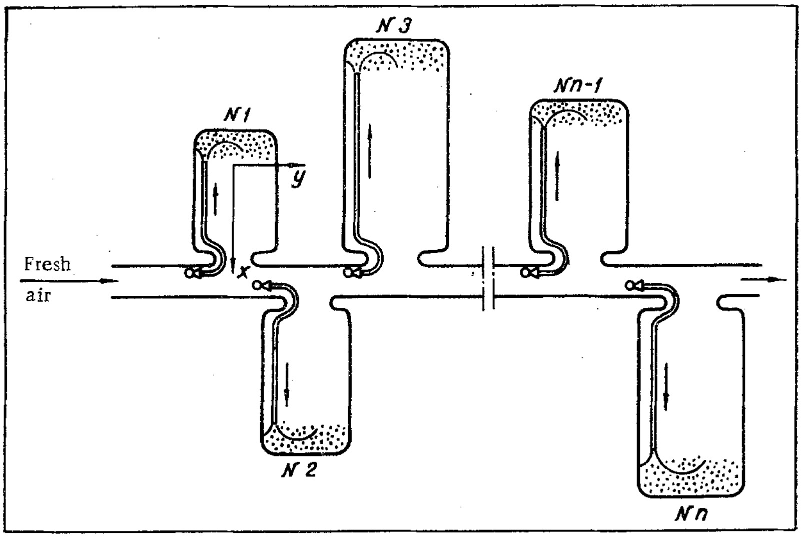

Fig. 1. Schematic diagram of a sequential ventilation of a series of chambers when an admixture is momentarily exuding from the pocket ends.

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TABLE 1. Comparison of Calculated Values for c_1, c_2, and c_3, with Experimental Data, c = 0.008%

Length of chamber $l_{1,2,3}$	Volume of chamber $V_{1,2,3}$	Fan capacity g_1	g_2	g_3	Ventilation time* t_1	t_2	t_3	Initial concentration $c_{0\,1,2,3}$	Volume of the spatter zone V_{SZ}	Concentration of gas emerging from chamber c_1	c_2	c_3	Mean-squared error δ_1	δ_2	δ_3
		2,50	2,50	2,50	2340	3000	3400	0,083	1290	0,0086	0,0095	0,0077			
		2,50	2,50	2,50	2450	3570	4310	0,094	1580	0,0091	0,0087	0,0077			
100	6400	2,50	3,75	6,25	2930	4860	4880	0,104	2040	0,0108	0,0087	0,0093	0,11	0,35	0,09
		2,50	4,00	7,00	3140	3300	3400	0,114	2880	0,0110	0,0108	0,0073			
		2,50	3,75	6,25	2440	2360	2330	0,094	1580	0,0078	0,0078	0,0082			
150	9600	2,50	3,75	6,25	3000	3060	3370	0,104	2040	0,0078	0,0078	0,0082	0,07	0,09	0,06
		2,50	4,00	7,00	4980	5160	5100	0,114	2880	0,0090	0,0074	0,0078			

* Time of ventilating is counted till the concentration at the exit from each chamber is equal to c = 0.008%.

Toward each following chamber (except to the first one) is moving an already partially contaminated jet with an admixture concentration

$$c_n' = \frac{g_{n-1}}{G_0} c_{n-1} + \frac{(G_0 - g_{n-1}) g_{n-2} c_{n-2}}{G_0^2} + \ldots$$

$$\ldots + \frac{(G_0 - g_{n-1}) \cdots (G_0 - g_2) g_1 c_1}{G_0^{n-1}}. \quad (3)$$

The problem of determining the relative admixture concentration at the exit from the n-th chamber at any instant of time is in the one-dimensional case

$$\frac{\partial c}{\partial t} + v \frac{\partial c}{\partial x} = D \frac{\partial^2 c}{\partial x^2}, \quad (4)$$

$$\left.\frac{\partial c}{\partial x}\right|_{x=L_n} = 0, \quad c(0, t) = f_n(t), \quad c(x, 0) = 0. \quad (5)$$

Function $f_n(t)$ is [3]:

$$f_n(t) = \left[\int R_n' c_n' \exp(R_n' t)\, dt + \mu\right] \exp(R_n' t). \quad (6)$$

The value of μ is found from the condition $f_n(0) = c_{0n}$.

In dimensionless form, with the substitution

$$u(x, \tau) = c(x, \tau) \exp(P_n \tau - 2P_n x) \quad (7)$$

our problem reduces to the problem of heat conduction with the combined boundary conditions

$$\frac{\partial u}{\partial \tau} = \frac{1}{4P_n} \cdot \frac{\partial^2 u}{\partial x^2}, \quad P_n = \frac{1}{4}\mathrm{Pe}_n, \quad (8)$$

$$\frac{\partial u}{\partial x} + 2P_n u\Big|_{x=1} = 0,$$

$$u(0, \tau) = c(0, \tau) \exp(P_n \tau) = f_n(\tau) \exp(P_n \tau), \quad (9)$$

$$u(x, 0) = 0.$$

With the substitution $w(x, \tau) = u(x, \tau) - j - j_1 x$, where $j = f_n(\tau)$ and $j_1 = -2P_n/(1 + 2P_n) f_n(\tau)$, we have

$$\frac{\partial w}{\partial \tau} - \frac{1}{4P_n} \cdot \frac{\partial^2 w}{\partial x^2} = -\frac{df_n(\tau)}{d\tau}\left(1 - \frac{2P_n x}{1 + 2P_n}\right), \quad (10)$$

$$\frac{\partial w}{\partial x} + 2P_n w\Big|_{x=1} = 0,$$

$$w(0, \tau) = 0,$$

$$w(x, 0) = -\left(1 - \frac{2P_n x}{1 + 2P_n}\right). \quad (11)$$

The problem was solved by the method of separating the variables [2] and in the original notation at x = 1 (at the exit from the n-th chamber) the solution is

$$c_n(\tau) = \left\{\frac{f_n(\tau)}{1 + 2P_n} - \sum_{N=1}^{\infty}\left[f(\lambda_N) \exp\left(-\frac{\lambda_N \tau}{4P_n}\right) \times \int \exp\left(\frac{\lambda_N \tau}{4P_n}\right) \frac{df_n(\tau)}{d\tau}\, d\tau + a_N \exp\left(-\frac{\lambda_N \tau}{4P_n}\right)\right] \sin\sqrt{\lambda_N}\right\} \exp(2P_n). \quad (12)$$

The eigenvalues are found from the condition $\sqrt{\lambda_N} = -\sqrt{\lambda_N}/2P_n$.

The obtained solution was checked on a hydraulic model consisting of three sequentially ventilated chambers [4]. Dimensional similitude was established on the basis of the Schmidt number.

Calculations performed for the model have shown that the series in expression (12) is a fast converging one and the error of cutting it off is insignificant (less than 10%).

Allowing for such an error, one can obtain an expression for calculating the admixture concentration at the exit from the first, the second, and the third chamber – all ventilated in sequence:

$$c_1(\tau)=\frac{\exp(2P_1-R_1\tau)}{1+2P_1}, \tag{13}$$

$$c_2(\tau)=\frac{\exp(2P_2-R_2\tau)}{1+2P_2}\left\{\frac{g_1}{G_0}\cdot\frac{\exp 2P_1}{(1+2P_1)\left(1-\frac{R_1}{R_2}\right)}\left[\exp(R_2-R_1)\tau-1\right]+1\right\}, \tag{14}$$

$$c_3(\tau)=\frac{\exp 2P_3}{1+2P_3}\left\{\frac{A\left[\exp(-R_1\tau)-\exp(-R_3\tau)\right]}{1-\frac{R_1}{R_3}}-\frac{A\left[\exp(-R_2\tau)-\exp(-R_3\tau)\right]}{1-\frac{R_2}{R_3}}+\frac{B\left[\exp(-R_2\tau)-\exp(-R_3\tau)\right]}{1-\frac{R_2}{R_3}}+\frac{c\left[\exp(-R_1\tau)-\exp(-R_3\tau)\right]}{1-\frac{R_1}{R_3}}+\exp(-R_3\tau)\right\}, \tag{15}$$

where

$$A=\frac{g_2}{G_0}\cdot\frac{\exp 2P_2}{1+2P_2}\cdot\frac{g_1}{G_0}\cdot\frac{\exp 2P_1}{(1+2P_1)\left(1-\frac{R_1}{R_2}\right)},$$

$$B=\frac{g_2}{G_0}\cdot\frac{\exp 2P_2}{1+2P_2},$$

$$c=\frac{(G_0-g_2)\,g_1\exp 2P_1}{G_0(1+2P_1)}.$$

The results of this simulation, recalculated for a natural system, and a comparison with calculated data are given in Table 1.

The comparison shows that the proposed method of calculation yields satisfactory results in most cases and that, moreover, the accuracy of calculations increases as the chambers become longer.

NOTATION

c is the gas concentration, %;
c_{0n} is the initial concentration of the gas produced as a result of an explosion in the blasting zone of the n-th chamber, %;
v_n is the air velocity in the n-th chamber, m/sec;
D is the turbulent diffusivity, m^2/sec;
c'_n is the gas concentration at the entrance to the n-th chamber, %;
c_n is the gas concentration at the exit from the n-th chamber; %;
g_n is the fan capacity, established in the n-th chamber, m^3/sec;
L_n is the distance from the outlet of the air duct to the outlet of the n-th chamber, m;
V_n is the volume of the spatter zone in the n-th chamber, m^3;
k is the free-jet efficiency;
Pe_n is the Peclet number for n-th chamber.

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