УДК 614.71; https://doi.org/10.37878/2708-0080/2024-1.11
https://orcid.org/0009-0001-1782-1417
https://orcid.org/0009-0005-4823-2489

DUST COLLECTION EFFICIENCY UNDER IN-PHASE TURBULENCE CONDITIONS IN THE PRESENCE OF PHASE TRANSITIONS


G.Y. TILEUOV,
Senior Lecturer,
gamidulla_nca@mail.ru

M.Z. YESKENDIROV,
Doctor of Technical
SciencesProfessor,
mares@inbox.ru

M. AUEZOV SOUTH KAZAKHSTAN UNIVERSITY,
Tauke Khan Avenue 5, Shymkent, Republic of Kazakhstan, 160012

The article presents the results of a study of the dust collection efficiency in a regular packing layer of a rotoclone-type hybrid apparatus on the particle inertia index in the presence of phase transition processes. The effect of phase transitions on the efficiency of gas purification processes under in-phase turbulence conditions is considered. Based on the conditions of stability of the in-phase vortex formation regime of the gas phase in a regular packing layer, the dominant influence of turbulent diffusion mechanisms on the intensity of phase transition processes and, as a consequence, on the dust collection efficiency has been established. In this case, the predominant influence is in the area of highly dispersed and finely dispersed dust fractions. The results of the experimental studying the patterns of dust collection efficiency depending on the particle inertia index in the presence of phase transition processes are presented.

The studies were carried out for three phase transition modes: condensation of vaporsfrom a vapour-gas mixture, evaporation of a spraying liquid as well as a neutral mode. Using A.N. Kolmogorov's hypothesis,the basic equations and results of calculating the numerical values of local characteristics of a turbulent gas flow in a regular packing layer are presented under the assumption of isotropic turbulence realized in a layer of a regular packing, whose local characteristics do not depend on coordinates and direction.

***KEY WORDS:** gas, purification, apparatus,dust, absorption, rot clone, packing, turbulence, in-phase, phase transition.*

ФАЗАЛЫҚ АУЫСУЛАРДА СИНФАЗАЛЫҚ ТУРБУЛЕНТТІЛІК ЖАҒДАЙЫНДАҒЫ ШАҢ ЖИНАУДЫҢ ТИІМДІЛІГІ

Г.Е. ТИЛЕУОВ, аға оқытушы, *gamidulla_nca@mail.ru*
М.З. ЕСКЕНДИРОВ, техника ғылымдарының докторы, профессор, *mares@inbox.ru*

М. ӘУЕЗОВ АТЫНДАҒЫ ОҢТҮСТІК ҚАЗАҚСТАН УНИВЕРСИТЕТІ,
Қазақстан Республикасы, 160012, Шымкент қ., Тәуке хан даңғылы, 5

Мақалада фазалық ауысу процестерінде бөлшектердің инерция көрсеткіші бойынша ротоклон типті гибридті аппараттың әдеттегі толтыру қабатында шаң жинаудың тиімділігін зерттеу нәтижелері келтірілген. Фазалық ауысулардың жалпы фазалық турбуленттілік жағдайында газды тазарту процестерінің тиімділігіне әсері қарастырылды. Тұрақты тығыздау қабатындағы газ фазасының фазааралық құйын режимінің тұрақтылық жағдайларына сүйене отырып, турбулентті диффузия механизмдерінің фазалық ауысу процестерінің қарқындылығына және нәтижесінде шаң жинау тиімділігіне басым әсері анықталды. Бұл жағдайда жоғары дисперсті және ұсақ дисперсті шаң фракцияларының аймағына басым әсер етеді. Фазалық ауысу процестері болған кезде бөлшектердің инерция көрсеткішіне байланысты шаң жинау тиімділігінің заңдылықтарын эксперименттік зерттеу нәтижелері ұсынылған. Зерттеулер фазалық ауысудың үш режимі үшін жүргізілді: бу-газ қоспасынан булардың конденсациясы, бүріккіш сұйықтықтың булануы, сондай-ақ бейтарап режим. А.Н.Колмогоровтың гипотезасын қолдана отырып, тұрақты саптама қабатындағы турбулентті газ ағынының жергілікті сипаттамаларының сандық мәндерін есептеудің негізгі теңдеулері мен нәтижелері тұрақты саптама қабатында жүзеге асырылатын изотропты турбуленттілік туралы болжамда келтірілген, оның жергілікті сипаттамалары координаттар мен бағытқа тәуелді емес.

ТҮЙІНДІ СӨЗДЕР: *газ, тазалау, аппарат, шаң, сіңіру,ротоклон,саптама, турбуленттілік, жалпы фазалық, фазалық ауысу.*

ЭФФЕКТИВНОСТЬ ПЫЛЕУЛАВЛИВАНИЯ В УСЛОВИЯХ СИНФАЗНОЙ ТУРБУЛЕНТНОСТИ ПРИ НАЛИЧИИ ФАЗОВЫХ ПЕРЕХОДОВ

Г.Е. ТИЛЕУОВ, ст. преподаватель, *gamidulla_nca@mail.ru*
М.З. ЕСКЕНДИРОВ, доктор технических наук, профессор, *mares@inbox.ru*

ЮЖНО-КАЗАХСТАНСКИЙ УНИВЕРСИТЕТ ИМ. М. АУЭЗОВА,
Республика Казахстан, 160012, г. Шымкент, пр-т Тауке хана, 5

Представлены результаты исследования эффективности пылеулавливания в обычном набивочном слое гибридного аппарата ротоклонного типа по показателю инерции частиц при наличии процессов фазового перехода. Рассмотрено влияние фазовых переходов на эффективность процессов очистки газа в условиях синфазной турбулентности. Исходя из условий стабильности режима внутрифазового вихреобразования газовой фазы в регулярном уплотнительном слое, установлено доминирующее влияние механизмов турбулентной диффузии на интенсивность процессов фазового перехода и, как следствие, на эффективность пылеулавливания. В этом случае преобладающее влияние приходится на область высокодисперсных и мелкодисперсных пылевых фракций.

Представлены результаты экспериментального изучения закономерностей эффективности пылеулавливания в зависимости от показателя инерции частиц при наличии *процессов фазового перехода. Исследования проводились для трех режимов фазового перехода: конденсации паров из парогазовой смеси, испарения распыляемой жидкости, а также нейтрального режима.*

Используя гипотезу А.Н. Колмогорова, представлены основные уравнения и результаты расчета численных значений локальных характеристик турбулентного газового потока в слое регулярной насадки в предположении об изотропной турбулентности, реализуемой в слое регулярной насадки, локальные характеристики которой не зависят от координат и направления.

КЛЮЧЕВЫЕ СЛОВА: *газ, очистка, аппарат, пыль, поглощение, ротоклон, насадка, турбулентность, синфазность, фазовый переход.*

Introduction. Gas purification processes underlie many technologies – chemical, petrochemical, paint and varnish, coke, oil, gas, food ones, etc.

Thus, the production of various products is accompanied by formation of technological gases containing by-product gas components (pollutants) and aerosols (dusts, fumes, mists). These impurities must be removed in special gas purification systems [1,2].

One of the simplest and most effective methods for purifying industrial gases from gas impurities and suspended particles that meets the above requirements is a "wet" purification method [3].

Recently, hybrid impact-inertial apparatuses with a regular movable packing [4,5], operating in conditions of intense turbulence of a gas flow, have become widespread. However, the insufficiently high efficiency of purifying industrial gases from poorly soluble gases and finely dispersed aerosols limits their use. Increasing their operating efficiency is possible with the use of condensation effects (Stephan flow, thermophoresis and diffusion phoresis) [6]. At the same time, the influence of phase transitions on the efficiency of gas purification processes under in-phase turbulence conditions [7] has not yet been studied.

Experimenta lmethods. Works [8] indicate that the nature of the interaction of particles with turbulent pulsations of a continuous flow can be assessed using the inertia index $\omega\tau_r$, where ω is the frequency of medium pulsations; τ_r is the particle relaxation time. Moreover, if $\omega\tau_r > 1$, then the inertial deposition mechanism predominates, but if $\omega\tau_r < 1$, then the diffusion deposition mechanism takes place. In this connection, studying the dependence of dust collection efficiency on the particle inertia index in the presence of phase transition processes is of great interest.

The experimental scheme and measurement technique are presented in [9]. The results of the study of the collection efficiency – particle inertia index dependence are shown in *Figure 1*.

The studies were carried out for three phase transition modes: condensation of vapors from a vapor-gas mixture, evaporation of the spraying liquidand a neutral mode. In this case, the vapour pressure drop was calculated using the formula:

$$\Delta P = P_{s.v.}(T_d) - P_p(T_g) \qquad (1)$$

Where $P_{s.v.}(T_d)$ – the saturated vapour pressure at the temperature of the spraying liquid's drops; $P_p(T_g)$ – the partial vapour pressure in a vapour-gas mixture at a given temperature.

The maximum pressure drop ΔP was: =–5.78·10^5 Pa for the condensation mode; ΔP =4.45·10^5 Pa for the evaporation mode; ΔP = –400÷+400 Pa for the neutral mode.

The curve (*Figure 1*) shows that a significant effect of the phase transition process on the catching efficiency is in the area of diffusion deposition. In the case of condensation, the main increase in the efficiency relates to $\omega\tau_r$<1, and for $\omega\tau_r \approx$ 0.01 it is 57%, and when $\omega\tau_r$>2, the effect of condensation on the increasing the efficiency decreases exponentially.

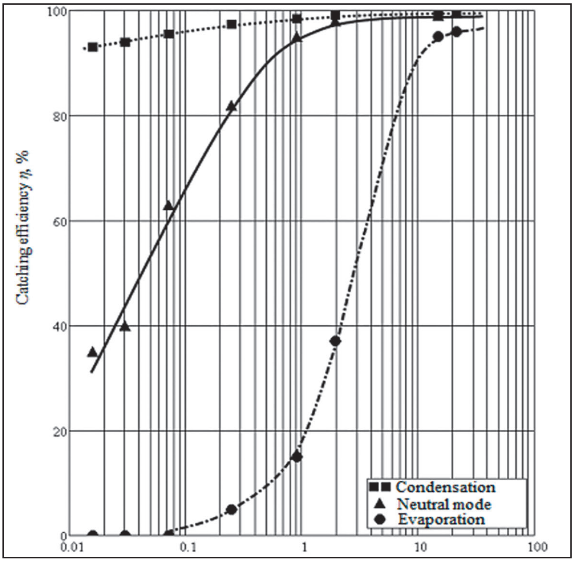

Figure 1 – **The dustcatching efficiency – particle inertia index curve**

Particle inertia index $\omega\tau_r$. Experimental conditions: W_g = 15 m/s, L = 50 m^3/m^2·h, $H_{p.l.}$ = 1 m, d_{50}=0,47µm.

When the experimental setup operates in the spraying liquid evaporation mode, the catching efficiency decreases to zero in the region of $\omega\tau_r$< 1, and in a case of $\omega\tau_r \approx$ 1 the decrease was 77%. For $\omega\tau_r$ >10, in the area of the inertial deposition mechanism, the evaporation process no longer has such a significant effect.

Governing equations. Assuming the isotropic turbulence, realized in a layer of a regular packing, whose local characteristics do not depend on the coordinates and direction (such turbulence is formed at Re>10^4÷10^5 in the flow core, far from the interface), A.N. Kolmogorov's hypothesis is valid, which allows us to obtain a number of useful theoretical relationships using the dimensional method.

For the internal scale of the turbulence, [10] is valid:

$$l_0 \cong \left(\frac{\nu^3}{E}\right)^{1/4} \qquad (2)$$

Where ν – the kinematic viscosity coefficient; E – dissipation energy.

In this case, the maximum rate of small-scale pulsations is determined by the expression

$$u_0' \cong \frac{1}{4} l_0 \cdot \left(\frac{E}{\nu}\right)^{1/2} \cong \frac{1}{4}(\nu \cdot E)^{1/4} \tag{3}$$

And the turbulen ceintensity can be calculated using the formula

$$I = \left(\frac{u_0'}{u_g}\right) \cong \frac{1}{4}\mathrm{Re}^{-1/4} \tag{4}$$

Here *Re* is the Re ynoldscriterion.

The lower limit of the turbulent pulsations'frequency corresponds to large-scale vortices with size of L~b, where b is the size of the regular packing element, and it can be foundas:

$$\omega_b \approx Sl \cdot \bar{u}_g / b, \tag{5}$$

Where *Sl* – the Strouhal number; $\bar{u}_g$– the average gas rate.

Accordingly, the upper limit of the frequency of small-scale pulsations with size of l0 is determined by the formula:

$$\omega_0 \approx u_0' / l_0 \approx \frac{1}{4} \cdot \left(\frac{E}{\nu}\right)^{1/2} \tag{6}$$

Then the dissipation rate of turbulent energy can be calculated using the formula:

$$E \approx \frac{\bar{u}_g^{\,3}}{b} = B \cdot \frac{\bar{u}_g^{\,3}}{b} \tag{7}$$

Here *B* is the experimental correction coefficient.

Results and discussion. The results of calculating the numerical values of the local characteristics of a turbulent gas flow in a layer of a regular packing using the above formulas are presented in *Table 1*.

Table 1 – **Calculated values of the local characteristics of the gas flow turbulence in a layer of a regular packing**

Gas flow rate $\bar{u}_g$, m/s	Numerical values of the gas flow characteristics						
	$Re_b \cdot 10^{-4}$	$E \cdot 10^{-5}$, W/kg	$l_0 \cdot 10^5$, m	u_0', m/s	I, %	ω_b, s^{-1}	$\omega_0 \cdot 10^{-4}$, s^{-1}
5	4,03	0,63	1,56	0,25	1,76	62,5	1,59
7	5,64	1,72	1,21	0,32	1,62	87,5	2,63
9	7,26	3,65	1,01	0,39	1,52	112,5	3,83
11	8,87	6,66	0,87	0,45	1,45	137,5	5,18
15	12,1	16,9	0,69	0,57	1,34	187,5	8,25
20	16,1	40,2	0,55	0,7	1,25	250	12,7

In *Table 1*, the gas flow rate is defined as the gas rate in the free section of the apparatus without spraying. The calculations were carried out using the true gas rate at the free section of a horizontal row of a regular packing S_0=0.5 m^2/m^2 and spraying density L=50 $m^3/m^2 \cdot h$.

Now, knowing the characteristics of the medium'sturbulence, we can calculate the inertia index of aerosol particles $\omega\tau_r$. It should be taken into account that the pulsations with a frequency of $\omega_r \sim \omega_b$, characteristic of the turbulent flow core in the volume of a cell of a regular packing, completely entrain highly dispersed and finely dispersed aerosol fractions and ensure a constant concentration of the particles at the phase boundary surface. And the pulsations with a frequency of $\omega_r \sim \omega_0$, that occur in the interphase boundary layer, have a dominant effect on the diffusion deposition of highly dispersed and finely dispersed aerosol particles. Thus, the catching efficiency depends on the particle inertia index in the region of small-scale pulsations, which will be defined as $\omega_0 \tau_r$.

The relaxation time for highly dispersed and finely dispersed particles is calculated using the following equation [6,8]:

$$\tau_r = \frac{\rho_ч \cdot d_ч^2}{18 \cdot \mu} \quad (8)$$

For particles whose diameter varies within 0.2÷10 μm, the relaxation time under normal conditions varies within $10^{-8} \div 3 \cdot 10^{-4}$ s.

Conclusion. Based on the above, we can conclude that the phase transition processes have a significant impact on the deposition efficiency in the range of action of the turbulent and molecular diffusion mechanisms ($\omega \tau_r < 1$), i.e. the predominant influence is in the region of highly dispersed aerosol fractions.

It should be noted that when the experimental setup operates in the condensation mode, the phase transition can occur not only on drops of the spraying liquid, but also on the aerosol particles. However, in contrast to the temperature of the spraying liquid, the temperature of the aerosol particles corresponded to the temperature of the carrier gas-vapour flow and, as a result, the vapour pressure drop, determined by equation (1), relative to the aerosol particles was equal to zero ($\Delta P \approx 0$). Therefore, it can be unambiguously stated that of the two possible mechanisms, one of which consists in the capture of aerosol particles by thevapour flow diffusing to the colder surface of the spraying liquid, and the other – in the enlargement of aerosol particles due to the condensation of the vapour on them, the first mechanism is of dominant importance.

REFERENCES

1 Schifftner K.C. Air pollution control equipment selection guide. – Boca Raton, Florida: CRC Press, 2002. – 223 p.

2 Louis Theodore. Air Pollution Control Equipment Calculations. – New Jersey: John Wiley & Sons, Inc., 2008. – 574 p.

3 Flagan R.C., Seinfeld J.H. Fundamentals of air pollution engineering. – New Jersey: Prentice-Hall, Inc., 1988. – 542 p.

4 Yeskendirov M.Z., Khussanov ZhYe., Yeskendirova M.M., TileuovG.Ye., Ermetova K.T. Purification of multicomponent gases in a hybrid apparatus / VII International Conference of Industrial Technologies and Engineering (ICITE-2020). - M.Auezov SKSU. - Shymkent, 2020. – P. 25-28.

5 Yeskendirov M., Volnenko A., Khussanov Zh., Yeskendirova M., Tileuov G. Size Distribution of Droplets in A Regular-Packed Scrubber// Chemical Engineering Transactions. – 2020. – Vol. 80. – P. 115-120.

6 Fuks N.A. Mekhanikaaerozoley [Aerosol mechanics]. – Moscow: USSR Academy of Sciences, 1955. – 352 p.

7 Balabekov O.S., Petin V.F. A regularity of interaction of the vortices forming at the detached flow of a gas or liquid stream around the elements discretely arranged along it. - Diploma No. 144 on the discovery. – Moscow,- 2000.

8 Mednikov Ye.P. Turbulent transport and deposition of aerosols. – Moscow: Nauka, 1980. – 176 p.

9 Yeskendirov M., Marina M. Yeskendirova, Gamidulla Ye. Tileuov, Leonid D. Plyatsuk. Studying the hydrodynamics of a rotoclone with a regular packing// Proceeding VIII International Conference «Industrial Technologies and Engineering» ICITE. – 2021. – Vol. 5. – P. 145-152.

10 Kolmogorov A.N. Dissipation of energy in the locally isotropic turbulence // Proc. Math. Phys. Sci. – 1991. – № 434(1890). – P. 15-17.