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THEORETICAL BASIS OF DEFINING THE USABILITY OF DEVICES FOR AIR INTOXICATION

A theoretical, comparative analysis for the efficiency of two different instruments collecting dust, depending on wind speed and dust grain diameters, was made. The analysis of the directional dust sampler's usability consisted in an outlay estimation of its cross-section depending on the angle upon which the dust particles fall. For angles smaller than 45° the dust sampler's efficiency is high, being higher than for Weck's jars. A parallel exposition of the directional dust sampler and Weck's jar is purposeful. Knowing the average wind velocity it is possible to estimate, on the basis of a nomogram, which of the instruments gives more authoritative results in given conditions.

1. INTRODUCTION

Collecting representative samples is an essential problem for the estimation of environment pollution. In order to find an adequate device for sampling of dustfall, a theoretical comparative analysis of some devices is presented.

2. METHODS

The usability of a directional dust sampler is defined by the size of its cross-section depending on the angle upon which the dust particles fall.

It has been assumed:

1. Flux of falling particles is homogeneous, i.e., surface density of pollutants is constant for every cross-section of the above-mentioned flux. By surface density we mean the quantity of the dust falling on the surface unit of a given cross-section which is determined by the flux of dust particles.

2. The particles have the same diameters.

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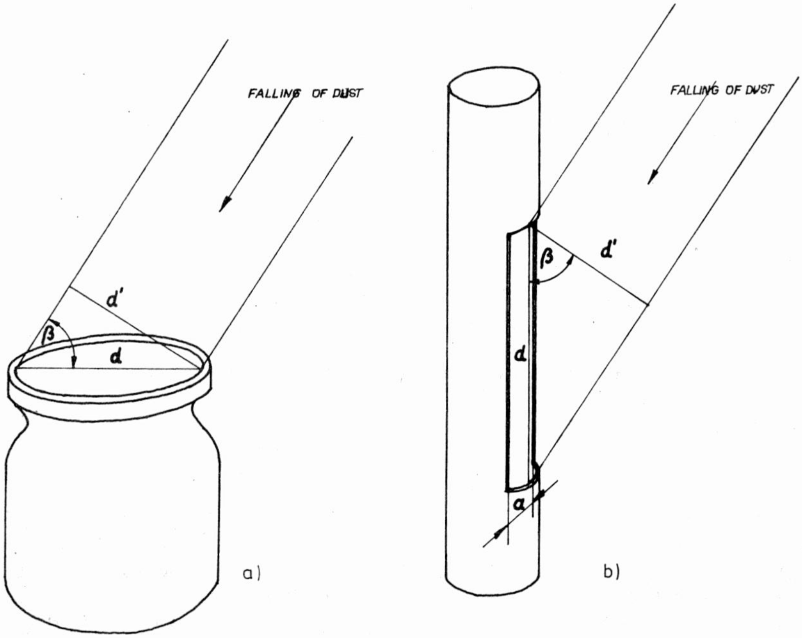

Fig. 1. Dust collecting by means of Weck's jar (a) and directional dust sampler (b)

In the case of Weck's jar (fig. 1) the surface density of the flux of falling dust is equivalent to that of the dust which precipitates on the jar bottom if the direction of dust fall is perpendicular to the ground surface. Density in question is proportional to the surface of the jar $s = \pi(d^2/4)$, d being the diameter of the jar.

When the flux of particles falls on the ground surface at the angle β, the value of measurement in Weck's jar is underrated. The value of surface density of the particles precipitating on the jar bottom is lower than that in the intersection of the flux. Moreover, surface density of particles precipitating on the jar bottom is proportional to surface density of the flux of dust. The factor of proportionality is equal to the quotient of surface of ellipsis s' and jar surface s

$$s' = \pi \frac{d \cdot d'}{4}$$

where $d' = d \cdot \sin\beta$. The device efficiency, i.e., a quotient of density of dust precipitating on the jar bottom ϱ and density of falling dust ϱ', can be defined as

$$\frac{\varrho}{\varrho'} = \frac{s'}{s} = \frac{\pi \cdot \frac{d^2}{4} \cdot \sin\beta}{\pi \cdot \frac{d^2}{4}} = \sin\beta .$$

Proportion ϱ/ϱ' is regarded as efficiency of the device, the measure of which is the value of $\sin\beta$.

The directional dust sampler has a rectangular inlet perpendicular to the ground (fig. 1). Therefore its maximal collecting efficiency is achieved when the flux of particles is horizontal to the ground. In that case surface density in the flux is equal to the surface density of dust settled. That density is inversely proportional to the intersection of the inlet s

$$s = a \cdot d$$

where a and d are dimensions of the inlet.

If the angle $\beta > 0$, the cross-section of the flux reaching the inlet is smaller because the area of the inlet surface is diminished:

$$s' = a \cdot d,$$

$$d' = d \cdot \cos\beta.$$

Similarly, a quotient is

$$\frac{\varrho}{\varrho'} = \frac{s'}{s} = E_p = \frac{a \cdot d \cdot \cos\beta}{a \cdot d} = \cos\beta,$$

$$E_p = \cos\beta.$$

The comparison of Weck's jar with a directional dust sampler shows that when $\beta = 45°$, both devices work with the same efficiency of 70.7%. When $\beta < 45°$, then dust sampler efficiency is high, being greater than that of Weck's jar.

The characteristics of particle falling implies that:

settling rate of dust particles coming from a great height resolves into horizontal and vertical constituents which are equal to the wind velocity and settling rate, respectively,

grain strikes the horizontal cross-section at the angle β approximately equal

$$\tan\beta = \frac{\text{settling rate}}{\text{wind velocity}}.$$

According to Bagnold [1], in the case of secondary dusting this angle ranges within 10°–16° which can be justified as follows: Initial ascending velocity is low, hence the height attainable by the dust is low. In such a case the dust reaches a horizontal velocity lower than a half of wind velocity. Simultaneously there is no time for the dust to reach the final settling rate. Physics of dust allow us to estimate the settling rate of particles which have various diameters. A particle moves in air with uniformly accelerated motion till the moment of balancing gravity forces. Afterwards the particle falls with the constant rate.

To determine the settling rate of particles of aerodynamic diameters (1–100 μm), Stokes's law can be applied:

$$V = \frac{g \cdot d^2 (\varrho_1 - \varrho_2)}{18 \eta}$$

where:

V – final settling rate, $m \cdot s^{-1}$,
g – acceleration of gravity, $m \cdot s^{-2}$,
d – diameter of a particle, m,
ϱ_1 – density of a particle, $kg \cdot m^{-3}$,
ϱ_2 – density of the air, $kg \cdot m^{-3}$,
η – viscosity of air, $kg \cdot m^{-1} \cdot s^{-1}$.

Particles of diameters exceeding 100 μm interact, forming an aerodynamic tail, which withstands the air. On the other hand, particles of diameters smaller than 1 μm may slide between air molecules and fall quicker than it may be expected when Stokes's law is taken into account. Settling rate of dust in the air of the density of 1 $mg \cdot cm^{-3}$ at pressure 1 atm and in temperature 273 K given by CUNNINGHAM [2] is presented in tab. 1.

Table 1

Falling velocity of dust particles of different diameters

Aerodynamic diameters of dust particles μm	Falling velocity of dust particles $cm \cdot s^{-1}$
0.1	8×10^{-5}
1.0	4×10^{-3}
10.0	0.3
100.0	25.0
1000.0	390.0

Summing up, it may be stated that if the settling rate of dust consisting of particles of various diameters is known, it is possible to calculate the angle of dust falling, and thus the efficiency factor of dust sampler which is essential for the problem discussed.

The value of the angle versus the grain diameter is presented in tab. 2. When settlement rate is equal to 0.2 $m \cdot s^{-1}$, 0.5 $m \cdot s^{-1}$, then $\beta < 1°$ for the diameters below 10 μm inclusively, i.e., particles of diameters > 10 μm are suspended in the air. Only particles of diameters at least 100 μm are of practical importance for the analysis. Therefore the calculations were made for the dust of 100 μm diameter (fig. 2).

For the dusts of 100 μm diameters, Weck's jar is not a satisfactory dust sampler

Table 2

Values of falling angles of dust particles of different diameters at wind velocity of 0.2 and 0.5 $m \cdot s^{-1}$

Diameter of grain µm	Angle β	
	Velocity of wind 0.2 $m \cdot s^{-1}$	Velocity of wind 0.5 $m \cdot s^{-1}$
0.1	2×10^{-4}	9.2×10^{-5}
1.0	1.1×10^{-2}	4.58×10^{-3}
10.0	0.859	0.344
100.0	52.34	26.56
1000.0	87.06	82.69

because at the wind velocity of 0.5 $m \cdot s^{-1}$ its efficiency is lower than 50%. Directional dust sampler proves to have a very good efficiency, as for the same wind velocity its 70% efficiency is comparable with that of Weck's jar. Efficiency factor of directional dust sampler increases quickly and at wind velocity of 1 $m \cdot s^{-1}$ it is higher than 95%.

Table 3

Change of falling angle depending on the wind velocity and diameters of dusts

Diameters of dust particles µm	Falling velocity of particles $m \cdot s^{-1}$	Angle β at wind velocity of 2 $m \cdot s^{-1}$	Angle β at wind velocity of 10 $m \cdot s^{-1}$
20	0.08	2.3^0	0.5^0
200	1.60	38.7^0	9.1^0
450	3.93	63.0^0	11.1^0

The situation is somewhat different for dusts of 1000 µm diameters. It can be seen that when the wind velocity ranges within 0 – 3.8 $m \cdot s^{-1}$, escapement efficiency of the grains of 1 mm diameters is higher for Weck's jar than for a directional dust sampler which gives reasonable results when wind velocity is higher than 4 $m \cdot s^{-1}$.

Assuming dust density ($\varrho_p = 32\,000$ $kg \cdot m^{-3}$), air density ($\varrho_0 = 1.166$ $kg \cdot m^{-3}$ at temperature 293 K) and dynamic air viscosity ($\mu_0 = 185.5 \times 10^{-7}$ $N \cdot s \cdot m^{-2}$ at temperature 293 K), it is possible to obtain the respective values of angle of falling for the wind velocity of 2 and 10 $m \cdot s^{-1}$ and the dusts of various diameters.

The values presented in tab. 3 illustrate the efficiencies of compared measuring instruments. Falling velocity was calculated on the basis of JUDA's nomograms [3].

Comparison of the data included in tabs. 2 and 3 and, first of all, diagrams in fig. 2 shows that the adopted stricter criteria (small wind velocity and diameters of

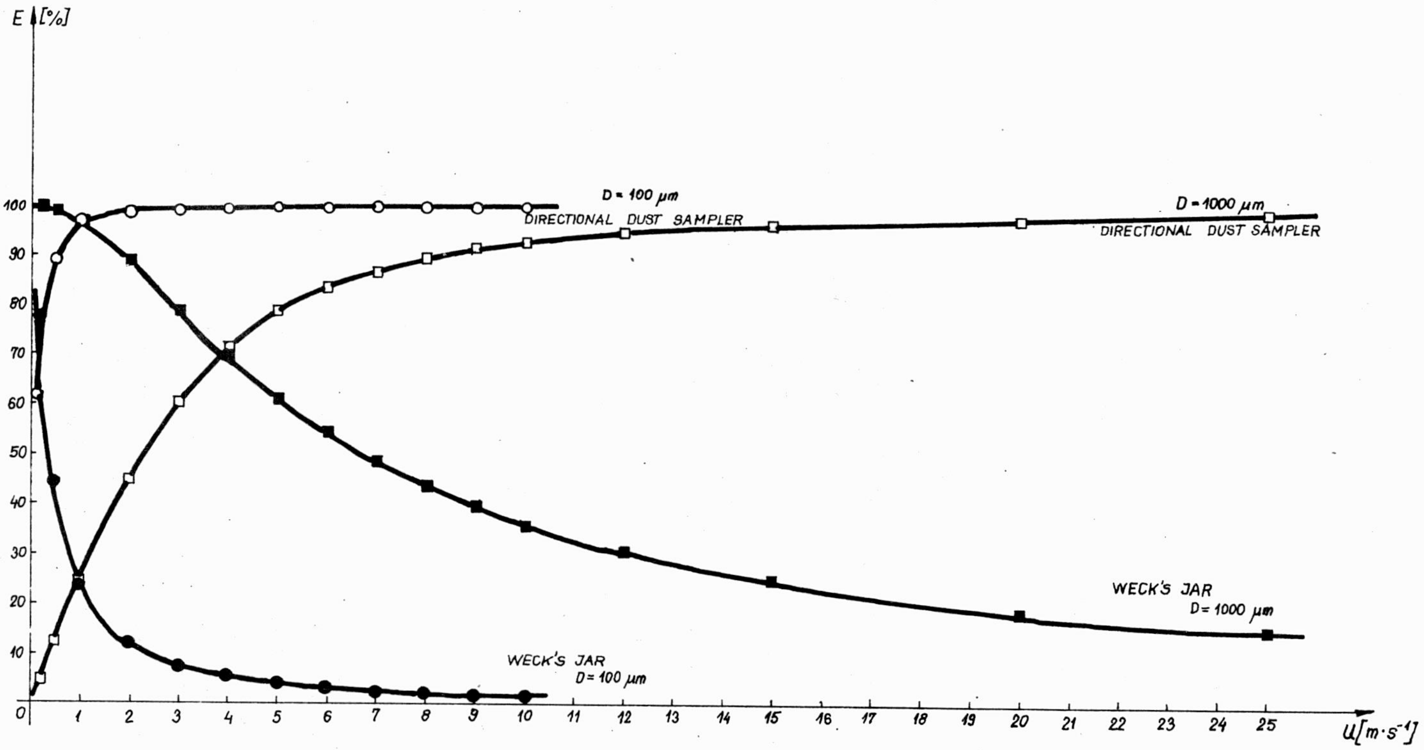

Fig. 2. Dust collecting efficiencies by directional dust sampler and Weck's jar, depending on wind velocity

grains) are also suitable when estimating the efficiency of dust samplers presented.

It should be remarked that for the small dust diameters (> 100 μm) Bagnold's model gives higher values of falling velocity than that of Juda, e.g., for particles of 10 μm diameters, 8 and 30 $cm \cdot s^{-1}$, according to Juda and Bagnold, respectively.

3. CONCLUSIONS

1. Both changes of wind velocity in time of exposition and typical fractional composition of dust on the given area should be known when correctness of directional dust sampler's indications is established.

2. Parallel exposition of a directional dust sampler and Weck's jar is advisable. If average wind velocity is known, it is possible to state (on the basis of nomogram 2) which of the dust samplers is the best in given conditions.

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TEORETYCZNE PODSTAWY OKREŚLANIA PRZYDATNOŚCI URZĄDZEŃ DO POBORU OPADAJĄCYCH PYŁÓW

Zmierzono efektywność zbierania pyłu przez pyłomierz kierunkowy i słój Wecka przy różnych prędkościach wiatru i różnych wielkościach cząstek pyłu. Ocena przydatności pyłomierza kierunkowego polegała na określeniu jego czynnego przekroju w zależności od kąta padania cząsteczek pyłów. Jeżeli kąt ten jest mniejszy od 45°, efektywność pyłomierza jest duża i większa od efektywności słoi Wecka. Celowa jest jednoczesna ekspozycja pyłomierza kierunkowego i słoja Wecka. Znając średnią prędkość wiatru można ustalić na podstawie nomogramu, który z przyrządów daje w określonych warunkach miarodajniejsze wyniki.

ТЕОРЕТИЧЕСКИЕ ОСНОВЫ ОПРЕДЕЛЕНИЯ ПРИГОДНОСТИ УСТРОЙСТВ ДЛЯ СОБИРАНИЯ ПЫЛЕЙ

Измерена эффективность собирания пыли направленным кониметром или банкой Векка при разных скоростях ветра и разных габаритах частиц пыли. Оценка пригодности направленного кониметра заключается в определении его действующего сечения в зависимости от угла падания частиц пылей. Если этот угол меньше 45°, эффективность кониметра большая и больше эффективности банок Векка. Целенаправленна одновременная экспозиция направленного кониметра и банки Векка. Зная среднюю скорость ветра можно установить на основе номограммы, который из приборов даёт в определённых условиях лучшие результаты.