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CALCULATION AND IMPLEMENTATION OF A CYCLONE-VORTEX DEVICE IN CHROMIC SULPHATE PRODUCTION

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Abstract. Traditional gas cleaning schemes are mainly equipped with separate gas cleaning devices that perform the functions of ensuring a given efficiency in cleaning from dust particles and gas components. In this regard, the creation of combined apparatuses combining several zones for carrying out various processes in one apparatus is in demand. Analysis of the operation of combined gas purification devices for purifying multicomponent gases made it possible to develop the design of a cyclone-vortex action device, in the lower zone of which a centrifugal mechanism for collecting dust is realized, and in the upper zone – vortex interaction of a gas-liquid flow in the volume of a regular packing, which provides absorption cleaning. The development and implementation of such devices seems to be relevant. In the manufacture of a laboratory installation, the structural ratios of the cyclone and packed stages of the apparatus of cyclone-vortex action were obtained based on the recommendations for the manufacture of cyclones, as well as the results of research and recommendations for the design of apparatuses with a regular movable nozzle. In the process of research, standard methods for determining the hydraulic resistance and dust collection efficiency were used. Based on the results of laboratory studies, the main calculated dependences of the hydraulic resistance and dust collection parameters of the cyclone and packed stages and the device as a whole were obtained, which, along with the recommendations, were used to calculate and design an industrial device. The cyclone-vortex action device was tested in industrial conditions and implemented in the technological scheme for the purification of gases leaving the boiling bed dryer in chromic sulfate production at Aktobe Plant of Chromic Compounds JSC. According to the results of industrial tests, it was noted that in the cyclone part, the increase in hydraulic resistance with an increase in gas velocity is due to an increase in dynamic pressure and losses associated with a change in the direction of gas movement and friction losses. The effective force acting on suspended solids is the centrifugal force, the magnitude of which is largely determined by the velocity of the gas flow. In the packed zone, the operation of the apparatus proceeds in a drop mode, characterized by a uniform distribution of flows over the cross section of the apparatus, an increase in the turbulence of the gas-liquid flow, and an increase in the intensity and frequency of pulsations. This contributes to an increase in the efficiency of dust collection.

Keywords: gas purification device, cyclone-vortex device, hydraulic resistance, dust collection efficiency, gas velocity, industrial tests, implementation

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ХРОМ СУЛЬФАТЫН ӨНДІРУДЕ ЦИКЛОНДЫ-ҚҰЙЫНДЫ АППАРАТТЫ ЕСЕПТЕУ ЖӘНЕ ЕНГІЗУ

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Аннотация. Газды тазартудың дәстүрлі сұлбалары негізінен шаң бөлшектері мен газ компоненттерінен тазартудың берілген тиімділігін қамтамасыз ету функцияларын орындайтын жеке газ тазарту аппараттарымен жабдықталған. Осыған байланысты бір аппаратта әртүрлі процестерді жүргізу үшін бірнеше аймақтарды біріктіретін біріктірілген аппараттарды құру сұранысқа ие. Көп компонентті газдарды тазартуға арналған қолданыстағы біріктірілген газ тазарту аппараттарының жұмысын талдау циклонды-құйынды әсер ететін аппараттың конструкциясын әзірлеуге мүмкіндік берді, оның төменгі аймағында шаңды ұстаудың орталықтан тепкіш механизмі, ал жоғарғы жағында – сіңіргіш (абсорбциялық) тазалауды қамтамасыз ететін тұрақты саптама көлеміндегі газ-сұйықтық ағынының құйынды өзара әрекеттесуі жүзеге асырылады. Мұндай аппараттарды әзірлеу және енгізу өзекті болып көрінеді. Зертханалық қондырғыны дайындау кезінде циклонды-құйынды әсер ететін аппараттың циклондық және саптамалық сатыларының конструктивтік арақатынасы циклондарды дайындау жөніндегі ұсынымдарға, сондай-ақ зерттеу нәтижелеріне және тұрақты жылжымалы саптамасы бар аппараттарды жобалау жөніндегі ұсынымдарға сүйене отырып алынды. Зерттеу барысында гидравликалық кедергілер мен шаң аулаудың тиімділігін анықтаудың стандартты әдістері қолданылды. Зертханалық зерттеулердің нәтижелері негізінде гидравликалық кедергінің және циклондық және саптамалық сатылардың және тұтастай алғанда аппараттың шаң аулау параметрлерінің негізгі есептік тәуелділіктері алынды, олар ұсыныстармен қатар өнеркәсіптік аппаратты есептеу және жобалау үшін пайдаланылды. Циклонды-құйынды әсер ететін аппарат өнеркәсіптік жағдайларда сыналды және "Ақтөбе хром қосылыстары зауыты" АҚ-да хром сульфатын өндіруде қайнаған қабатты кептіргіштен шығатын газдарды тазартудың технологиялық схемасына енгізілді. Өнеркәсіптік сынақтардың нәтижелері бойынша циклон бөлігінде газ жылдамдығының жоғарылауы кезінде гидравликалық кедергінің өсуі динамикалық қысымның өсуіне және газдың қозғалыс бағытының өзгеруіне және үйкеліс шығындарына байланысты шығындарға байланысты екендігі атап өтілді. Қатты қалқыма бөлшектерге әсер ететін тиімді күш-бұл ортадан тепкіш күш, оның мәні негізінен газ ағынының жылдамдығына байланысты. Саптама аймағында аппараттың жұмысы ағындардың аппараттың көлденең қимасы бойынша біркелкі бөлінуімен, газ-сұйықтық ағынының турбуленттілігінің өсуімен, пульсация жиілігінің қарқындылығымен және ұлғаюымен сипатталатын тамшы режимінде жүреді. Бұл шаң аулау тиімділігінің артуына ықпал етеді.

Түйін сөздер: газ тазалау аппараты, циклонды-құйынды аппарат, гидравликалық кедергі, шаң аулау тиімділігі, газ жылдамдығы, өнеркәсіптік сынақтар, енгізу

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РАСЧЕТ И ВНЕДРЕНИЕ ЦИКЛОННО-ВИХРЕВОГО АППАРАТА В ПРОИЗВОДСТВЕ СУЛЬФАТА ХРОМА

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Аннотация. Традиционные схемы очистки газов оснащены в основном отдельными газоочистными аппаратами, выполняющих функции по обеспечению заданной эффективности по очистке от пылевых частиц и газовых компонентов. В этой связи востребованным является создание комбинированных аппаратов сочетающих несколько зон для проведения различных процессов в одном аппарате. Анализ работы существующих комбинированных газоочистных аппаратов для очистки многокомпонентных газов позволил разработать конструкцию аппарата циклонно-вихревого действия, в нижней зоне которого реализуется центробежный механизм улавливания пыли, а в верхней – вихревое взаимодействие газожидкостного потока в объеме регулярной насадки, обеспечивающего абсорбционную очистку. Разработка и внедрение таких аппаратов представляется актуальной. При изготовлении лабораторной установки конструктивные соотношения циклонной и насадочной ступеней аппарата циклонно-вихревого действия получены исходя из рекомендаций по изготовлению циклонов, а также результатов исследований и рекомендаций по проектированию аппаратов с регулярной подвижной насадкой. В процессе исследований использовались стандартные методы определения гидравлического сопротивления и эффективности пылеулавливания. На основе результатов лабораторных исследований получены основные расчетные зависимости гидравлического сопротивления и параметров пылеулавливания циклонной и насадочной ступеней и аппарата в целом, которые наряду с рекомендациями были использованы для расчета и проектирования промышленного аппарата. Аппарат циклонно-вихревого действия был испытан в промышленных условиях и внедрен в технологической схеме очистки газов, отходящих от сушилки кипящего слоя в производстве сульфата хрома на АО «Актюбинский завод хромовых соединений». По результатам промышленных испытаний отмечено, что в циклонной части рост гидравлического сопротивления при увеличении скорости газа обусловлен ростом динамического напора и потерями, связанными с изменением направления движения газа и потерями на трение. Эффективной силой, воздействующей на взвешенные твердые частицы, является центробежная сила, величина которой в значительной степени обуславливается скоростью газового потока. В насадочной зоне работа аппарата протекает в капельном режиме, характеризующимся однородностью распределения потоков по поперечному сечению аппарата, ростом турбулентности газожидкостного потока, интенсивностью и увеличением частоты пульсаций. Это способствует росту эффективности пылеулавливания.

Ключевые слова: газоочистной аппарат, циклонно-вихревой аппарат, гидравлическое сопротивление, эффективность пылеулавливания, скорость газа, промышленные испытания, внедрение

Introduction

The existing technological gas purification schemes provide for installation of separate devices in which dust collection and absorption processes are carried out sequentially, as well as combined devices combining several zones for carrying out different processes in one device. In this connection, schemes with combined devices are often preferred due to their compactness and low material consumption.

Combined devices include inertial-turbulent devices with a movable (regular) packing (Tarat et.al., 1979: 208; Strauss, 1974: 392; Ramatullayeva, 2009: 113), which implement shock interaction of the gas flow with the liquid mirror and vortex interaction in the regular packed zone. In these devices, one and the same absorbing solution is used in the dust collection and absorption zones. This is not always appropriate. So, for example, when trapping soluble dust, simultaneous absorption of gaseous components is difficult due to a decrease in the gas solubility.

This problem is solved in the design of a combined device with autonomous irrigation circuits, separately for each of the zones – shock-inertial and packed, which prevent the formation of deposits and increase the driving force of the absorption process (Khussanov, 2011: 141). At the same time, this device has significant hydraulic resistance.

For separate carrying out of dust collection and absorption processes, we have developed a design of a cyclone-vortex action device (Issayeva et al., 2021: 8), in the lower zone of which a centrifugal mechanism of dust collection is realized in the absence of irrigation with a liquid, and in the upper zone there is a vortex interaction of a gas-liquid flow in the volume of a regular packing.

The purpose of the article is to obtain a methodology for calculating the hydraulic resistance and dust collection parameters of the cyclone and packed stages and the cyclone-vortex device as a whole, as well as to analyze the results obtained in the process of industrial tests and the introduction of this device in the technological scheme for purifying gases leaving the boiling bed dryer in production of chromic sulfate at Aktobe Plant of Chromic Compounds JSC.

The research methodology included standard methods for determining hydraulic resistance and dust collection efficiency.

Materials and methods

The experimental plant for conducting studies of hydraulic resistance and dust collection efficiency included a cyclone-vortex dust collector, a fan, a pump, circulation and pressure liquid containers for irrigating the upper contact stage, a container for collecting dry dust from the lower contact stage, a compressor for spraying dust at the dust collector inlet.

In all experiments, the dust concentration at the inlet to the device was maintained at about 2 g/m3. KP–3 dusty quartz, additionally milled in a vibrating mill, was used as the standard dust.

When determining the overall dust collection efficiency, the internal filtration method was used (Gordon et.al., 1977: 456). Glass wool was used to fill the allonge. The gas consumption through the allonge was set based on the condition of isokinetic sampling. To measure the dispersed composition of dust in a gas flow, an impactor was used instead of allonges (Rusakov et. al., 1970: 52).

The hydraulic resistance of the device ΔP was measured by a differential pressure gauge and controlled by a DSR-type device.

Research results

The basis for creating the design of the cyclone-vortex action device (Issayeva et al., 2021: 7; Torskiy et.al., 2018: 8) was the recommendations for the manufacture of cyclones mainly of the design of NIIOGAZ (Shvydkiy et. al., 2002: 640; Vetoshkin, 2005: 210), as well as the research results and recommendations for the design of devices with a regular movable packing (Volnenko, 2018: 176), ITPN, UID with RPN (Balabekov, 2018: 184), device with shock-vortex interaction of flows, combined gas-liquid device with autonomous irrigation circuits (Khussanov, 2011: 141).

The recommended design ratios of the cyclone-vortex action device were: For the cyclone stage (here D is the diameter of the cylindrical part of the device):

– the inner diameter of the exhaust pipe d = 0.59D;
– the inner diameter of the dust outlet d_1 = 0.4D;
– the width of the inlet fitting in the cyclone part (internal dimension) b = 0.2D;
– the width of the inlet fitting at the inlet (internal dimension) b_1 = 0.26D;
– the length of the inlet fitting l = 0.6D;
– the height of the plant flange h_{pf} = 0.1D;
– the angle of inclination of the cover and inlet fitting α= 15°;
– the height of the inlet fitting (internal dimension) a=0.66D;
– the height of the exhaust pipe h_p = 1.74D;
– the height of the cylindrical part H_{cl} = 2.26D;
– the height of the cone H_{cn} = 2D;

– the height of the outer part of the exhaust pipe h_{op}=0.3D;
– the total height of the cyclone part of the device H_{cp} = 4.56D.
For the vortex stage:
– the vertical pitch between the packed elements t_v/b=2;
– the horizontal pitch between the packed elements horizontally t_r/b = 2;
– the size of the packed elements (plates) bxbxδ = 40x40x1 mm;
– the height of the packed zone H_L = 2.5D.
The total height of the device H_{ap} = 9.75D.
The laboratory plant included a device D = 400 mm.

Based on the results of laboratory studies, the main calculated dependences of the hydrodynamic characteristics and dust collection parameters were obtained.

To calculate the total hydraulic resistance of the device, the following formula was obtained (Zhumadullayev et.al., 2020: 7):

$$\Delta P_{ap} = \Delta P_{cp} + \Delta P_L, \quad (1)$$

where ΔP_{cp} – the hydraulic resistance of the cyclone stage, Pa; ΔP_L – the hydraulic resistance of the packed zone, Pa.

The hydraulic resistance of the cyclone stage is determined by the equation:

$$\Delta P_{cp} = \Delta P_{in} + \Delta P_{az} + \Delta P_{out}, \quad (2)$$

where P_{in} – the hydraulic resistance of the inlet section, Pa; ΔP_{az} – the hydraulic resistance of the annular zone, Pa; ΔP_{out} – the hydraulic resistance of the outlet section, Pa.

The hydraulic resistance of the inlet section:

$$\Delta P_{in} = \xi_{in} \cdot \frac{\rho_g \cdot w_{in}^2}{2}, \quad (3)$$

where $\xi_{in} = 3{,}32$ – the resistance coefficient at the gas inlet; w_{in} – the gas velocity at the inlet, m/s.

The hydraulic resistance of the annular zone:

$$\Delta P_{az} = \xi_{az} \cdot \frac{\rho_g \cdot w_{az}^2}{2}, \quad (4)$$

where $\xi_{az} = 4{,}1$ – the resistance coefficient when passing the annular gap; w_{az} – the gas velocity in the annular gap, m/s.

The hydraulic resistance of the outlet section:

$$\Delta P_{out} = \xi_{out} \cdot \frac{\rho_g \cdot w_{out}^2}{2}, \quad (5)$$

where $\xi_{out} = 5{,}7$ – the resistance coefficient at the gas outlet; w_{out} – the gas velocity at the outlet, m/s.

The hydraulic resistance of the packed zone is determined by the formula used to calculate devices with a regular movable packing (Balabekov, 2018: 184):

$$\Delta P_L = \xi_L \frac{H}{t_v} \cdot \frac{\rho_g \cdot W_g^2}{2\varepsilon_0^2}. \quad (6)$$

Here H – the height of the packed zone, m; ε_0 – the porosity of the packing:

$$\varepsilon_0 = 1 - \left(\frac{b}{t_r}\right)^2. \quad (7)$$

The resistance coefficient of the irrigation packing takes into account the degree of interaction of vortices in the vertical and radial directions, the pressure loss due to the gas friction against the liquid surface (Balabekov, 2018:184). By processing the experimental data, the expression was obtained to determine :

$$\xi_L = 0{,}7 \cdot \theta_v \cdot \theta_r \cdot \frac{Re_l^{0{,}25}}{Re_g^{0{,}1}}, \quad (8)$$

where Re_l and Re_g – the Reynolds numbers for gas and liquid; θ_v and θ_r – coefficients that take into account the degree of interaction of vortices in the vertical and radial directions.

The Reynolds number for the gas phase, which is determined by the formula:

$$Re_g = \frac{W_g \cdot d_{eq}}{\nu_g}. \quad (9)$$

here d_{eq} – the equivalent diameter of the packing, m.

The Reynolds number $Re_ж$ is determined by the formula:

$$Re_l = \frac{U_l \cdot d_{eq}}{\nu_l}, \quad (10)$$

where U_l= L/3600 – the liquid velocity, m/s.

The overall efficiency of the cyclone-vortex device, taking into account the efficiency of the dry and wet stages, can be calculated by the formula:

$$\eta_{gen} = 1 - (1 - \eta_{ds})\,(1 - \eta_{ws}). \quad (11)$$

The dust collection efficiency of a dry stage, based on the centrifugal-inertial model (Shvydkiy, et.al., 2002:640) can be determined by the formula:

$$\eta_{ds} = 1 - exp\left[-2(C_{ds} \cdot \psi)^{1/(2n+2)}\right], \quad (12)$$

where C_{ds} – the coefficient that depends on the design ratios of the device of a dry stage.

For a dry stage, the coefficient C_{ds} is calculated according to the equation (Torskiy et. al., 2019: 6):

$$C_{ds} = \frac{\pi \cdot D_{cp}^2}{a \cdot b_1} \cdot \left[1 - \left(\frac{d}{D_{cp}}\right)^2\right] \cdot \left(\frac{2 \cdot h_T}{D_{cp}} - \frac{h_v}{D_{cp}}\right) + \left[\left(\frac{d}{D_{cp}}\right)^2 - \left(\frac{d_1}{D_{cp}}\right)^2\right] \cdot \left(\frac{4 \cdot H_{cp}}{D_{cp}} + \frac{4 \cdot H_{ds}}{D_{cp}}\right) \quad (13)$$

The equation (13) uses the design ratios recommended above.

The quantity in the equation (12) is a modified inertial parameter characterizing the state of the dust-gas mixture (Shvydkiy et. al., 2002: 640):

$$\psi = \frac{d_{ch}^2 \cdot \rho_{ch} \cdot W_{in}}{18 \mu_g \cdot D_{cp}} (n + 1), \quad (14)$$

where W_{in} – the gas velocity at the inlet to the dry stage, m/s.

The quantity n in the equations (12) and (14) according to (Shvydkiy, et.al., 2002:640) is:

$$n = 1 - (1 - 0{,}0165 \cdot D_{cp}^{0{,}14}) \cdot \left(\frac{T_g}{283}\right)^{0{,}3}. \quad (15)$$

Here T_g – the absolute temperature of gases, °K.

The dust collection efficiency of the cyclone-vortex device's packed zone is determined by the formula:

$$\eta_{pz} = 2{,}97 \cdot \left(\frac{W_g \cdot d_{ds}}{D_T}\right)^{-1/4} . \quad (16)$$

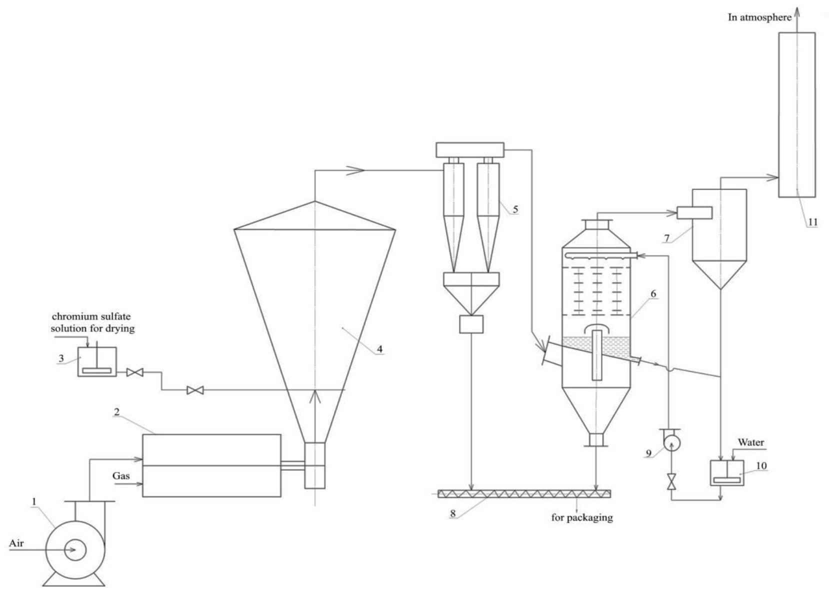
The turbulent diffusion coefficient is determined by the formula:

$$D_T = B_T \cdot (\xi_L)^{1/3} \cdot (1 - \varepsilon_0)^{1/3} \cdot \left(\frac{H}{t_v}\right)^{1/3} \cdot \left(\frac{\rho_g}{\rho_l}\right)^{1/3} \cdot \left(\frac{1}{h_0}\right)^{1/3} \cdot d_{ds}^{4/3} \cdot u_g \cdot Stk, \quad (17)$$

where $B_T = 8{,}38 \cdot (1 - \varphi)$ – the correcting coefficient; $Stk = \frac{\rho_{ch} \cdot d_{ch}^2 \cdot u_{ch}}{18 \mu_g \cdot d_{ds}}$ – the Stokes criterion.

The cyclone-vortex action device's design was proposed for the reconstruction of the technological scheme for the purification of gases leaving the boiling bed dryer in chromic sulfate production at Aktobe Plant of Chromic Compounds JSC.

The method for chromic sulphate (basic) production is based on the interaction of sulfur dioxide with a solution of sodium dichromate. Sulfur dioxide is formed when sulfur is burned in a furnace. During the production process, a solution of sodium bichromate with a concentration of (230–300) g/l in terms of CrO_3 enters the reduction column, where the sulfur dioxide gas formed during the combustion of sulfur in the furnace flows in a countercurrent flow, resulting in the formation of a solution of chromic sulfate. The resulting solution of chromic sulfate goes for drying in the "boiling bed" dryer, dried chromic sulfate goes for packaging (Fig 1) (Permanent technological regulations for chromic sulfate production, shop, 2015: 91).



1 – smoke exhauster; 2 – firebox; 3 – boiling bed dryer feeder; 4 – boiling bed dryer; 5 – a group of 6 cyclones; 6 – cyclone-vortex device; 7 – trap; 8 – screw; 9 – pump; 10 – irrigation tank; 11 – sanitary pipe.

Fig 1. The technological scheme for the purification of gases leaving the boiling bed dryer in chromic sulfate production.

From the feeder 3, a syrupy solution of chromic sulfate with a concentration of CrO_3 (380–415) g/l is fed through an atomizer into the "boiling bed" dryer 4. The "boiling bed" dryer is a hollow container with a lattice in the lower part, on which the layer of granular chromic sulfate "cushion" lies. Above the lattice, a disintegrator is installed, which serves to crush the "cushion". The flue gases obtained by burning natural gas in the firebox 2 enter the lower part of the dryer. As a result of intense heat exchange between the flue gases, the "cushion" and the chromic sulfate solution, the latter is dried. The temperature in the dryer under the lattice is maintained at the level of (145–155)°C due to the dilution of hot gases with cold air. The temperature in the layer is (70–75)°C. The dried chromic sulphate together with the steam-gas mixture with the smoke exhauster D–12 1 is pulled through a group of cyclones 5, where its main part (90–95) % is trapped and collected in the cyclone bunker, from there through the "flashers" and then a system of screws, the dried chromic sulphate enters into the supply hopper of the filling conveyor.

For a more complete purifying (before the reconstruction), the steam-gas mixture passes through a scrubber and the trap 7 irrigated with water, then is thrown out through the sanitary pipe 11 into the atmosphere. Process water is used to irrigate the scrubber. Upon reaching the concentration of (110–120) g/l in terms of CrO_3, the solution from the irrigation tank of the dryer is pumped into a collection tank, from where it is pumped into the irrigation tank as required.

Air is supplied to the boiling bed dryer by the smoke exhauster 1. Part of the air goes to the atomizer as “primary” for the gas combustion, the rest of the air is supplied directly to the firebox 2 to dilute and cool the flue gases.

During the examination of the existing purification technological scheme, in which the irrigated hollow scrubber was installed as the final stage, the maximum decrease in the dust concentration (average quantity) was C_{ds} = 0.22 g/Nm^3, which is higher than the standard indicator (C_{std} = 0.174 g/Nm^3).

In the reconstructed purification scheme, the irrigated scrubber was replaced by the cyclone-vortex device 6.

The diameter of the device was determined from the results of measurements of the velocity field, and the dimensions of the stages were determined according to the recommendations obtained based on the laboratory studies.

The cyclone-vortex device operates as follows.

The gas flow entering the purification is supplied through the nozzle installed tangentially in the lower part of the device. With the tangential supply of the gas flow, a centrifugal force arises, which acts on solid dust particles, pressing them against the inner wall of the device. Under the action of gravity, solid dust particles slide into the conical bottom of the lower contact stage and are removed from the device through the lower fitting.

The dust-free gas flow through the lower cut of the central pipe enters the upper contact stage. At the inlet to it, the central pipe is equipped with a cap to prevent the ingress of flowing irrigation liquid.

The lower and upper stages of contact are separated by an inclined partition, as a result of which they operate autonomously.

The operation of the upper stage of contact occurs in a counter-current mode. In this case, the gas flow entering from below interacts with the irrigation liquid supplied through the irrigator in the packed zone volume. The packed elements’ arrangement on the strings is made with the pitch of 2 of the packed body caliber (for plates). This pitch ensures the simultaneous vortex formation mode (in-phase mode) achievement. The simultaneous vortex formation mode is characterized by the coincidence of the time of vortex formation behind the packed bodies and the time of motion of the formed vortices behind the chain of packed bodies located in the gas flow direction. At the moment of approach, there is an interaction of the vortexes that have flown in and have completed the cycle of vortex formation behind the packed bodies. As a result of this interaction, the total power of the vortices increases, which makes it possible to do a lot of work on crushing the irrigation liquid and creating a highly developed surface.

The purified gas flow is removed from the device through the outlet fitting. The spent liquid in the upper stage is removed from the device through the fitting.

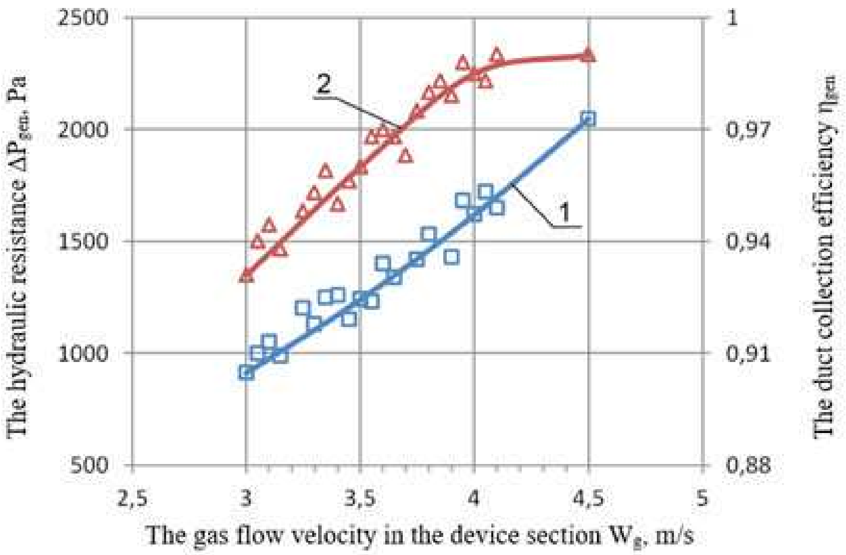
During the tests of the reconstructed technological scheme, carried out jointly with the enterprise employees, the following research results were obtained. The ranges of changes in the main gas flow parameters during the passage of gas cleaning equipment:

Up to a group of cyclones

– gas temperature 61–65°C;

– pressure (350–460) Pa;
– gas consumption 6780–7760 Nm^3/h;
– average dust concentration 8.0 g/Nm^3.
After a group of cyclones
– gas temperature 58–63°C;
– pressure (480–510) Pa;
– gas consumption 8100–8770 Nm^3/h;
– average dust concentration 2.405 g/Nm^3.
After the cyclone-vortex device
– gas temperature 43–52°C;
– pressure (160–200) Pa;
– gas consumption 10630–11770 Nm^3/h;
– average dust concentration 0.029 g/Nm^3.

Figure 2 shows graphical dependences of the hydraulic resistance and the dust collection efficiency of the cyclone-vortex device obtained as a result of industrial tests and the calculated quantities according to the equations (1) and (11).



Experimental conditions: irrigation density L = 25 m^3/m^2h; the vertical pitch between the plate packed elements t_v= 2b, in the radial direction t_r=2b; the size of the plates bxbxδ = 50x50x1 mm; the average diameter of the trapped particles d_{cht} = 5 microns.
The curves – calculation; the points – experimental data
1 – ΔP_{gen}; 2 – η_{gen}.

Fig 2. Dependence of the hydraulic resistance and the dust collection efficiency of the cyclone-vortex device on the gas flow velocity in the section of the device.

As can be seen from the figure, the hydraulic resistance and the dust collection efficiency of the cyclone-vortex device increase in the entire range of gas velocities.

Discussion

The hydraulic resistance of the device consists of the resistances of the cyclone and packed parts. In the cyclone part, an increase in the hydraulic resistance with an increase in the gas velocity is due to an increase in the dynamic head and losses associated with a change in the direction of gas motion and friction losses. The results of laboratory studies of the hydraulic resistance of the packed zone indicate that in the velocity range from 2.5 to 4 m/s a drop mode occurs, in which the liquid phase is mainly presented in the form of drops. The operation of the device achieves the highest stabilization at 4.0 m/s. The uniformity of the distribution of flows over the cross-section of the device improves, the turbulence of the gas-liquid flow increases due to the intensification of the process of formation and separation of vortices behind the streamlined bodies.

The dust collection efficiency in the device consists of the efficiency of the cyclone and packed parts.

In cyclone-type devices, the most effective force acting on suspended solids is the centrifugal force, the quantity of which is largely determined by the gas flow velocity. With an increase in the gas consumption, and, consequently, its velocity, the centrifugal force increases, and the efficiency of collecting particles increases.

The dust collection efficiency of the packed zone in the drop mode achieves its maximum quantities, after which a further increase in the gas velocity leads to the entrainment of liquid from the device and the efficiency of the process is somewhat reduced. High quantities of the degree of dust collection are due to the vortex crushing of liquid in the packed zone of the device. Since the vortex separation frequency from the packed elements and, accordingly, the intensity and frequency of pulsations increase in proportion to the gas velocity, with unchanged packed parameters, this leads to an intensification of the process of the liquid film separation and its subsequent crushing into smaller drops. This naturally increases the contact surface of the phases, and, ultimately, the dust collection efficiency.

The tests carried out confirmed the possibility of effective dust collection from gas emissions in the cyclone-vortex device.

The cyclone-vortex device was implemented in the technological scheme for the purification of gases leaving the boiling bed dryer in chromic sulfate production at Aktobe Plant of Chromic Compounds JSC.

Conclusions

Based on recommendations for the manufacture of cyclones, as well as the research results and recommendations for the design of devices with a regular movable packing, with shock-vortex interaction of flows, the design ratios of the cyclone and packed stages of the cyclone-vortex action device were established.

Based on the results of laboratory studies, the main calculated dependences of the hydraulic resistance and dust collection parameters of the cyclone and packed stages and the device as a whole were obtained.

The cyclone-vortex action device's design was proposed for the reconstruction of the technological scheme for the purification of gases leaving the boiling bed dryer in chromic sulfate production at Aktobe Plant of Chromic Compounds JSC.

Based on the results of industrial tests, the graphical dependences of the hydraulic resistance and the dust collection efficiency of the cyclone-vortex device on the gas flow velocity in the cross-section of the device were obtained and the analysis was carried out. It was noted that in the cyclone part, an increase in the hydraulic resistance with an increase in the gas velocity is due to an increase in the dynamic head and losses associated with a change in the direction of gas motion and friction losses. The effective force acting on suspended solids is the centrifugal force, the quantity of which is largely determined by the gas flow velocity. In the packed zone, the operation of the device proceeds in the drop mode, characterized by the uniformity of the distribution of flows over the cross-section of the device, an increase in the turbulence of the gas-liquid flow, the intensity and increase in the frequency of pulsations. This contributes to an increase in the dust collection efficiency.

The cyclone-vortex device was implemented in the technological scheme for the purification of gases leaving the boiling bed dryer in chromic sulfate production at Aktobe Plant of Chromic Compounds JSC.

As recommendations for improving the proposed device design, it can be noted that to purify high-temperature multicomponent gases, it is necessary to use a regular structure tubular packing as a packing.

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