УДК 502.174:66.074 – 963

L. D. Pliatsuk, Dr. Sc. (Tech.), Prof.,
L. L. Gurets, Cand. Sc. (Tech.), Assoc. Prof.,
I. S. Kozii, Cand. Sc. (Tech.),
R. A. Vaskin, Cand. Sc. (Tech.), Assoc. Prof.

Sumy State University, Sumy, Ukraine, e-mail: koziy.ivan@gmail.com

INDUSTRIAL RESEARCH STUDIES OF GAS TREATMENT DEVICE WITH A LARGE HOLE SIEVE TRAYS

Л. Д. Пляцук, д-р техн. наук, проф.,
Л. Л. Гурець, канд. техн. наук, доц.,
І. С. Козій, канд. техн. наук,
Р. А. Васькін, канд. техн. наук, доц.

Сумський державний університет, м. Суми, Україна, e-mail: koziy.ivan@gmail.com

ПРОМИСЛОВІ ДОСЛІДЖЕННЯ ГАЗООЧИСНОГО АПАРАТУ З ПРОВАЛЬНИМИ ТАРІЛКАМИ ВЕЛИКИХ ОТВОРІВ

Purpose. Dedusting efficiency determination of the device with large-hole sieve trays (LHST) in the chemical industry.

Methodology. Dedusting efficiency determination was conducted according to the Murphy efficiency factor. Dust concentration at the device outlet was measured using the gravimetric method according to "The measurement technique of substance mass concentration in the form of suspended solid particles (dust) in the vent emissions of stationary sources using the gravimetric method at the gas-dust flow temperature under 600 °C".

Findings. The device with LHST was constructed to conduct the industrial test of dedusting efficiency in the titanium dioxide production facility according to the manufacturing instructions. Titanium dioxide gas dedusting efficiency was at the level of 99.2 % and ilmenite dedusting efficiency was at the level of 99.5 %. The authors provide recommendations concerning the operation of gas-cleaning device with LHST. The device with LHST can be used instead of the existing dedusting equipment at three stages of titanium dioxide production: ilmenite grinding, tempering and titanium dioxide grinding.

Originality. On the basis of data pilot testing device, expressions are obtained to determine the velocity of the gas, ensuring stable operation of devices with LHST.

Practical value. Based on the industrial tests recommendations have been developed for using the device with LHST in the chemical industry.

Keywords: *dust and gas emission, dedusting, titanium dioxide, wet cleaning, operation consistency*

Introduction. Priority attention to the protection of the natural environment and to the rational use of natural resources, as well as ensuring of ecological safety of the population is an essential condition for sustainable development of the region and the country as a whole. Therefore, on the territory of Ukraine there should be carried out policies, aimed at achieving a harmonious interaction between the society and the nature and the rational use, protection and renewal of natural resources.

Among anthropogenic factors in the formation of environmental safety we should mention the air pollution caused by industrial enterprises.

Chemical industry enterprises are one of the sources of pollutants and dust into the air and represent a significant environmental hazard. The problem is complicated by the fact that the chemical companies are mostly located within populated areas. This negatively affects the state of the environment in general and health in particular, and that conditions the relevance of the work.

Unsolved aspects of the problem. Among the enterprises of the chemical industry PJSC "Sumykhimprom" was considered which is a typical chemical manufacturing plant. The choice of this enterprise is not occasional, since PJSC "Sumykhimprom" is included in the list of 100 greatest environmental contaminants in Ukraine. The main facilities include: the production of sulphate acid, complex mineral fertilizers and pigments (the main product is titanium dioxide), which causes the integrated pollution of the air by gas and dust emissions. The emissions of the plant contain the dust of different size and properties.

Analysis of the existing gas cleaning systems of PJSC "Sumykhimprom" suggests that not all the dust and gas handling equipment provides the required cleaning efficiency. One reason is the physical wear, because equipment was installed in the 60–70-ies of the 20th century. This does not only lead to the environmental pollution, but also results in the loss of valuable raw materials and the finished product. For example, a significant amount of raw materials and products is lost per year in the production of titanium dioxide at PJSC "Sumykhimprom" due to imperfect gas purification devices [1].

Thus, the above-mentioned facts raise the task of choosing equipment that provides high efficiency dust and gas collection.

Analysis of the recent research. Complexity of the gas cleaning in the chemical industry is conditioned by the need for simultaneous removal of gaseous impurities and particulate (solid or liquid) components from flue gases. Reducing the concentration of pollutants in emissions to the maximum permissible norms can be achieved by introducing new technological processes of purification of exhaust gases and intensifying the existing ones.

Experience of operating dust removal devices shows that they have to meet the following requirements:

- high efficiency and intensity;
- simplicity of design;
- universality;
- stable operation without clogging of the equipment;
- low power consumption.

The traditional dust catching patterns of the chemical industry are represented by machines of dry and wet types. Cyclones and bag filters are mainly used as devices for dry dust collection. Devices of this type are not capable of handling gas streams that contain easily coalescent and resinous substances, as well as different dispersion of dust.

The wet dedusting apparatus are represented mainly by spray and disc scrubbers, vortex type devices. Wet cleaning does not require additional gas treatment, allows the simultaneous cleaning both from gaseous emissions and particulate matter. Wet dust collection has a high efficiency while trapping fine-dispersed dust, but the problem of gas purification from easily coalescent and resinous substances, leading to clogging of the equipment, eliminates the possibility of effective use of the apparatus of the wet type. This leads to the use of multistage gas cleaning systems, which are difficult to manufacture and operate. One way to solve this problem is to use a gas treatment equipment of high capacity, which can provide integrated gas cleaning from dust and gaseous contaminants.

Cleaning of industrial exhausted gases involves large amounts of processed areas, so one of the promising ways of intensification of processes of gas cleaning is the use of devices that operate in a developed turbulence mode [2]. Increase in gas velocity leads to increasing productivity of the apparatus, reduces the consumption of materials, improves the efficiency of dust collection. The devices operating in the specified mode include LHST devices.

The use of sieve plates with large diameter holes can significantly prolong the operation time of the dust collecting equipment and facilitates the maintenance of the equipment. These plates work well at treating contaminated gases and liquids, of which inlays drop out. Devices with LHST are used in the processes of absorption and desorption in the soda industry and in the wet dedusting process [3].

According to the effectiveness of operation, the apparatus with LHST (hole diameter = 0.06 m) is not inferior to such constructions of dust collecting equipment as machines with weighted showerheads, and appliances with a regular moving extension. Experience of operating machines with LHST proves minor material costs, long service life, as well as the possibility of retrofitting existing dust collecting equipment by mounting of the contact device (plates with large holes) during scheduled shutdowns for cleaning of equipment [4].

Dust collecting equipment with LHST has the following advantages:

- simplicity and reliability of the design;
- developed surface of phase contact;
- high hydrodynamic coefficient of efficiency;
- large device productivity;
- plates are not clogged by the presence of the workable environment of solid particles, which have high adhesive properties and are capable of forming agglomeration [5];
- a wide range of stable operation under different loads of the gas and liquid phases;
- high efficiency of dust cleaning.

Objectives. The aim of the work is to determine the effectiveness of the dust-collecting device with LHST in industrial conditions and consider possible options for its use in the process.

Presentation of the main research. According to the rules of production the maximum allowable concentration of ilmenite dust and titanium dioxide in the air of the working area is 10 mg/m^3. The sanitary protection zone of the enterprise as a factory of A hazard class, is 1000 m. Out of SPZ borders there are placed administrative buildings and residential area of Sumy, where concentrations of titanium dioxide and ilmenite dust in the air should not exceed 0.5 mg/m^3. In the current production of pigment titanium dioxide, the cleaning of solid and gaseous components in the apparatus of the dry and wet dedusting is provided.

During the drying process of ilmenite concentrate, flue gases which form from the combustion of natural gas, together with the ilmenite dust concentrate come in a two-step cleaning, consisting of battery cyclones and wet scrubber. The total efficiency of dust collection equipment is 92 %, due to both particle size distribution and physical-chemical properties of ilmenite dust. The concentration of dust at the outlet of the pipe is to be less than 1 g/m^3 (maximum permissible emissions), according to the manufacturing specification.

During the grinding of ilmenite concentrate the air with dust impurities from the grinding equipment is blown by fans into the cyclone, then passes through a bag filter and is vented with a mass concentration of dust less than 1 g/m^3. The overall efficiency of the gas cleaning dust is less than 84 % and an additional source of secondary dust is formed due to dry dust collecting devices, which adversely affects the level of ecological safety of the enterprise.

During calcination of hydrated ferric titanium in calcining furnace, gases formed by the combustion of natural gas, water evaporation and decomposition of sulfates, with a temperature of 375–400 °C fall into gas cleaning device. The gas cleaning device (wet-type) consists of a carbonator, the Venturi scrubber, and the ammonia scrubber. The total efficiency of the chosen scheme of dedusting does not exceed 92 % that is caused by finely-divided composition of the dust of titanium dioxide and its high adhesion properties [6]. In the process of dedusting, dust galls on the walls of the hollow scrubber, which leads to blocking the equipment and higher operating costs. Moreover, this process is characterized by high cost of irrigation fluid, which in turn results in high water consumption and the formation of large amounts of sludge. During titanium dioxide fracture at the rolling- pendulum mill, the air with impurities of titanium dioxide passes a backwash in a sock filter and a mass concentration of no more than 0.6 g/m^3 is vented into the atmosphere. The effectiveness of gas cleaning treatment from dust is approximately 95 % and an additional source of secondary dust production is formed.

Thus, the basic components of gases that pollute the air in the preparation of the pigment are ilmenite dust and titanium dioxide, and sulfur-containing gases. The imperfection of gas cleaning systems results in the atmosphere air pollution of workplaces, industrial areas and areas adjacent to the territory of a company as well as the loss of raw material and the target product (Table 1).

The current scheme of cleaning gases which are formed at the stage of drying and pulverization of ilmenite manufactory titanium dioxide provides dedusting from ilmenite scrubbers, C-15 cyclone and sock filters. The substantial loss of raw materials occurs.

In order to improve the efficiency of dust collection we proposed a method for purification of exhaust gases in the dust collecting device of the wet type (Fig. 1).

The analyzed device is manufactured in a diameter of 2.4 m, 5.0 m height and has two perforated trays with holes of 0.15 m and a 21.5 % clear opening. The productivity of the device is 15,000 m^3/h.

In the middle of the framework *1* through the gas distributing device *2* a contaminated gas is supplied. Simultaneously, in the upper part of the apparatus through the irrigation device *4* fluid is supplied. During the passage of the gas through the hole of a tray *6*, the gas contacts the fluid, which is accompanied by the formation of a bubble. The disruption of the bubble leads to the appearance of eddy currents and eddy formation of gas-liquid flow and developed surface contact of phases in the working area of the apparatus. All these factors contribute to increasing effectiveness of the device.

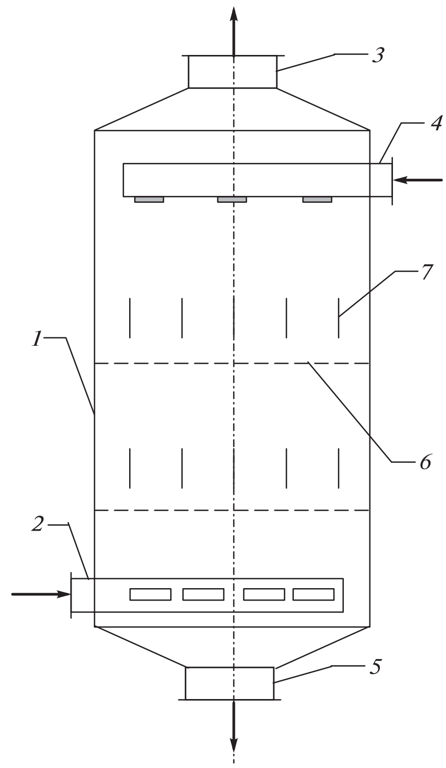

Fig. 1. Industrial plant with LHST:

1 – the framework; 2 – a nozzle of gas distributing device; 3 – an outlet nozzle for the purified gas; 4 – a nozzle of a distributing device for liquid; 5 – a nozzle for fluid removal; 6 – a tray; 7 – stabilizer

In the device a high-intensity, turbulized foam layer 0.6 m high is formed. Additionally, in the decay of a bubble vibrating pulsations of a foam layer are transmitted to the tray deck, which prevents clogging of the hollows of the contact device. Purified gas is withdrawn from the device through a nozzle *3*, while the liquid is removed from the device through a nozzle *5*.

The main purpose of the stabilizer *7*, which is located in the foam layer, is to prevent the appearing of rolling oscillations of the gas-liquid layer at a high velocity of gas in a full cross-section of the device, and baring the tray deck. Due to location of the stabilizer, the gas-liquid layer, which is uniformly distributed over the entire height, is formed in the device. At the same time a uniform distribution of the gas content of the layer and a liquid layer along the entire longitudinal section of the column is observed (including the space near the walls and tray).

Previously conducted experimental studies of hydrodynamics and dust collecting on the lab bench per-

Table 1

Characteristics of dust and gas emissions of titanium dioxide production

The stage of production	The amount of gas entering the dust collection system, th.m^3/hr	Dust content, g/m^3
The drying of ilmenite	11.5	32.4
The pulverization of ilmenite	18.9	20.5–40.2
Calcining furnace	18.4	2.3–2.4
The pulverization of titanium dioxide	4.9	8.5–12.8

mitted determining the operating mode of the device with LHST, i.e. secondary foaming. Therefore, the research of hydrodynamic of the device was conducted for two values of the density of irrigation (L) 15 and 20 $m^3/(m^2 \cdot h)$ and the gas velocity (w) 2.5–3 m/s, which were identified as the optimal conditions for appearance of a given mode of operation of the device [6].

Results. The results of the studies of the effectiveness of dust collecting of the device with LHST are shown in Table. 2.

As we can see from Table 2, according to the results of industrial testing, the effectiveness of gas cleaning from dust of titanium dioxide and ilmenite is 99.2 and 99.5 % respectively, which almost confirms the previous research on the laboratory desk of Sumy State University. The efficiency of gas purification from dust of ilmenite and titanium dioxide is virtually at the same level, although due to size-consist of ilmenite, particles are much larger than titanium dioxide (average size (d_{50}) is equal to 7.2 microns and 0.3 microns, respectively). This can be explained by the formation of a high layer of foam, in which the turbulent-diffusion mechanism of deposition of micronized particles is well realized.

Moreover, on the basis of industrial testing and analysis of previous research, recommendations for the use of the device with LHST were worked out. Operation of gas-cleaning equipment is possible provided a stable operation of the device, which allows a defined cleaning efficiency within a certain load range of gas and liquid.

The lower limit of the stable operation of the machine corresponds to the gas velocity, at which the dynamically stable gas-liquid layer is formed on a tray and is determined according to the

$$\frac{w_{kr1}^2}{S_o g d_o} \cdot \frac{\rho_g}{\rho_l} = B \cdot \exp\left[-4\left(\frac{L}{G}\right)^{0.25}\left(\frac{\rho_g}{\rho_l}\right)^{0.125}\right], \quad (1)$$

where w_{kr1} is critical gas velocity, which corresponds to the appearance of a secondary foaming mode, m/s; S_0 is the area of free section of a tray ,%; g is acceleration due to free-drop; d_0 is the diameter of the holes of a tray, m; ρ is gas density (g) and liquid density (l), kg/m^3; B is a coefficient depending on the diameter of the holes of a tray (when $d_0 = 0.15$ m, $B = 0.635$); L is the volume flow of the fluid, m^3/s; G is volumetric gas discharge, m^3/s.

The upper limit of the LHST device performance is determined by appearing of substantial entrainment and can be determined depending on the

$$d_{vd} = \frac{3}{4}\xi_k \frac{w_{kr2}^2 \rho_g}{\left(\rho_l - \rho_g\right) g}, \quad (2)$$

where d_{vd} is the diameter of drop hovering, m; ξ_k is the drag coefficient of the drop; w_{kr2} is critical gas velocity, which corresponds to the occurrence of drop entrainment, m/s.

In order to increase the degree of purification of gas from dust and the level of environmental safety of the enterprise, the developed device is proposed to be used in the technological scheme at the above stages of the production of titanium dioxide instead of the existing dust collection equipment (Fig. 2–4).

Since devices with LHST work steadily with contaminated fluids, then, in order to reduce water con-

Table 2

The value of the dust collection efficiency, % regarding the gas velocity and density irrigation

Type of dust and density of irrigation of a device (L), $m^3/(m^2 \cdot h)$	Dust collection efficiency,%, at a gas velocity,w, m/s			
	2.5	2.9	3.2	3.5
Titanium dioxide, $L = 15$	80	89	94.5	96
Titanium dioxide, $L = 20$	83	93	98	99.2
Ilmenite, $L = 15$	85	92	96	98
Ilmenite, $L = 20$	88	94	98.5	99.5

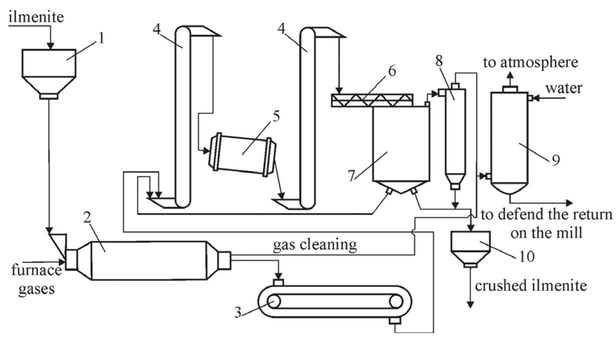

Fig. 2. The proposed scheme of gas cleaning at the stage of drying ilmenite concentrate:

1 — a loading bin; 2 — a drying drum; 3 — a flight conveyer; 4 — an elevator; 5 —a tube mill; 6 — a feeder; 7 — an air separator; 8 — a cyclone; 9 — a device with LHST; 10 — a bin of ejection

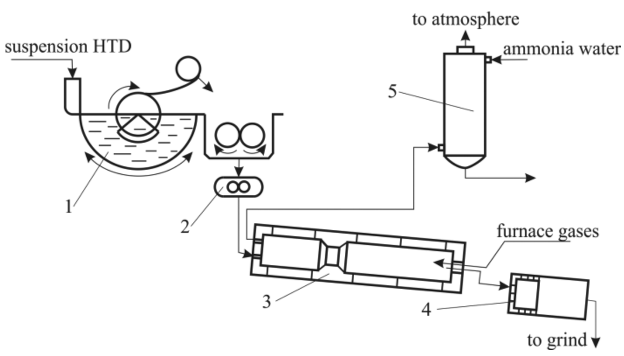

Fig. 3. The proposed scheme of gas purification at the stage of filtration and calcination of titanium dioxide:

1 — a drum-type vacuum filter (it is possible to use a press filter); 2 — a gear pump; 3 — a calcining furnace; 4 — a cooling drum; 5 — a dust chamber; 6 — a device with LHST

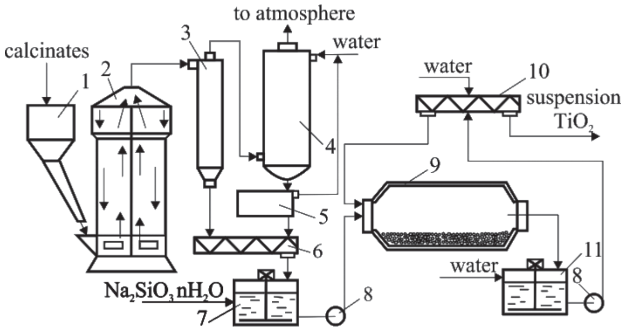

Fig. 4. The proposed scheme of gas purification at the stage of dry and wet grinding of titanium dioxide:

1 – a storage hopper; 2 – Raymond mill; 3 – a cyclone; 4 – the device with LHST; 5 – a cleaning settler; 6 – a screw; 7 – a repulpator; 8 – a pump; 9 – a wet grinding mill; 10 – a settling centrifuge; 11 – a receptacle

sumption, it is suggested to use them partly as irrigation clarified liquid after settling the resulting sludge.

The resulting precipitate is also proposed to return to various stages of the process. For example, caught at the stage of drying and grinding the dust of ilmenite can be again returned to the technological scheme for mixing with the feedstock after settling sludge dedusting. Caught at the stage of calcining and grinding the titanium dioxide, the particles of the finished product will be returned to the stage of "white" filtration after settling.

Conclusions: Industrial research of a device with LHST made it possible to establish the effectiveness of gas purification from dust titanium dioxide at 99.2 % and ilmenite dust at 99.5 %. Recommendations regarding the use of the device with LHST were given instead of the existing dust collection equipment at the three stages of the production process of titanium dioxide: ilmenite milling, calcinating and milling titanium dioxide.

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Мета. Визначення ефективності пиловловлення апарату з провальними тарілками великих отворів (ПТВО) у промислових умовах.

Методика. Дослідження ефективності пиловловлення проводилось шляхом розрахунку показника ефективності за Мерфі. При визначенні концентрації пилу на виході з апарату використовували гравіметричний метод у відповідності до „Методики проведення вимірювань масової концентрації речовини у вигляді суспендованих твердих частинок (пилу) в організованих викидах стаціонарних джерел гравіметричним методом при температурі газопилового потоку до 600 °С".

Результати. У відповідності до технологічного регламенту виробництва двоокису титану було створено апарат з ПТВО для промислових досліджень ефективності пиловловлення в цеху спеціальних марок двоокису титану. У ході проведеної роботи була визначена ефективність очистки газу від пилу двоокису титану – 9,2 % і пилу ільменіту – 99,5 %. Запропоновані рекомендації з експлуатації газоочисного апарату з ПТВО. Розглянуті пропозиції відносно впровадження апарату з ПТВО замість існуючого пиловловлюючого обладнання на трьох стадіях процесу виробництва двоокису титану: розмел ільменіту, прожарювання та розмел двоокису титану.

Наукова новизна. На основі обробки даних дослідно-промислових досліджень апарата отримані вирази для визначення швидкості газу, що забезпечує стабільну роботу апаратів з ПТВО.

Практична значимість. На основі промислових досліджень були розроблені рекомендації з експлуатації апарата з ПТВО на підприємствах хімічної промисловості.

Ключові слова: *пилогазовий викид, пиловловлення, двоокис титану, мокре очищення*

Цель. Определение эффективности пылеулавливания аппарата с крупнодырчатыми провальными тарелками (КДПТ) в промышленных условиях.

Методика. Исследование эффективности пылеулавливания проводилось путем расчета показателя эффективности по Мерфи. При измерении концентрации пыли на выходе из аппарата использовали гравиметрический метод в соответствии с „Методикой проведения измерений массовой концентрации вещества в виде суспендированных твердых частиц (пыли) в организованных выбросах стационарных источников гравиметрическим методом при температуре газопылевого потока до 600 °С".

Результаты. В соответствии с технологическим регламентом производства двуокиси титана был создан аппарат с КДПТ для промышленных испытаний эффективности пылеулавливания в цехе специальных марок двуокиси титана. В ходе проведенной работы была определена эффективность очистки газа от пыли двуокиси титана – 99,2 % и пыли ильменита – 99,5 %. Предложены рекомендации по эксплуатации газоочистного аппарата с КДПТ. Разработаны предложения относительно внедрения аппарата с КДПТ вместо существующего пылеулавливающего оборудования на трех стадиях процесса производства двуокиси титана: размол ильменита, прокалка и размол двуокиси титана.

Научная новизна. На основе обработки данных опытно-промышленных испытаний аппарата получены выражения для определения скорости газа, обеспечивающей стабильную работу аппаратов с КДПТ.

Практическая значимость. На основании промышленных испытаний были разработаны рекомендации по эксплуатации аппарата с КДПТ на предприятиях химической промышленности.

Ключевые слова: *пылегазовый выброс, пылеулавливание, двуокись титана, мокрая очистка*

Рекомендовано *до публікації докт. техн. наук Л. Г. Філатовим. Дата надходження рукопису 25.05.15.*