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THE INFLUENCE OF PACKING POROSITY ON AEROSOL PARTICLE DEPOSITION IN A SCRUBBER

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Аннотация—Процесс проникновения массы в скруббере (т.е. проникновение аэрозольных частиц из газовой фазы в поверхностный слой жидкой фазы) принято рассматривать по аналогии с диффузионными процессами. На этом основании введено понятие общего коэффициента проникновения массы и выведены формулы, позваляющие вычислить этот коэффициент из изменения массовой концентрации потока аэрозоля после прохода через пористый слой в скруббере. Описаны : экспериментальная установка, условия испытаний и метод определения массовой концентрации потока аэрозоля и дисперсии его частиц. В исследованиях процесса мокрой очистки воздуха от аэрозольных частиц в скруббере с пористым слоем установлен рост коэффициентов проникновения массы с одновременным ростом критерия Рейнольдса и снижением пористости слоя в скруббере.

NOMENCLATURE

A_F, interfacial surface of the packing [m^2];

A_{Fe}, interfacial surface related to the wet surface of the packing [m^2];

a_F, specific surface of the packing [m^2/m^3];

a_{Fe}, specific surface related to the wet surface of the packing [m^2/m^3];

c_0, mass stream aerosol concentration at the outlet of the scrubber [kg/m^3];

c_i, mass stream aerosol concentration at the inlet of the scrubber [kg/m^3];

$\bar{d}$, mean value of the aerosol particle diameter [m];

d_z, equivalent diameter of Raschig rings [m ;mm];

E, penetration (emission coefficient $= c_0/c_i$);

G_c, overall mass flux of the deposited aerosol particles [kg/h];

H, height of the bed in the scrubber [m];

i, wetting density [m^3/(m^{2}h)];

K, dimensionless number of the aerosol particle deposition by interception;

Re_z, Reynolds number for the gas $(=\bar{u}_z d_z/\bar{v}_g)$;

Re_{zkan}, Reynolds number related to the equivalent linear velocity of the carrier gas in the pores of the packing, $\bar{u}_{ekan}$, and to the equivalent diameter of these pores, d_{zkan};

t_{gw}, stream aerosol temperature at the inlet of the scrubber [°C];

$t_{\omega w}$, temperature of the wetting liquid at the inlet of the scrubber [°C];

$\bar{u}_z$, mean equivalent linear velocity (superficial velocity) of the carrier gas in the packed scrubber [m/h; m/s];

$\bar{w}_z$, mean equivalent mass velocity (superficial mass velocity) of the carrier gas in the packed scrubber $(=\bar{u}_z\rho_g)$ [kg/m^{2}h)];

$\bar{V}_g$, mean value of the volumetric flux of the carrier gas [m^3/h];

v_F, volume of the packing of the scrubber [m^3];

Greek symbols

α_F, packing density of the filter layer;

β, mass-transfer local surface coefficient [kg/m^{2}h];

β_c, overall mass-transfer surface coefficient [kg/(m^{2}h)];

β_c^*, overall mass-transfer surface coefficient related to the wet surface of the packing [kg/(m^{2}h)];

β_{vc}, overall mass-transfer volumetric coefficient [kg/(m^{3}h)];

ε, porosity of the packing;

η, net-efficiency of the aerosol particle deposition;

η_e, effective efficiency of the aerosol particle deposition on a single filament surrounded with the other ones;

η_{ew}, effective efficiency of the aerosol particle deposition by interception on a single filament surrounded with the other ones;

η_n, net efficiency of the aerosol particle deposition on a single isolated filament;

σ, surface tension of the wetting liquid [mN/m];

μ, dynamic viscosity of the wetting liquid [mNs/m^2];

$\bar{v}_g$, mean kinematic viscosity of the carrier gas [m^2/s];

$\Delta\pi$, local driving modulus;

$\overline{\Delta\pi}_c$, overall driving modulus;

$\bar{\rho}_g$, mean density of the carrier gas [kg/m^3].

INTRODUCTION AND AIM

AEROSOL particles can be removed from gas with the help of liquid. This is the very essence of the so called wet-aerosol deposition methods. The contact of gas with a stream of aerosol can be maintained if the aerosol is made to flow either on the free surface of liquid, or downward along a wetted wall, or along the surface of liquid which spreads over some movable elements; the barbotage of aerosol streams through a layer of liquid or foam; the spraying of liquid into the stream of aerosol; the flow of aerosol stream through some porous wet filter layers.

In wet-aerosol deposition process liquid plays at least two parts, viz. it changes the adhesive properties of aerosol particles as related to capturing surfaces and it cleans these surfaces by driving deposit aerosol particles out of the system

Wet-aerosol deposition can take place due to certain mechanisms the major of which is deposition by inertia, as well as of electrostatic precipitation, gravitation effect besides interception and also in the result of turbulent, molecular and thermal diffusion. The number of mechanisms engaged in wet-aerosol deposition process depends mainly upon the mode of contact between the aerosol and the liquid, on the physico-chemical parameters of dispersed phase and carrier gas and also to a certain extent on the constructional parameters of the aerosol deposition system applied.

In the investigation under consideration a scrubber was used whose porous filtrating layer was wetted with clean water. The aim of the experiments was to find the influence of linear velocity (superficial velocity) of the carrier gas and filter layer porosity on the process of wet-aerosol deposition in the test scrubber.

Wet filter layers are a specific case of a dry bed. They are the very basic element-members in filters, dust settling chambers and scrubbers. The results of such investigation, similar to these presently referred, can be found in the works of, among others, Bonn [1], First and co-workers [2], Ciborowski and Hulewicz [3, 4], Kamack and Lapple [5] and others [6–15].

Deposition of aerosol particles in a wet-filter bed follows the same principles, excluding electrostatic precipitation which has no practical significance here, as for a dry bed, therefore, all the theories on aerosol deposition applicable for dry beds are valid for wet beds, as well [16–60].

This article, although constituting a separate whole, presents the results of one of a series of researches undertaken by the authors in order to investigate more fully the process of wet aerosol deposition. The basic aim of the research was to establish what influence on the wet aerosol deposition is effected by some parameters, e.g. concentration and velocity of the aerosol stream, porosity and height of the bed, wetting density, surface tension of the wetting liquid etc., as well as to establish the dominating mechanism in various test conditions of the process, and also to try present the process in the convention of diffusion processes.

Different types of filters and scrubbers, widely used in industry for removing aerosol pollution from air and other gases, generally work on principles worked out empirically. Nevertheless a detailed scientific analysis of this process is still a problem open to solution, usually on account of a lack of basic data which are necessary for a full characteristic of the system. Resulting from this is a well-grounded tendency for using model apparatus in investigations, especially when the figure-values obtained are the only instrument for establishing quality correlations. In the presented work the tests have been made with the use of a test glass-packed scrubber which, not being a small-scale replica of any type of industrial scrubber, fully met and realized the conditions of a counter-current contact of the aerosol stream with the stream of liquid.

The investigations presented here concerned establishing the influence of the aerosol superficial velocity and the porosity of the bed on the process of wet aerosol deposition.

OVERALL MASS-TRANSFER COEFFICIENT

Aerosol particles' deposition in a scrubber during the flow of an aerosol stream through a porous, wet bed has been treated in a similar way to diffusion processes, e.g. as a process of mass-transfer from the gas phase to the liquid one [3, 4, 61–65].

The principal equation of this mass-transfer for the discussed process and on the basis of this similarity can be set up in the following integrated form [3, 4]

$$G_c = \beta_c A_F \overline{\Delta\pi_c} \quad (1)$$

or

$$G_c = \beta_{vc} v_F \overline{\Delta\pi_c} \quad (2)$$

where β_c and β_{vc} are overall mass-transfer surface coefficient [kg/(m^{2}h)], and, overall mass-transfer volumetric coefficient [kg/(m^{3}h)], respectively.

The same mass of deposited aerosol particles G_c is determined by the balance equation

$$G_c = \overline{V}_g(c_i - c_0). \quad (3)$$

In general case equations (1) and (3) have the differential form

$$dG = \beta dA_F \Delta\pi \quad (4)$$

$$dG = -V_g dc. \quad (5)$$

Combining the two equations, viz. (4) and (5), integrating for the area between the scrubber's inlet and outlet, and using some simplifying assumptions [3, 66] one comes to an equation which determines the coefficient of mass-transfer

$$\beta_{vc} = (\overline{w}_z/H) \ln(1/E) \quad (6)$$

where

$$E = c_0/c_i \quad (7)$$

or

$$E = 1 - \eta \quad (8)$$

and

$$\overline{w}_z = \overline{u}_z \overline{\rho}_g. \quad (9)$$

From equations (6) and (8) we get

$$\eta = 1 - \exp(-\beta_{vc} H/\overline{w}_z). \quad (10)$$

The detailed derivation of equation (6) has been performed in the earlier cited works [3, 66]. Equations (6) and (10) which link efficiency with mass-transfer coefficient are the auxiliary tools useful in investigations on the influence of various factors on a wet aerosol deposition process. In the present work they are used to calculate quantitative results of the investigation to find out the efficiency of aerosol particle deposition with varying porosity of the bed in the scrubber.

DESCRIPTION OF EXPERIMENTAL EQUIPMENT

The experimental equipment which was used in these investigations can be employed in many other investigations on wet aerosol deposition processes; one can list here studies carried out on the efficiency of aerosol deposition dependent on the parameters of the aerosol stream (velocity, mass-concentration or particle number-concentration, aerosol particle-size distribution, particle size, temperature, pressure), kind of liquid and particularly its physico-chemical parameters (e.g. surface tension, viscosity, temperature, wetting density), kind of bed and its parameters (height of bed, shape and size of elements of bed, porosity, tortuosity, resistance of flow) and on the geometrical parameters of the scrubber and the mode of phase contact.

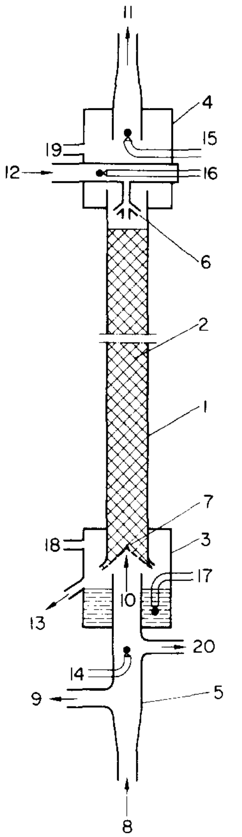

FIG. 1. The experimental scrubber. 1—glass column, 2—porous packing, 3—lower head, 4—upper head, 5—inlet connector of the aerosol, 6—sprayer, 7—drain cone, 8—aerosol inlet, 9—excess aerosol flow-off, 10—inlet of aerosol into the column, 11—outlet of aerosol from the column, 12—inlet of liquid, 13—draining of liquid, 14, 15—thermocouples for the temperature measurement of the aerosol stream, 16, 17—thermocouples for the temperature measurement of the liquid, 18, 19—connectors for the measurement of the gas pressure, 20—by-pass.

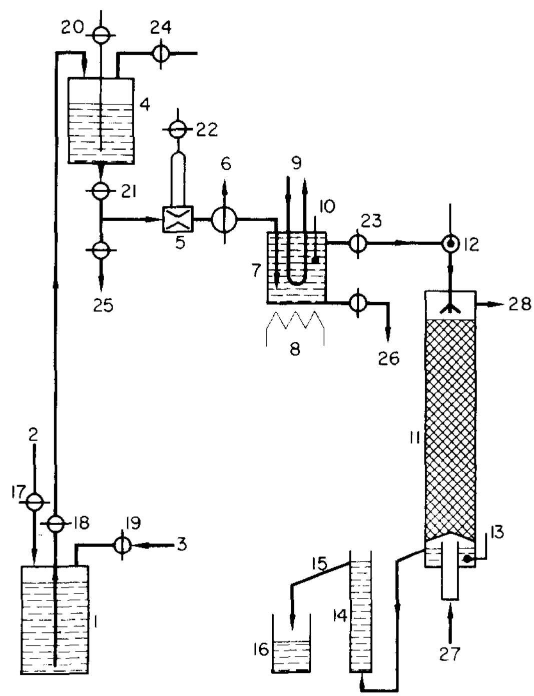

FIG. 2. Scheme of the spray system. 1—liquid storage bin, 2—liquid pouring-in, 3—compressed air, 4—Mariotte bottle, 5—capillary flow-meter, 6—flux liquid regulation, 7—thermostat, 8—electric heater, 9—cooling water, 10—contact thermometer, 11—experimental scrubber, 12, 13—measurement of inflow and outflow liquid temperature, 14—hydraulic seal, 15—overflow, 16—sewer tank, 17–23—stop valves, 24—vent valve, 25, 26—drain of the liquid, 27, 28—inlet and outlet of the aerosol stream.

The equipment consisted of several systems, viz. that for wetting, of air system, aerosol generation system, aerosol stream analyser, and of thermal, and control systems. To measure liquid flow there were engaged capillary flowmeters; measurements of pressure were taken with U-tube manometers and micro-manometers, of temperature—with mercurial and

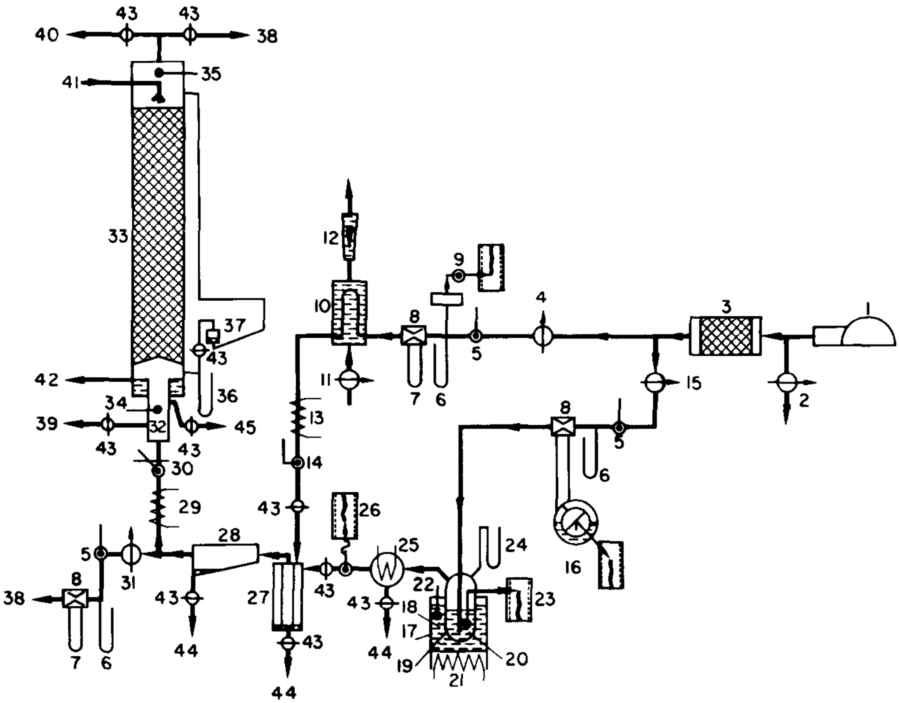

FIG. 3. Scheme of the air and aerosol generation system. 1—blower, 2—by-pass with the control flux valve, 3—dust filter, 4—flux control of the diluting air, 5—temperature measurement before the capillary reducer, 6—pressure measurement before the capillary reducer, 7—pressure drop measurement in the capillary reducer, 8—capillary flow-meter, 9—pressure recorder before the capillary reducer, 10—water cooler, 11—control of the cooling water flux, 12—rotameter, 13—air heater, 14—temperature measurement of the diluting air, 15—control of the flux air for the aerosol generation, 16—ring balance-meter with recorder, 17—aerosol generator, 18—glycerol bath, 19—oil tank, 20—oil, 21—electric heater of the generator, 22—temperature measurement of the heating bath, 23—thermocouple for the oil temperature measurement, 24—pressure measurement in the oil tank, 25—thermal ionizer, 26—electric thermometer with the recorder, 27—condensation air cooler–mixer, 28—settle chamber, 29—electric heater, 30—thermometer of the thermo-control system, 31—flux control of the by-passing aerosol stream, 32—inlet connector of the scrubber, 33—scrubber, 34, 35—temperature measurement of the aerosol stream at the scrubber inlet and outlet, 36—pressure measurement at the scrubber inlet, 37—pressure drop in the bed, 38—outlet aerosol, 39, 40—aerosol sampling for the analysis, 41, 42—inflow and drain of the wetting liquid, 43—stop valves, 44—drain of the oil condensate, 45—outlet of the stream aerosol during the preparatory measurement cycle.

resistance thermometers as well as with thermoelements.

The test scrubber was a glass column of about 100 cm height and 5 cm dia. (Fig. 1) filled with Raschig glass rings which made 70 cm high bed. The upward aerosol stream was contrary to gravity direction flow of the liquid.

The wetting system, as presented in Fig. 2, was designed to carry a definite quantity of liquid of fixed properties to the scrubber and let the liquid out. Density of wetting was kept unchanged owing to the use of Mariotte cylinder. Quantity of wetting liquid was determined by weighing the outflowing liquid in a given time. To maintain the fixed temperature a thermostat was used.

The scheme of air and aerosol generation system is presented in Fig. 3. The system was aimed at producing a stream of aerosol which would have the required initial parameters. The carrier gas was air from a blower. Aerosol was produced by a thermal generator in which a fraction (240–260°C) of solar oil was used. Oil vapour has been condensed in the result of cooling the hot mixture of oil–vapour–air in a stream of dilutent, cold air.

Estimation of aerosol particles' deposition from the air stream in the scrubber was based on the results of the analysis of the aerosol stream. A scheme for the measurement system is presented in Fig. 4. The measurement of mass-stream aerosol concentration was the main one in the test. Aerosol particle-size distribution was determined by microscopic measurements of the aerosol particles which deposited by gravity on microscopic slides in a gravity settling test-chamber [4, 66]. An electrostatic measurement filter [4, 66] was used to measure mass concentration of aerosol. The filter consisted of a negative-charge corona electrode, and of a cup-like collective electrode charged up to 8 kV positive potential. While flowing through the filter the aerosol particles obtained negative charge in the region of corona discharge so that the particles could be attracted by the positive-charge collecting electrode, which made them deposit electrically on its inner surface. A flow ultramicroscope was used to control the

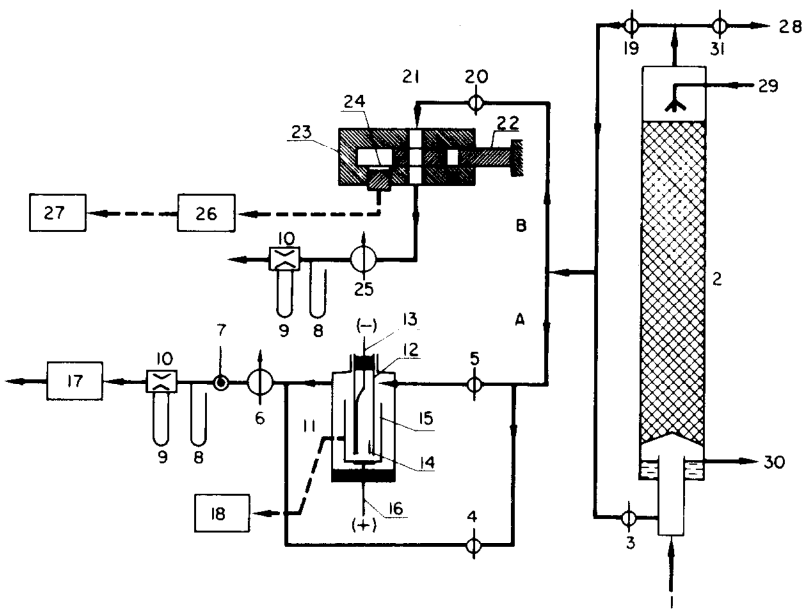

FIG. 4. Scheme of the aersol analysis system. 1—inlet aerosol, 2—scrubber, 3—stop valve in the conduit for the inlet aerosol sampling, 4—by-pass stop valve, 5—stop valve in the electro-filter conduit, 6—flux control of the sampled aerosol stream, 7—temperature measurement before the capillary reducer, 8—pressure measurement before the capillary reducer, 9—pressure drop measurement in the capillary reducer, 10—capillary flow-meter, 11—electrostatic filter, 12—tube, 13—negative electrode, 14—ring of the coronna brush, 15—settle cup-like electrode, 16—electrode bar, 17—flow ultramicroscope, 18—semi-micro analytical balance, 19, 20—stop valves in the conduit of the outlet sampling stream, 21—gravitational settler, 22—pilot bar, 23—housing, 24—settle glass, 25—flux valve control, 26—microscope with camera, 27—projector, 28—outlet aerosol, 29, 30—inflow and drain of the wetting liquid, 31—stop valve of the outlet of the aerosol stream during the preparatory measurement cycle.

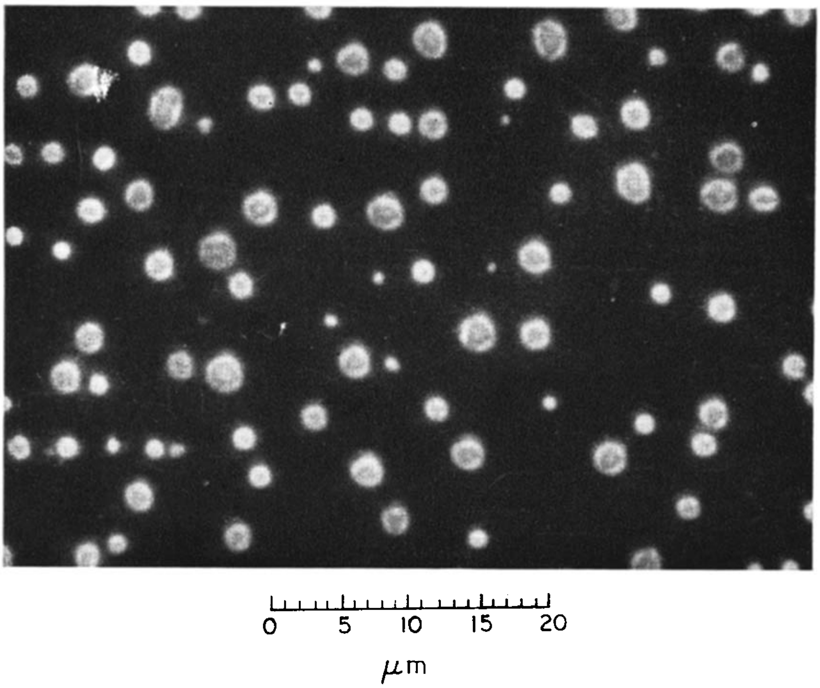

FIG. 5. Microphotography of the test aerosol particle

aerosol particles deposited in the measurement filter quantitatively. The mass of the deposited aerosol particles was determined with the help of a semi-microanalytical balance with precision of 0·005 mg. On the basis of this mass and the known volume of aerosol stream flowing through the measurement filter one could establish mass concentration of the aerosol stream (e.g. g/m^3). Samples for analysis were taken from the main stream of aerosol at the inlet and outlet of the scrubber (Fig. 3) by way of a bleed. The flow rate of the aerosol stream under the probe was about 200 cm^3/min.

MEASUREMENT CONDITIONS

Aerosol stream and wetting liquid met in counter-current in the scrubber of dimensions 5 × 100 cm packed with Raschig glass rings which made a random layer 0·7 m high, and porosity undergoing the change from 0·776 to 0·872. Raschig rings of three granulations were used: 7·5 × 7·5 mm; 10 × 10 mm; 14 × 14 mm of, respectively:

(a)	form factor	2.69;	3·26;	4.44;
(b)	equivalent diameter [mm]	7·37;	8·36;	10·17;
(c)	total porosity	0·776;	0·825;	0·872;
(d)	effective porosity	0·574;	0·643;	0·715;
(e)	specific surface [m^2/m^3]	195;	380;	650.

Wetting liquid was distilled water of surface tension equal to 68 mN/m. The water flowed under its weight through packing at a wetting density equal to 1·40 $m^3/(m^2h)$. Temperature of these two phases at their inlets was fixed at 25°C. Also, dispersion of aerosol particles was kept on the same level. The particles of aerosol were spheres (Fig. 5) of mean diameter equal to 1·97 μm. About 70 per cent of all the particles in use belonged to 1–2.5 μm. Maximum fraction belonged to the particles of diameter 1·65 μm. Carrier gas for the aerosol particles was clean atmospheric air.

The parameters, which were variable, were porosity of packing (amounting to 0·776; 0·825; 0·872) and superficial velocity of aerosol stream (referred to free cross-section of the scrubber) made to change from 5 to 50 cm/s.

PRINCIPLES IN USE WITH THE INVESTIGATIONS AND ESTIMATION OF ERRORS

In the course of the investigations there was traced the dependence of aerosol particles penetration, equation (7), on the equivalent linear velocity of aerosol stream and on the porosity of the bed in the scrubber while all the other parameters, being under control, were kept steady as the process was going on.

All the investigations were carried out in conditions securing dynamic balances of physico-chemical and physical processes. After coming to the intended values of variables and fixed parameters in the measurement system the apparatus was given a full-pace pre-run for about 30 min preceding the taking of readings. Each measurement was repeated several times, never under three, in order to find out its mean value. Measurements of most of physical quantities like temperature, pressure, surface tension, mass, moisture and fluid flow were taken in regular way and with the use of regular instruments. Only for dispersion and concentration of aerosol stream were applied the methods whose outline is given above (Fig. 4).

Three series of test followed for each of the three values of the porosity of the packing. The superficial velocity in each series covered the whole range of the change, i.e. 5–50 cm/s.

The fundamental measured quantity was a drop of the initial mass concentration of aerosol stream caused by passing it through the wetted, porous packing in the scrubber.

In order to simplify the calculations, the penetration, E, for the fixed values of $\bar{u}_z$, equal to 6, 11, 21, 34 and 48 cm/s, was taken from the graphs $E = f(\bar{u}_z)$, Fig. 8. The graphs in turn were based on test results. For the same $\bar{u}_z$ values the Reynolds number, Re_z, and $\bar{w}_z$ values, equation (9), have been calculated. The β_{vc}

coefficient has been taken from equation (6) for the E and $\bar{w}_z$ values fixed in the above way.

The influence of the change in the conditions of the wet aerosol deposition process has been established on the basis of the change in the overall mass-transfer coefficient obtained from equation (6). The penetration, E, found in equation (6) has been established from direct measurements of c_0 and c_i quantities. The relative systematic error in the measurements of mass aerosol particles deposited in the electrofilter, with the precision of weighing equal to 0·005 mg and an absolute increase in the electrofilter-deposit electrode of 1–2 mg, is 0·5–0·25 per cent. The maximum absolute error of penetration, ΔE, is 0·015. The maximum relative error in the overall mass-transfer coefficient, $\Delta\beta_{vc}/\beta_{vc}$, is from 8 to 4 per cent for β_{vc} values within the range of 100–1000 kg/(m^{3}h).

INFLUENCE OF THE POROSITY OF PACKING ON THE EFFICIENCY OF AEROSOL DEPOSITION ACCORDING TO SOME LITERATURE DATA

The influence of the porosity of bed (filtering packing) on the process of aerosol deposition (aerosol filtration) has been dealt with by, among others, Ramskill and Anderson [18], Chen [16], Friedlander [33], Wong [24], Gallily [21], Davies [17], Radushkevich and Kolganov [25] and Kostin and Shabalin [13]. The beds used in those tests have been granular [13], fibrous [16–18, 24, 33] as well as other beds [21, 25]. The influence in question has not found a uniform treatment by these authors. For example, Wong [24] has come to a conclusion that porosity of bed has but little effect on dust deposition while the others, however, point to a more or less evident presence of such influence. Chen [16] states that efficiency of filtration takes a linear order decrease as porosity of packing increases.

$$\eta_e = \eta_n(1 + 4{\cdot}5\alpha_F). \qquad (11)$$

According to Davies [17] it decreases faster, viz. with the second power of porosity

$$\eta_{ew} = K(0{\cdot}16 + 10{\cdot}9\alpha_F + 17\alpha_F^2). \qquad (12)$$

The graphs in Figs. 6 and 7 show a dependence of emission on porosity according to the tests carried by Gallily [21] on the one hand—Kostin

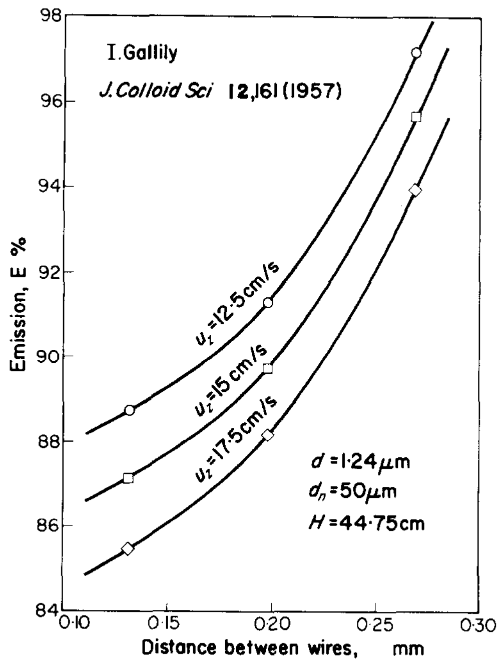

FIG. 6. Dependence of emission on porosity according to Gallily, and Kostin and Shabalin.

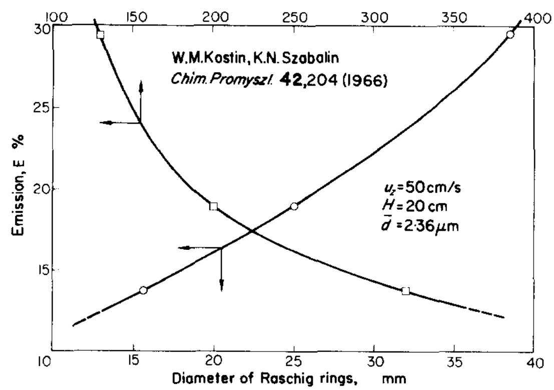

FIG. 7. Dependence of emission on porosity according to Gallily, and Kostin and Shabalin.

with Shabalin [13] on the other. These charts in absence of porosity use its dependent factors; no doubt, the shape of the dependence changes, however, it does not obscure greatly the fact that such dependence is present.

RESULTS OF MEASUREMENTS AND DISCUSSION

The process of aerosol particle separation in the scrubber was traced for three values of its bed porosity, viz. 0·776, 0·825 and 0·872. The results are seen in Fig. 8 and they stand in under the investigated range of velocity $\bar{u}_z$ and porosity ε (Figs. 8 and 9). Subject to velocity $\bar{u}_z$ is a displacement of lines $E = f(\varepsilon)_{\bar{u}_z=\text{const}}$ (Fig. 9) which can also be found in Gallily [21] (Fig. 6). It does not seem that a change in the nature of flow—especially within the laminar flow region, $Re_z < 10$, and the transition flow region, $10 < Re_z < 100$, could have an effect on

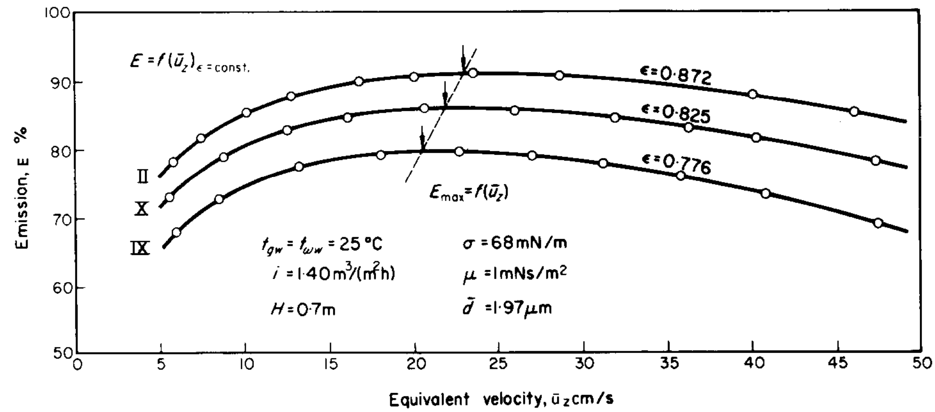

FIG. 8. Dependence of emission on linear velocity of aerosol stream in the scrubber and on packing porosity.

agreement with the results obtained by the above authors as far as the main direction of the course of the discussed dependence is concerned (Figs. 8 and 9). The dependence $E = f(\varepsilon)_{\bar{u}_z=\text{const}}$ (Fig. 9) makes almost a straight line and it would point to the conformity with Chen's researches [16]. The increase of porosity of bed causes almost proportional shift of curve $E = f(\bar{u}_z)_{\varepsilon=\text{const}}$ to areas of greater emission E

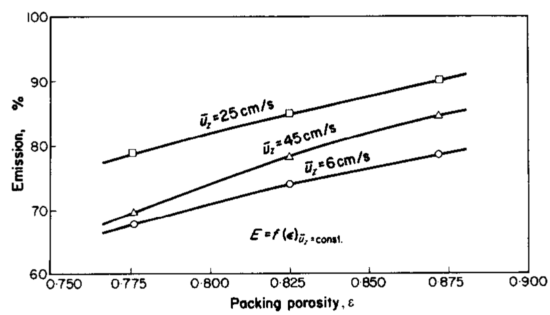

FIG. 9. Graphs of dependence $E = f(\varepsilon)_{u_z=\text{const}}$.

the direction these lines run; within the range $\bar{u}_z$ = 6–25 cm/s (which partially covers also the turbulent flow region to $Re_z \approx 170$) the run of these lines is nearly straight and their inclination varies little from 1·1 to 1·2 (Fig. 9). It is only when turbulence of flow grows further that it causes the increase of their inclination which in the case of, for example, $\bar{u}_z$ = 45 cm/s, reaches about 1·55. Along with greater porosity of bed the maximum of curves $E = f(\bar{u}_z)$ *for* ε = const. (Fig. 8) move in the direction of greater velocity $\bar{u}_z$ and greater values of penetration, E.

On the basis of the above observations and other data (not yet published) [66] concerning the influence of bed porosity on the partial mass-transfer coefficients (inertial, diffusion and interception ones) one can state that a change in bed porosity of the scrubber does not change the number of the individual mechanisms in the system, but may change the proportion of these coefficients in the set aerosol deposition process.

In the case under investigation the inertial and diffusion mass-transfer coefficients increase, and the mass-transfer coefficients by interception decrease with the decrease of bed porosity in the scrubber within the investigated range of Reynolds number.

In Figs. 10–12 there are shown counter-dependencies between variables β_{vc}, Re_z, ε and a_F. The rate of the increase of coefficients β_{vc}, viz. $\Delta\beta_{vc}/\Delta Re_z$, precedes as the Re_z number increases and becomes extremely high in the region of full-developed turbulent flow ($Re_z > 100$; Fig. 10). What is more, this rate increases as porosity of bed decreases e.g. for the range $150 \leqslant Re_z \leqslant 200$ the rates of the increase of the β_{vc} coefficient amount to 1·2 where $\varepsilon = 0{\cdot}872$; 3·8 where $\varepsilon = 0{\cdot}835$; 7·0 where $\varepsilon = 0{\cdot}776$. Thus, intensity of the process grows as porosity of bed goes down, which can be well seen if one looks at the curves standing for turbulence flow (Fig. 11) and especially in the region of full-developed turbulent flow ($Re > 100$). It turns out that the course of curves in Fig. 11 does not depend on the way one may express Reynolds number i.e. by equivalent diameter of packing d_z and equivalent velocity $\bar{u}_z$ reckoned for an empty scrubber (Re_z) or, finally, by equivalent diameter of packing channels d_{zkan} and velocity through them $\bar{u}_{ekan}$ (Re_{zkan}); thus, we have: laminar flow for $Re_{zkan} < 15$, turbulent flow for $Re_{zkan} > 150$. For the given conditions of flow (e.g. $Re_z = 200$) the increase of coefficients, while porosity decreases (Fig. 11), finds its explanation in increase of interfacial surface (Fig. 13). In the whole investigated range of Re_z the increase of coefficient β_{vc} is proportional to the increase of

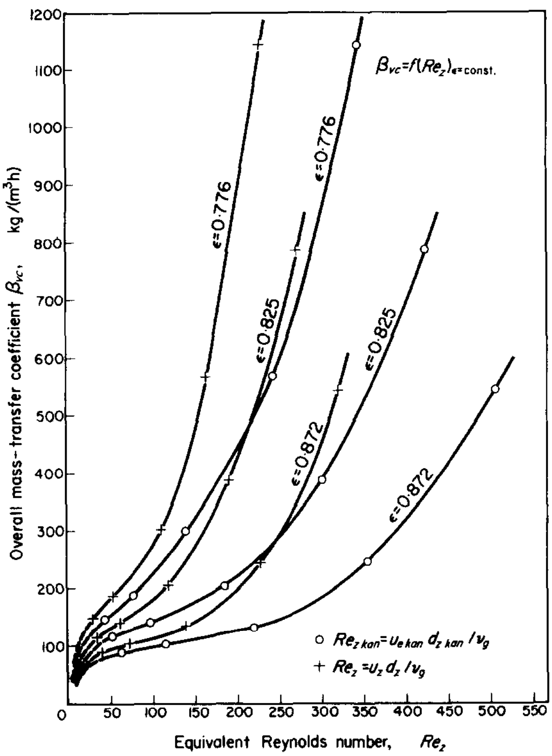

FIG. 10. Graphs of dependence $\beta_{vc} = f(Re_z)_{\varepsilon = \text{const}}$.

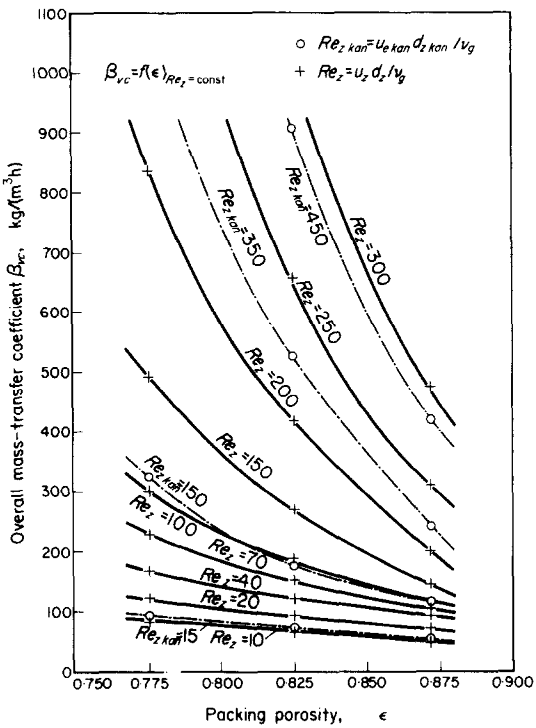

FIG. 11. Graphs of dependence $\beta_{vc} = f(\varepsilon)_{Re_z = \text{const}}$.

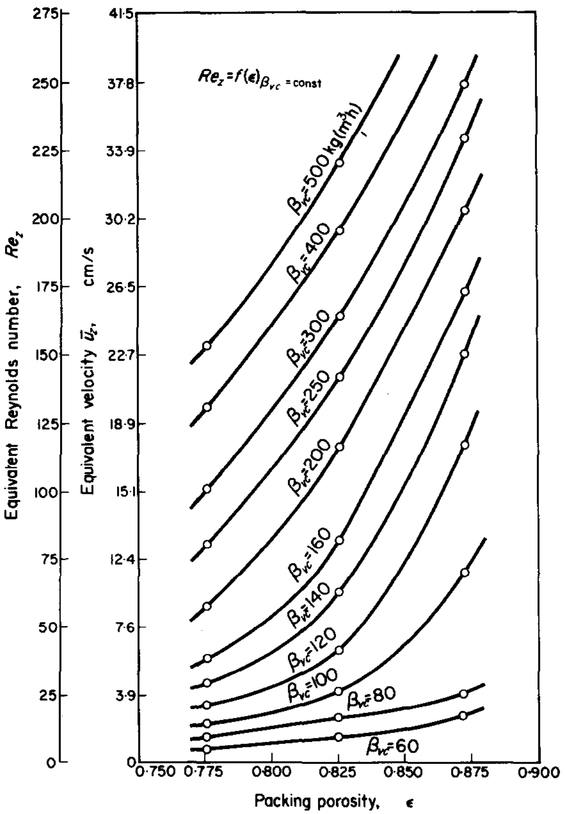

FIG. 12. Graphs of dependence $Re_z = f(\varepsilon)_{\beta_{vc} = \text{const}}$.

specific surface of the packing, a_F; inclination of tangent lines becomes greater as value of Re_z goes up and for $Re_z = 50$, 100, 150 and 200 the inclination is 0·20, 0·41, 0·76 and 1·19, respectively. One concludes that turbulence of flow has decisive influence on the process of mass-transfer.

Let us put down the general equation of mass-transfer, equation (1) this way

$$G_c = \beta_c A_{Fe} \overline{\Delta\pi}_c = \beta_c^* a_{Fe} v_F \overline{\Delta\pi}_c \tag{13}$$

where β_c^* is overall mass-transfer surface coefficient related to wet surface of packing (m^2/m^3), i.e. to surface A_{Fe} (or otherwise a_{Fe}). If the observed increase of mass-transfer coefficient for various packings comes out from the increase of effective surface of wetted packing, then, comparing equations 12 with 2 we should get

$$\left.\begin{aligned} a_{Fe1}\beta_c^* &= \beta_{vc1} \\ a_{Fe2}\beta_c^* &= \beta_{vc2} \end{aligned}\right\} \tag{14}$$

whence we further get the fraction

$$a_{Fe1}/a_{Fe2} = \beta_{vc1}/\beta_{vc2} \tag{15}$$

which for Re_z = const and fixed wetting density expresses quantitative formulation of the dependencies presented in Fig. 13.

The dependence, equation (15), can be expressed this way: mass-transfer coefficients are directly proportional to effective interfacial surface. This surface can be changed either by altering the density of wetting, or porosity of bed, or shape of its elements. For the given

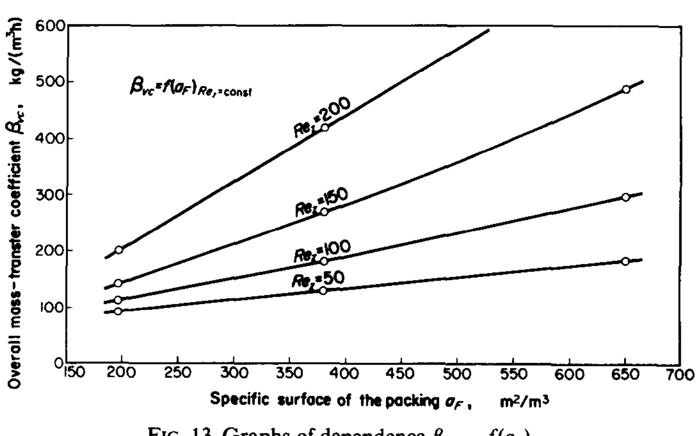

FIG. 13. Graphs of dependence $\beta_{vc} = f(a_F)_{Re_z = \text{const}}$.

aerosol system coefficients of proportion—linear coefficients of straight lines $\beta_{vc} = f(a_{Fe})_{Re_z=\text{const}}$—are, above all, the function of Re_z (Fig. 13). The course of dependency in Fig. 12 shows that with the growth of porosity increases the velocity of the aerosol stream, $\bar{u}_z$, which is indispensable to keep to the given value of coefficients β_{vc}. Nevertheless, within various ranges of porosity and in various regions of aerosol stream flow there emerge differences in the course of these dependencies; in the turbulent flow region and, to some extent, in the transition flow region ($Re_z > 50$) lessening of bed porosity strongly influences a drop of velocity $\bar{u}_z$ for a given value of coefficient β_{vc}; in the other part of the transition flow region as well as in the laminar flow region a drop of bed porosity brings about slower and gradually disappearing alterations of velocity $\bar{u}_z$ for a fixed value of β_{vc} (e.g. equal to 100).

Subject to the intensity of the process (e.g. values of coefficients β_{vc}) it changes the porosity scope of the packing, in which further changes in porosity do not improve much the efficiency of the process e.g. for $\beta_{vc} \leqslant 80$ the porosity of the packing is of no practical significance as the process is carried on. For growing values of β_{vc} the scope of the porosity wanders in the direction of descending values of ε (Fig. 12) e.g. for $\beta_{vc} = 100$ $\varepsilon \leqslant 0{\cdot}825$, for $\beta_{vc} = 120$ $\varepsilon \leqslant 0{\cdot}800$, for $\beta_{vc} = 140$ $\varepsilon \leqslant 0{\cdot}775$ etc. Therefore, the conclusion of Wong [23] about a meagre influence of filtering layer's porosity on efficiency of the process as well as conclusions of the other authors [16, 17], contrary to each other sometimes, find full support and explanation in the present work, since the influence of porosity on efficiency of aerosol filtration is largely due to the conditions applied in a process, and especially to the character of flow of aerosol stream.

FINAL REMARKS

In many investigations the size of test apparatus has a certain importance. Since the experiments carried out by the authors did not model industrial processes, their aim being to establish the mechanisms in wet aerosol deposition process and the trends in the changes of that process effected by changes in the different parameters, the size of the test scrubber used had no significant importance. For that reason, a scrubber 70 cm high and 5 cm dia. could be successfully used for a full realization of the task.

The distribution of the wetting liquid after packing and the edge effects and wall factors belong to problems which must be taken into consideration as far as packed scrubbers are concerned. As it has been shown by tests the fraction of the inner circumference of the scrubber as compared with the overall circumference of the elements of packing, depending on the size the Raschig rings used, is ca. 7–18 per cent. The above values would indicate the existence of meaningful wall factors. Considering that both the scrubber and the packing were made of glass, which caused absence of physical differences between the inner surface of the scrubber and the surfaces of the packing elements. The experiment has ascertained the absence of privileged places of flow of liquid through the bed of the scrubber. Tests made for several heights of packing showed the distribution of liquid in radial direction of scrubber cross-section to be almost even. The even distribution of liquid flow in the scrubber appeared at the height of less than one scrubber diameter (ca. 5 per cent of bed height). The wetting liquid was supplied by means of a liquid supplying device with several holes evenly distributed over the cross-section of the scrubber. In this situation, as far as aerosol particle deposition is concerned both elements, e.g. the inner surface of the scrubber wall and that of the packing had equal importance in the wet aerosol deposition process. It has to be noted that the inner surface of the scrubber wall cannot be considered as having equal importance in an empty scrubber and in a packed one. The presence of packing modifies in a specific way the inner surface of the scrubber wall making it similar in performance to that of the packing, particularly so when the scrubber walls are made of the same material as the packing.

CONCLUSIONS

1. It seems that overall mass-transfer coefficients on the basis of diffusion process model can be taken as convenient synthetic factors in investigations of aerosol collection processes and in checking the influence various factors have on these investigations.

2. In aerosol deposition processes in a porous-scrubber overall mass-transfer coefficients increase with the growth of Reynolds number and drop with the growth in the porosity of filter layer.

3. It is presumed that the method—shown by the example of aerosol deposition from gas in the scrubber with a porous bed—of handling the subject of wet aerosol deposition in a similar manner to diffusion processes can be applied to any other similar methods of removing aerosol particles from a stream of gas.

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Abstract—Using the analogy of the diffusional processes overall mass-transfer coefficients have been introduced, and formulae correlating these coefficients with the mass-stream aerosol-concentration changes in a scrubber have been derived. The experimental equipment, conditions of measurements, and the methods of the determination of the mass-stream aerosol concentration, and the aerosol particle-size distribution have been described. On the basis of the results obtained from the investigation it has been found that in the wet-collection of aerosol particles from the air-stream in the experimental packed scrubber the decrease of bed porosity and the increase of Reynolds number result in an increase of the overall mass-transfer coefficients.

INFLUENCE DE LA POROSITÉ DE GARNISSAGE SUR LE DÉPÔT DE PARTICULES D'AEROSOL DANS UN EXTRACTEUR

Résumé—Utilisant l'analogie des processus diffusionnels, les coefficients globaux de transfert de masse sont introduits et on obtient des formules reliant ces coefficients aux changements de concentration en aérosol dans l'écoulement. Le montage expérimental, les conditions de mesure et les méthodes de détermination de la concentration d'aérosol et la distribution granulométrique des particules de l'aérosol sont décrites. D'après les résultats obtenus, on a trouvé à partir de la collectiòn des particules d'aérosol provenant de l'écoulement d'air dans l'extracteur à garnissage expérimental la diminution de la porosité s'accompagne d'une augmentation des coefficients globaux de transfert de masse.

DER EINFLUSS DER PACKUNGS-POROSITÄT AUF DIE ABLAGERUNG VON AEROSOL-TEILCHEN IN EINEM NASSREINIGER

Zusammenfassung—Unter Verwendung der Analogie der Diffusionsprozesse wurden Gesamt-Stoffübertragungskoeffizienten eingeführt und Formeln abgeleitet, welche diese Koeffizienten mit den Änderungen der Aerosol-Konzentration des Stoffstromes in einem Nassreiniger verbinden. Der Versuchsaufbau, die Messbedingungen und die Methoden zur Bestimmung der Aerosol-Konzentration im Stoffstrom und der Verteilung der Aerosol-Teilchengrösse werden beschrieben. Aufgrund der Versuchsergebnisse wurde gefunden, dass bei der Feuchtigkeitsaufnahme der Aerosol-Teilchen aus dem Luftstrom im experimentell gepackten Nassreiniger die Abnahme der Packungsporosität und die Zunahme der Reynolds-Zahl zu einem Ansteigen des Gesamt-Stoffübertragungskoeffizienten führen.