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THEORY OF WORK OF THE IBK-1 AEROSOL CHAMBER FOR THE STUDY OF EXPERIMENTAL RESPIRATORY INFECTIONS—II. EVALUATION OF AEROSOL FROM CERTAIN PHYSICAL PARAMETERS*

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In the preceding paper we considered in detail the dynamics of the work of the IBK-1 chamber. The aim of the present paper is to define the weight of virus-containing suspension atomized in the chamber and the amount of the aerosol which passes into the respiratory system of various animals. In addition, we shall ascertain the stability of the aerosol obtained by us from physical parameters since it is perfectly clear that aerosols must be assessed not only biologically but also from the physical laws on their behaviour.

Knowledge of the main physical parameters is necessary for a fuller understanding of the conditions in which the animals become infected and to enable one to produce them and control them correctly.

In work with aerosols of various bacteria and viruses it is best to have a finely dispersed system. The two necessary conditions are selection of a suitable atomizer system and use of the properties of the aerosol itself, the dispersion of which is constantly raised through settling of the large particles. However, the second factor is not decisive since if the aerosol consists of an overwhelming number of large particles, then the concentration of the aerosol falls sharply on settling. Therefore, it is more desirable to select an atomizer expelling the bulk of the suspension in the form of small droplets.

To check on the atomizer we used the method of direct count of size and number of drops in the aerosol cloud with a micrometer inserted in the ocular of a microscope. The aerosol drops were picked up by special plexiglass cuvettes. The size of the cuvette corresponded to that of the slide. A 0·1 cm layer of neutral vaseline oil was applied to the surface of the cuvette. At various times after the start of atomization the cuvettes were placed for 3 min 3–4 cm distant from the nozzle of the atomizer. Following many investigations an atomizer was chosen giving the following distribution of aerosol particles (see Table 1).

The atomizer selected gave during the experiment an average of 0·11 g of virus suspension per min.

* Vopr. virusol. 6: No. 4, 458–462, 1961.

TABLE 1. SIZE DISTRIBUTION OF AEROSOL PARTICLES WITH TIME

Time from start of atomization, in minutes	Percentage of particles of diameter		
	to 1	1–2	here then 2
2	37	36	27
5	46	31	23
8	60	31	9

As Table 1 shows, within only 8 min of atomization 60 per cent of the aerosol particles were no bigger than 1 μ and only 9 per cent of the particles larger than 2 μ. The largest observed by us was 15 μ. Consequently, the aerosol is finely dispersed and the particle size sufficiently homogeneous.

In choosing the effective size of the droplets of the aerosol an important factor is the part of the animal respiratory system on which the aerosol is to act. The following data are available on the settling of an aerosol with particles of variable size in different parts of the animal respiratory system. In experiments on rabbits (4) it was found that on inhalation of aerosol with a particle radius of 0·5 μ 29 per cent of the particles settled in the nasopharynx, 13–19 per cent in the trachea and 51–58 per cent in the alveoli; with a radius of 2 μ 65 per cent in the nasopharynx and 98 per cent with a radius of 4 μ. Experiments on mice (6) showed the following particle distribution between the bronchi, broncheoli and alveoli: with a radius of 0·2–0·62 μ, 26, 32 and 42 per cent respectively; with a radius of 1·05–1·46 μ, 35, 37 and 38 per cent, and with a radius of 1·46–1·88 μ, 48, 37 and 15 per cent. Thus, the smaller the inhaled particles of virus-containing suspension, the deeper their location in the affected respiratory system.

From Table 1 and published findings (4, 6) it follows that about 80–90 per cent of the particles of the aerosol atomized by us will settle in the lower respiratory tract of the animal.

We can determine from the equation $x = fV/L$ the equilibrium amount of aerosol in the chamber (maximum value). Substituting the parameters of the IBK-1 chamber gives

$$x = \frac{0{\cdot}11 \text{ g/min} \times 1001.}{42 \text{ l./min}} = 0{\cdot}24 \text{ g}, \qquad (1)$$

or 0·0024 g per l. or 0·0000024 g per ml. The estimates given refer to calculations for the aerosol adopted by us consisting of uniform droplets of a certain mean radius.

We shall assume all droplets to have radius of 10^{-4} cm (this is the worst variant since in fact the mean radius is about one-half of this and the volume about 8 times less and their number roughly 8 times greater than according to our estimate).

Then the volume of one droplet is:

$$\frac{4}{3}\pi r^3 \times \frac{4}{3} \times 3{\cdot}14 \times 10^{-12} \text{ cm}^3 = 4 \times 10^{-12} \text{ cm}^3$$

The weight of one droplet is equal to its volume since the specific gravity is close to unity. The number of droplets in the chamber is equal to the ratio of the weight of the fluid atomized in the chamber (1) to the weight of one drop,

$$\frac{0{\cdot}24}{4\times10^{-12}} = \sim 0{\cdot}06\times10^{12} = \sim 6{\cdot}0\times10^{10} \qquad (2)$$

or 6×10^8 per l., or $\sim 6 \times 10^5$ per ml.

Knowing the respiratory volume of various animals (see below) one can determine the amount of virus-containing suspension taken up by them.

The amount of virus-containing suspension in grams is equal to the concentration of virus per ml multiplied by the respiratory volume in ml per min multiplied by the body weight in g multiplied by the time of contact with the aerosol in min.

Respiratory volume of various animals*
(in ml/min per 1 g weight)

White mice	1·1
Guinea-pigs	0·51
Rabbits	0·33
Monkeys	0·29
Dogs	0·18
Sheep	0·14

* Quoted from R. Rosebury.

For white mice we get:

0·0000024 g/ml × 1·1 ml/min × 7 g × 60 min = 0·001 g, and for monkeys 0·0000024 g/ml × 0·29 ml/min × 2000 g × 30 min = 0·04 g.

The results allow us to compare the doses of virus-containing material administered to an animal *via* the aerosol or other routes. Thus, for the usual intranasal infection of mice they were given 0·05 g of virus-containing suspension, i.e. about 50 times more than with the aerosol method, for 100 per cent mortality of both groups.

In order fo find out the number of droplets contained in the aerosol, for example in 0·001 g, this value must be divided by the weight of one drop:

$$\frac{0{\cdot}001}{4\times10^{-12}} = \frac{25}{10^{-7}} = 25\times10^{7} \text{ particles}$$

Thus, when a white mouse is in contact with the aerosol for 60 min an enormous number of droplets running into hundreds of millions pass into the respiratory tract. The volume of air passing in this time through the mouse respiratory tract is 420 cm³. It should be stressed that all the findings given are based on rough representations of aerosols as consisting of uniform droplets of average size and are therefore only to be regarded as tentative.

We shall now consider settling of the aerosol particles in the chamber after it is filled with atomized infective material. If the atomizer ceases work as from

this moment, the air neither enters nor leaves the chamber. In these conditions, the life span of the aerosol particles is determined by a number of factors which we shall examine in detail:

(a) *Settling according to Stokes' law*

The aerosol particle settles due to the force of gravity. The resistance of the air to the fall of the droplet is such that the rate of fall is constant and determined by the formula:

$$U = \frac{2}{9} \times \frac{r^2 g}{\mu} \times \rho_k \tag{3}$$

where r is the radius of the droplet in cm,

g, the acceleration due to gravity $= 981$ cm/sec^2,

ρ_k the density of the droplet in g/cm^3,

μ the coefficient of dynamic viscosity of the medium (air) in which the droplet falls, 2×10^{-4} poises (g/cm·sec), and U the rate of fall of the particles.

We shall determine the ratio of settling out of the droplets in our chamber. Taking as before the mean value of the radius of the drop as equal to 0·5 μ and assuming $\rho_k = 1$, we get from formula (3)

$$U = 0{\cdot}0025 \text{ cm/sec or } \sim 9 \text{ cm/hr.}$$

As the height of the chamber is 30 cm, then a drop of diameter 1 μ sediments from the aerosol cloud in a few hours. It should be noted that the rate of settling of the particles according to Stokes' law is proportional to the square of their radius. Therefore for particles half the size, the settling rate is 4 times less and the life span of such droplets 4 times greater.

Consequently, the large particles settle first and the aerosol becomes more finely dispersed. If the life span of the aerosol were determined solely by Stokes' law, λ denoting the life span of the aerosols in the chamber would equal

$$\lambda = \frac{2{\cdot}3V}{h} \tag{4}$$

where h is the height of chamber and U the settling rate according to Stokes' law.

Obviously, in these conditions increase in the duration of the stay of the animals in the chamber by a time exceeding λ is pointless.

From this formula we can determine λ also when other causes of destruction of the particles of the aerosol are taken into account since as we shall see below, Stokes settling is the main source of loss of particles.

We now consider various types of coagulation of the aerosol in relation to the conditions in the chamber.

(b) *Gravitational coagulation*

At the time of ending of atomization, an aerosol is obtained with a definite density of particle distribution by size. If the particles are small ($r < 15\ \mu$) then

the collision of the particles through differences in the velocities of the drops (gravitational coagulation) is virtually impossible (Langmuir's calculation (5). More accurate definition of Langmuir's calculations (2, p. 292) does not qualitatively alter the conclusions drawn by him. In other words, gravitational coagulation does not occur.

(c) *Brownian coagulation*

Collision of the particles may occur through Brownian movement. For each such collision two droplets of aerosol may run into one. If we term the number of droplets per unit volume of aerosol n, then the equation defining the change n as a result of Brownian coagulation has the form (1, 2)

$$\frac{dn}{dt} = \frac{4RTn^2}{3IN} \tag{5}$$

where R is the gas constant = 8·31 erg/g mole
T the absolute temperature ~ 300°C
N (Avogadro's number) ~ $6{\cdot}02 \times 10^{23}$
t the time
and n, see equation (3).

The solution of equation (5) has the form

$$n = \frac{n_0}{1 + \frac{4RTn_0t}{3IN}} \tag{6}$$

where n is the density of droplets at the initial time ($t = 0$).

When the denominator of equation (6) is equal to 2 then the number of particles of aerosol is half the original. Hence, we can determine the time during which the number of particles decreases by half

$$t = \frac{3}{4}\frac{IN}{RTn_0} \approx 3 \times 10^{11} \text{ sec} \sim 3 \times 10^7 \text{ hr, or } 1{\cdot}33 \times 10^6 \text{ days}$$

In addition, as shown by Shishkin (3) "for a particle radius of 1 μ and water content of the aerosol of 1 g/m³, a decrease in the number particles by one-half occurs in 70 hr". In our conditions, the water content of the aerosols was close to that discussed here and the mean radius of the particles ~ 0·5 μ which reduces even more the value of the losses from this type of coagulation.

Consequently, Brownian coagulation does not give appreciable losses in the number of aerosol particles.

(d) *Turbulent coagulation*

Losses may also result from turbulent coagulation from non-uniform movements of air in the chamber. However, this type of coagulation may be ignored since its effect covers a short time during atomization; after atomization the coagulation

rapidly wanes since the animals are in contact with the aerosol in static conditions without air movements.

(c) *Electrical coagulation*

We cannot as yet determine the effect of electrical coagulation since the charge on the particles atomized into the chamber has still to be established. It is to be supposed that it does not result in losses because the particles atomized in uniform conditions will have the same charge (if there is one) and coagulation results from charges of different sign.

CONCLUSIONS

(1) From the respiratory volume of various animals we have determined the amount of virus-containing material which they will take up on contact with a virus-containing aerosol in the aerosol chamber.

(2) The losses in the aerosol cloud due to settling out of the particles according to Stokes' law have been determined and it has been shown that for the various types of coagulation Stokes settling is the fundamental factor.

(3) As the results show, with the IBK-1 chamber a stable finely dispersed aerosol can be produced.

REFERENCES

1. SMOLUKHOVSKII M. V. Koagulyatsiya kolloidov. (Colloidal Coagulation.) p. 7. Moscow-Leningrad, 1936
2. FUKS N. A. Mekhanika aerozolei. (Aerosol Mechanics.) Moscow, 1955
3. SHISHKIN N. S. Oblaka, osadki i grozovoye elektrichestvo. (Clouds, Rainfall and Electricity Thunderstorms.) Moscow, 1954
4. EUKCLAND F. *et al.*, Nature London 166: 354, 1950
5. LANGMUIR J. J. Meteor. 5: 175, 1948
6. SHOSHKES M. *et al.*, Arch. Indust. Hyg. 1: 20, 1950

FEATURES OF AEROSOL INFECTION IN ORNITHOSIS*

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THE prime importance of the respiratory route of infection in ornithosis is indicated not only by experimental investigation but by a number of epidemiological studies carried out over the last 80 years (2).

* Vopr. virusol 6: No. 4, 463–469, 1961.