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THE FEASIBILITY GROUNDS FOR USING OF UNTWISTING DEVICES IN CYCLONES

The article presented a feasibility study of application of the developed constructions of untwisting devices in cyclone apparatus: blade untwisting device and the untwisting device with stream recirculation, allowing substantially to reduce pressure drop and promote efficiency of catching of dispersible particles. The calculations of economy of energy and money facilities are resulted at cleaning of gas in cyclones with the developed untwisting devices. Application in the most widespread cyclones CN-11 and CN-15 blade untwisting device power inputs on clearing 1,000 m^3 gas decrease on the average on 0.25 and 0.15 kW · h, and using of the untwisting device with recirculation of a stream – on 0.2 and 0.11 kW · h accordingly. The term of recoupment of additional expenses on an untwisting device will make less than year.

Introduction. Ecological problems caused by emissions of polluted gas streams in the atmosphere, gradually become more escalated due to the growth of industrial production and to the degree of air pollution. Solving of ecological problems of power-consuming industries is connected with following the active energy efficiency policy, implementation of energy-efficient technologies, modern means and devices for purification of gas emissions.

At present the most widespread type of dry dedusters in systems of gas cleaning and ventilation are cyclones, and in this field there are essential possibilities for energy saving [1].

Energy loss in a cyclone is caused by various factors. Their considerable part is connected with a rotary motion of gas and loss of kinetic energy of an emergent vortical flow. Therefore it is possible to reduce cyclone pressure drop essentially by reducing intensity of rotation of this flow by means of an untwisting device, allowing to transform kinetic energy of the rotary motion into potential energy of the static pressure.

Considering that energy saving is the priority direction of basic and applied scientific researches of the Republic of Belarus, decrease in energy loss at gas cleaning in cyclones is an urgent problem.

Main part. At the department of processes and apparatus of chemical production processes and devices of chemical productions of the Belarusian state technological university two new designs of untwisting devices are worked out: the blade untwisting device and the untwisting device with flow recirculation, presented in Fig. 1.

The blade untwisting device, placed within the exhaust pipe of the cyclone, consists of a cylindrical part (core) *1* with radial blades *2*, curved along the rotation direction of the gas flow, and cone *3*. The profile of blades *2* corresponds to a circular arc (according to the average line of the blade profile of axial fans [2, 3]) with radius r_b. The tilt angle of a forward edge α is determined by the aerodynamics of the gas flow in the exhaust pipe, and the outlet angle corresponds to axial movement of gas.

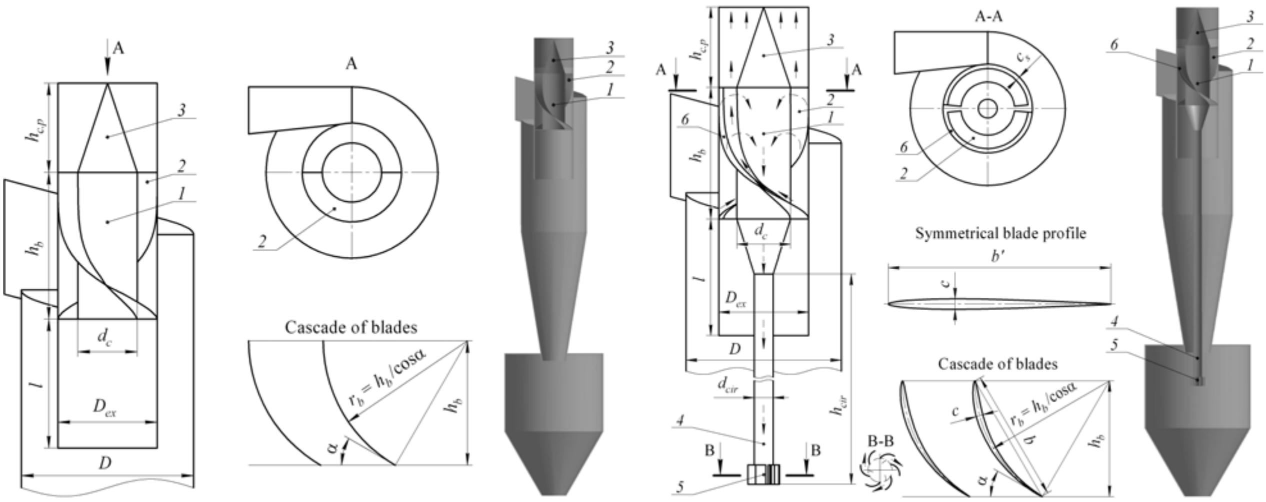
The operation principle of the developed device is as follows. The cleaned gas in the form of the vortex flow enters the exhaust pipe and gets to the blades *2* of the untwisting device, where the gradual straightening of the flow occurs. Due to the cone *3*, the gradual expansion of the gas flow over the whole section of the exhaust pipe is provided. The core *1* serves for the liquidation of the axial return flow.

The untwisting device with flow recirculation (Fig. 1, *b*) consists of the hollow cylindrical part (core) *1*, hollow radial blades *2*, curved along the rotation direction of the gas flow and having slots *6*, a cone *3*, a circulation pipe *4* and a static swirler *5*, placed at the bottom end of the circulation pipe *4*, the static swirler *5* makes the gas twisting in the direction of the flow rotation in the cyclone.

The operation principle of the untwisting device with flow recirculation is as follows. The vortex upflow enters the exhaust pipe and gets to the blades *2* of the untwisting device, where the gradual straightening of the flow occurs. The particles captured by this upward vortex move along the interior of the exhaust pipe. Through the slots *6* and hollows of blades *2* they fall into the core *1* and then by the circulation pipe *4* go into the bunker of the caught dust. To intensify the separation of circulating powder-gas flow, the outlet of the circulation pipe *4* is provided with the swirler *5*. Due to the cone *3*, the gradual expansion of the gas flow over the whole section of the exhaust pipe is provided.

The parameters of the blade untwisting device and the untwisting device with flow recirculation are presented in Table 1.

Researches of pressure drop and separation efficiency of cyclones TsN-11 and TsN-15 fitted with untwisting devices were carried out according to techniques described in work [4].



a *b*

Fig. 1. The cyclones fitted with the untwisting devices:
a – with the blade untwisting device; *b* – with the untwisting device with flow recirculation:
1 – cylindrical part (core); *2* – blade; *3* – conic part (cone); *4* – circulation pipe; *5* – static swirler; *6* – slot;
b is the chord of the blade profile; b' is the mean line length of the blade profile;
c is the maximum thickness of the blade profile; c_s is the slot width; D is the cyclone diameter;
D_{ex} is the exhaust pipe diameter; d_c is the core diameter; d_{cir} is the circulation pipe diameter;
h_b is the blade height; h_{cir} is the circulation pipe height; $h_{c.p}$ is the cone height; l is the mounting height of the untwisting device; r_b is the curvature radius of the blade profile; α is the slop angle of the blade profile

Table 1

The parameters of the untwisting devicesfor cyclones

Parameters	Untwisting devices		Untwisting device with flow recirculation	
	TsN-11	TsN-15	TsN-11	TsN-15
Core diameter d_c	(0.37–0.41)D	(0.32–0.38)D	(0.37–0.41)D	(0.32–0.38)D
Number of blades n	2			
Blade width h_b	0.87D			
Slope angle of the blade profile α	30°			
Cone width of the circulation pipe $h_{c.p}$	1.5d_c			
Machine height in the exhaust pipe l	1.12D	0.77D	1.12D	0.77D
Slot width of the front side of blade c_s	–		0.026D	
Inner diameter of the circulation pipe d_{cir}	–		0.12D	
Circulation pipe height h_{cir}	–		4D	3.7D

The ground ceramic brick (STB 1160-99) which particle-size distribution was defined by a method of laser diffraction by means of the laser analyzer of the particle sizes Analizette 22 Micro-Tec Fritsch GmbH (Germany) was used as a test dust. The median particle diameter of tile powder was equal to $d_m = (15.6 \pm 0.1)$ μm.

Pressure drop of cyclones TsN-11 and TsN-15 fitted with the untwisting devices and without them, and also calculated according to NIIOGAZ-procedure is given in Fig. 2. The analysis of the dependences presented in this figure shows that the difference between calculated according to NIIOGAZ values [5–7] and defined experimentally for cyclones TsN-11 and TsN-15 doesn't exceed 1.5–3.0% and 2.5–5.5% respectively. At the same time the pressure drop factor of the experimental cyclones TsN-11 and TsN-15 at mean velocity in cyclone body in a range w = 2.5–4.0 m/s is equal ζ = 231–235 and ζ = 140–145, i.e. its values changed slightly (didn't exceed 2–3%).

The use of the blade untwisting device allows to reduce pressure drop in the cyclones TsN-11 and TsN-15, which are the most widespread, by 28–30% and 26.0–27.5% respectively at the same separation efficiency.

The use of the untwisting device with flow recirculation allows to reduce pressure drop in the cyclones TsN-11 and TsN-15 on the average by 23 and 19% and to raise separation efficiency –

dust loss decreases by 10–17% and 7–12% respectively (Fig. 3).

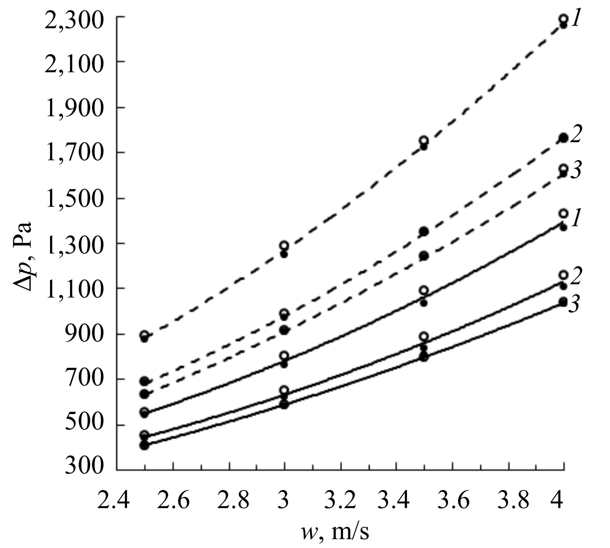


Fig. 2. Pressure drop of cyclone TsN-11 and TsN-15:
○ – experimental data; ● – – calculated data;
1 – without untwisting device;
2 – with the untwisting device with flow recirculation;
3 – with the blade untwisting device

Let's estimate economy of energy and money at carrying out processes of gas cleaning in cyclones TsN-11 and TsN-15 with the developed untwisting devices.

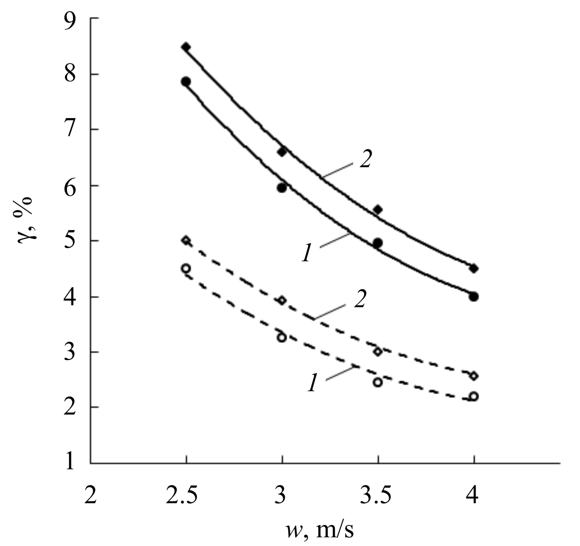


Fig. 3.The influence of the untwisting device
on dust loss coefficient (tile powder)
of the cyclones TsN-11 (- - -) and TsN-15 (—–):
1 – with the untwisting device with flow recirculation;
2 – with the blade untwisting device and without it

Power inputs in a cyclone are defined by its pressure drop. Power consumption for gas cleaning in the cyclone is calculated by equation [10]:

$$N_c = \frac{Q\Delta p}{1{,}000\eta_{fan}},$$

where Q – cyclone flow rate, m^3/s; η_{fan} – overall fan efficiency, determined by equation

$$\eta_{fan} = \eta_m \eta_{tr} \eta_f,$$

where η_m, η_{tr}, η_f – motor efficiency, transmission efficiency and fan efficiency accordingly.

Power inputs on clearing 1,000 m^3 of gas in cyclone are calculate by equation

$$N_{sp} = \frac{\Delta p}{3{,}600\eta_{fan}}.$$

Yearly electrical energy consumption depends on the cyclone operating schedule (one-, two- or three-shift) and is determined by formula

$$N_a = N_c \tau_y,$$

where τ_y – action period for a year, h.

Annual energy saving N_e, kW · h, decides by a difference between yearly electrical energy consumption at gas cleaning in cyclones without untwisting device and fittedwith it.

Consumers pay to electric energy on tariffs of the declaration installed since September 1, 2011 about a price level on the electric energy which is released by the republican unitary enterprises of power industry of GPO “Belenergo” for legal entities and individual businessmen, indexed according to an order stated in the resolution of the Ministry of Economics from February 28, 2011 of N 24, taking into account changes and additions to it. The power supplying organizations make payment papers on payment for energy on the tariffs of this declaration indexed on a change in the exchange rate of monetary unit of Republic of Belarus in relation to US dollar at date of registration of the payment document and put payments, according to a formula [11]:

$$T_p = T_f \left(0.11 + 0.89\frac{K_p}{K_f}\right),$$

where T_p, T_f – a tariff for the electric power, indexed on a change in the exchange rate of the Belarusian ruble to US dollar at date of registration of the payment document also put payments and established by the declaration respectively, (T_f = 737.7 rub./(kW · h) – for the industrial consumers and equated to them with the attached capacity not more than 750 kVA); K_p, K_f – value of a Belarusian ruble exchange rate in relation to US dollar at date of registration of the payment document also put payments and at establishment of tariffs for the electric power accordingly (K_f = 5,107 rub.).

Tariffs of the declaration are established without a value-added tax.

Cost of 1 kW · h for the industrial consumers and equated to them with the attached capacity not more than 750 kVA when the US dollar is equal to K_p = 8,660 rub. (on 23.10.2011) will make

$$T_p = 737.7 \cdot \left(0.11 + 0.89 \cdot \frac{8{,}660}{5{,}107}\right) = 1{,}195 \text{ rub.}$$

The annual capital saving at the expense of decrease in electricity consumption when using the untwisting device will make

$$E = N_e T_p.$$

We will carry out calculation for the most widespread cyclones TsN-11 and TsN-15 with average flow rate Q = 1.76 m^3/s (for the optimum operating mode characterized in the mean gas velocity of 3.5 m/s, diameter of cyclones will be equal to D = 0.8 m) at continuous work of a cyclone in a year τ_y = 8,760 h [1]. We will accept the overall fan efficiency equal η_{fan} = 0.6. Results of calculation are presented in Table 2.

Cost of all types of the equipment is estimated at the prices of existing price-lists for the equipment. In case of use of the original equipment which is absent in price-lists, it is allowed to estimate its cost by analogy to related species of the equipment [12]. In this regard the cost of the untwisting device can be defined on the basis of cost of TsN type cyclones taking into account their material capacity. The prices for cyclones without the untwisting devices, given in Table 2, are determined by price-lists of the most known Belarusian producers and are average.

It can be seen from Table 2 that the use of the blade untwisting device in the cyclones TsN-11 and TsN-15 decreases power inputs on clearing 1,000 m^3 of gas on the average by 0.25 and 0.15 kW · h, and while using the untwisting device with flow recirculation, so the power inputs reduction is 0.2 and 0.11 kW · h respectively. The use of the blade untwisting device in the given cyclones with diameter D = 0.8 m at optimum operating mode will allow to get annual economy of the electric power 13.7 and 8.3 MW · h that will save 16.36 and 9.93 million rub. accordingly when 1 kW · h the electric power costs 1,195 rub. The use of the untwisting device with flow recirculation will lead to a bit smaller annual economy of money with consumption decrease of the electric energy (12.97 and 6.99 million rub. accordingly), however owing to higher separation efficiency, considering cost of the caught dust and an ecological factor, the general economy of money resources can be more. At the same time decrease in cyclone pressure drop and consequently also in network will allow to use the fan with smaller created pressure and, respectively, engine capacity that will give additional effect in the form of economy on fan cost. The additional expenses defined as a difference between cost of cyclones fitted with the untwisting device and without it will pay off less than in a year.

Conclusion. Considering the noted above it is possible to draw the following conclusion.The use of the developed untwisting devices in the most widespread cyclones TsN-11 and TsN-15 will allow to decrease power inputs on clearing 1,000 m^3 of gas on the average by 0.11–0.25 kW · h. At the same time the payback period of the additional expenses for the untwisting devices will be less than a year that is essential less average payback period of actions for energy saving for the Republic of Belarus now.

Table 2

Results of calculation of power inputs on gas cleaning in cyclones TsN-11 and TsN-15

Parameters	Without untwisting device		Blade untwisting device		With the untwisting device with flow recirculation	
	TsN-11	TsN-15	TsN-11	TsN-15	TsN-11	TsN-15
Energy input N_c, kW · h	5.388	3.513	3.825	2.564	4.149	2.845
Power inputs on gas cleaning 1,000 m^3 N_{sp}, kW · h	0.851	0.555	0.604	0.405	0.655	0.45
Annual energy consumption N_y, kW · h	47,197	30,773	33,510	22,464	36,342	24,926
Annual energy saving N_e, kW · h	–	–	13,687	8,309	10,855	5,847
Annual economy of energy and money with consumption decrease of the electric energy (million rub.)	–	–	16.36	9.93	12.97	6.99
Weight, kg	733	738	786	774	814	801
Cost, million rub.	29	25	32	27.5	33.5	29

There is an obvious expediency for using of the developed untwisting devices taking into account that some cyclones are used at one enterprise.

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