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D. I. Misyulya, PhD (Engineering), assistant lecturer (BSTU);
V. V. Kyzmin, PhD (Engineering), assistant professor (BSTU);
V. A. Markov, D. Sc. (Engineering), professor (BSTU)

COMPARATIVE ANALYSIS OF TECHNICAL CHARACTERISTICS OF CYCLONE DUST COLLECTORS

The article presented an analytical review of existing designs of cyclone dust collectors, lists their main advantages compared to other vehicles of similar purpose. Classification of cyclone dust collectors, design features, advantages and disadvantages, application of back-and-flow cyclone, flow cyclone and whirl dust collectors are described. The factors influencing the efficiency of the cyclone apparatuses are analyzed. Advanced designs of cyclones CN are offered.

Introduction. The problem of environmental protection from fouled gas emissions is of current concern. According to the UN data, 2.5 million tones of dust per year is discharged to the atmosphere. As American ecologists say, the quantity of the dust formed in the industry, will annually increase by 4% at the expense of the industry production growth. It requires the development of the existing dust removal equipment while cyclone dust collectors (dedusters) are the most often used.

The wide spread occurrence of cyclone dedusters on production is caused by the following advantages in front of other devices of similar appointment [2–6]:

1) simplicity of a design and rather small cost;
2) functioning possibility in the conditions of high temperatures and pressure without any basic changes in designs;
3) possibility of catching and classification of abrasive inclusions at protection of internal surfaces of cyclones by special coverings;
4) high efficiency and preservation of demanded level of fractional separation efficiency with growth of mass concentration of a solid phase;
5) possibility of dry sedimentation of a product.

Main part. At all variety of a design cyclone dust collectors can be divided into the following groups [1]:

– counter-flow cyclones;
– direct-flow cyclones;
– vortical dust collectors (VDC) or dust collectors (dedusters) with the counter twirled flows (VTF).

Counter-flow cyclones. The most widespread dry mechanical dedusters are counter-flow cyclones [7–14]. They sometimes are called usual cyclones or simply cyclones.

The history of using of the cyclones is more than a century [15–17]. The term “cyclone” which denotes circular wind was introduced in scientific literature in 1842 by Henry Piddington, latinized the first letter in the Greek word “kyklon” (rotating) [18]. The priority of the invention of the cyclone belongs to the USA: the first patent (“Dust-collector”, N 325521) was received by Knickerbocker Company (Jackson, Michigan) in 1885. In Europe the first design of the cyclone was patented by the same company in Germany (“Staubsammler”, N 39219) in 1886, July 25. The mass production of dust cyclones begun in America, led to their wide spread occurrence in the industry and, first of all, at the woodworking enterprises for collecting sawdust and shaving, and a decade later – at cement works for the purpose of dust catching from kilns. In Europe the first cyclones were placed in operation at Friedrich-Augustus's German royal plants in Potshappel near Dresden [20]. Since then, being continuously improved, they extended worldwide, receiving all new and new scopes of application.

In oil-processing industry cyclone dust collectors are applied for gas cleaning of the catalyst at catalytic cracking of oil products, in technological and aspiration systems of carbon-black productions [21, 22]. In the chemical industry [23, 24] cyclones are used for gas cleaning of furnaces of roasting the pyrite, when drying superphosphate, in technological installations by production of the concentrated and difficult mineral fertilizers. On food productions by means of cyclones sugar particles, bards, a dry press after dryers [25] catch, and also they are used as the first step of cleaning in pneumatic conveying and aspiration systems of the grain-processing enterprises [26]. In pulp and paper industry cyclonedust collectors are applied generally to cleaning of smoke gases from power heat-recovery boiler units, working at wood fuel, and also as the first step of ash collecting at operation of coal-firedsteam boilers [27]. Cyclones found wide application at agglomeration plants of ferrous and nonferrous metallurgy [13, 28], for dust catching by production of construction materials [29, 30], in faience production [31], and also in aspiration systems and in many other cases where installation of electrical filter or fabric filters can't be carried out because of a lack of a place or economically doesn't justify.

In spite of external simplicity, there are difficult aerodynamic processesin a cyclone which are still insufficiently studied. Theoretical methods of calculation don't give the full answer to the questions connected with design of cyclones, and don't allow to define optimum parameters. Therefore various designs of the single, group and multicyclones developed on the basis of pilot studies are widespread in various industries.

The main parameters which characterise cyclone work are separation efficiency and pressure drop which depend on design features of the device and the gas flow velocity.

Fairly large number of cyclones was created owing to the absence of the reliable theory of gas cleaning process in search of optimum on metal consumption, pressure drop and efficiency of geometry of this type of dedusters [32]. According to P. A. Kouzov [33], only in the USSR more than 20 various models of cyclonic devices found application. Some ideas of a variety of constructional registration of cyclones are given in Fig. 1 and 2.

Cyclones are subdivided by the design of the gas inlet into the following types:

1) with simple tangential gas inlet (Fig. 1 poses. *34*, *40*; Fig. 2 poses. *1–5*, *9–11*, *21–24*);

2) with tangential gas inlet with a screw top part (Fig. 1 poses. *1–9*, *13–17*, *31–33*);

3) with simple spiral gas inlet (Fig. 1 poses. *10*, *11*, *18–26*, *28*, *29*; Fig. 2 poses. *7*, *8*, *12*, *13*, *18*, *20*);

4) with spiral gas inlet with a screw top part (Fig. 1 poses. *12*, *30*);

5) with axisymmetric gas inlet on directing shovels (Fig. 1 poses. *44*; Fig. 2 poses. *6*).

There are cylindrical (Fig. 1 poses. *1–6*; Fig. 2 poses. *1–5*, *10*, *11*, *25–27*) and conic (Fig. 1 poses. *22–24*, *28*, *29*) cyclones. The body of cylindrical cyclones is executed with the extended cylindrical part, and body of conic cyclones is executed with the extended conic part. Cylindrical cyclones differ high flow rate, and conic cyclones have high separation efficiency, but also big pressure drop owing to more intensive twisting of a gas flow in the conic part.

Cylindrical cyclones NIIOGAZ:TsN-11, TsN-15, TsN-15U, TsN-24 (Fig. poses. *1–4*) are intended for dry cleaning of gases which are allocating at technological processes (drying, roasting, agglomeration, fuel burning etc.), and also for cleaningthe aspiration air. They are applied at the enterprises of ferrous and nonferrous metallurgy, chemical and oil industry, the industry of construction materials, in mechanical engineering, power engineering. They aren't recommended for use when catching strong coherent dust (especially at small diameters of cyclones). TsN-15U cyclones (Fig. 1 poses. *3*) differ from other TsN cyclones in smaller height and have lower technical and economic indicators. Therefore their application can be justifiable only when there are restrictions of gas-cleaning installation on height.

Conic cyclones NIIOGAZ: SDK-TsN-33, SK-TsN-34, SK-TsN-22 (SK-TsN-34M) (Fig. 1 poses. *22–24*) are intended for catching of solid particles from technological gases after reactors and auxiliary systems (pneumatic conveying, aspiration, pneumocleaning). They are applied in production of technical carbon, in installations of catalytic cracking of oil products, butane dehydrogenation. Cyclones SK-TsN-22 are used for catching of the dust possessing high abrasivity of particles or their high adhesiveness.

Cyclones TsMS-27 (Fig. 1 poses. *5*) are developed specially for cleaning of smoke gases in small boiler rooms and the plants working at natural draft of chimneys.

TsR cyclone-dischargers (Fig. 1 poses. *6*) and TsRK (Fig. 1 poses. *7*) are developed for catching of a medium-dispersed dust in pneumatic conveying systems and in aspiration installations of grain-cleaning section of mills at the enterprises for grain processing, woodworking and other enterprises.

LTA cyclones (Fig. 1 poses. *8*) are applied to air cleaning of dry large particles and damp small particles of a wood waste of machines and power-saw benches. Also LTA cyclones are used as cyclone-dischargers.

Cyclones TsP-2 (Fig. 1 poses. *9*) are suitable for dust catching after systems of drying or a grinding of fuel of the steam generators burning powdered fuel. Also they can be used for dust catching as cyclones of common industrial type.

Cyclones TsPN-50 (Fig. 1 poses. *10*) and STsN-50 (Fig. 1 poses. *26*) are developed for catching of an abrasive dust in foundry productions, power, metallurgy, by production of construction materials.

Cyclones with a return cone TsOK (Fig. poses. *11*, *12*) are intended for cleaning of the air deleted from local suctions, dusty by a dry, not sticking together dust, and also for air cleaning of an abrasive dust and, as an exception, sticking together (soot, talc).

RISI cyclones (Fig. 1 poses. *13*), they are also called cyclones with a cone coagulator, are developed for air cleaning in aspiration systems of all types of a fibrous and sticking together dust at the enterprises of the woodworking industry (furniture productions, polishing processes). Also they are applied at the oil and fat enterprises to catching of the dust which is forming at processing of seeds of a cotton. This cyclone differs from other cyclones with a return cone existence of an additional element – a cone coagulator. Thus, its conic part consists of two cones connected by the bases.

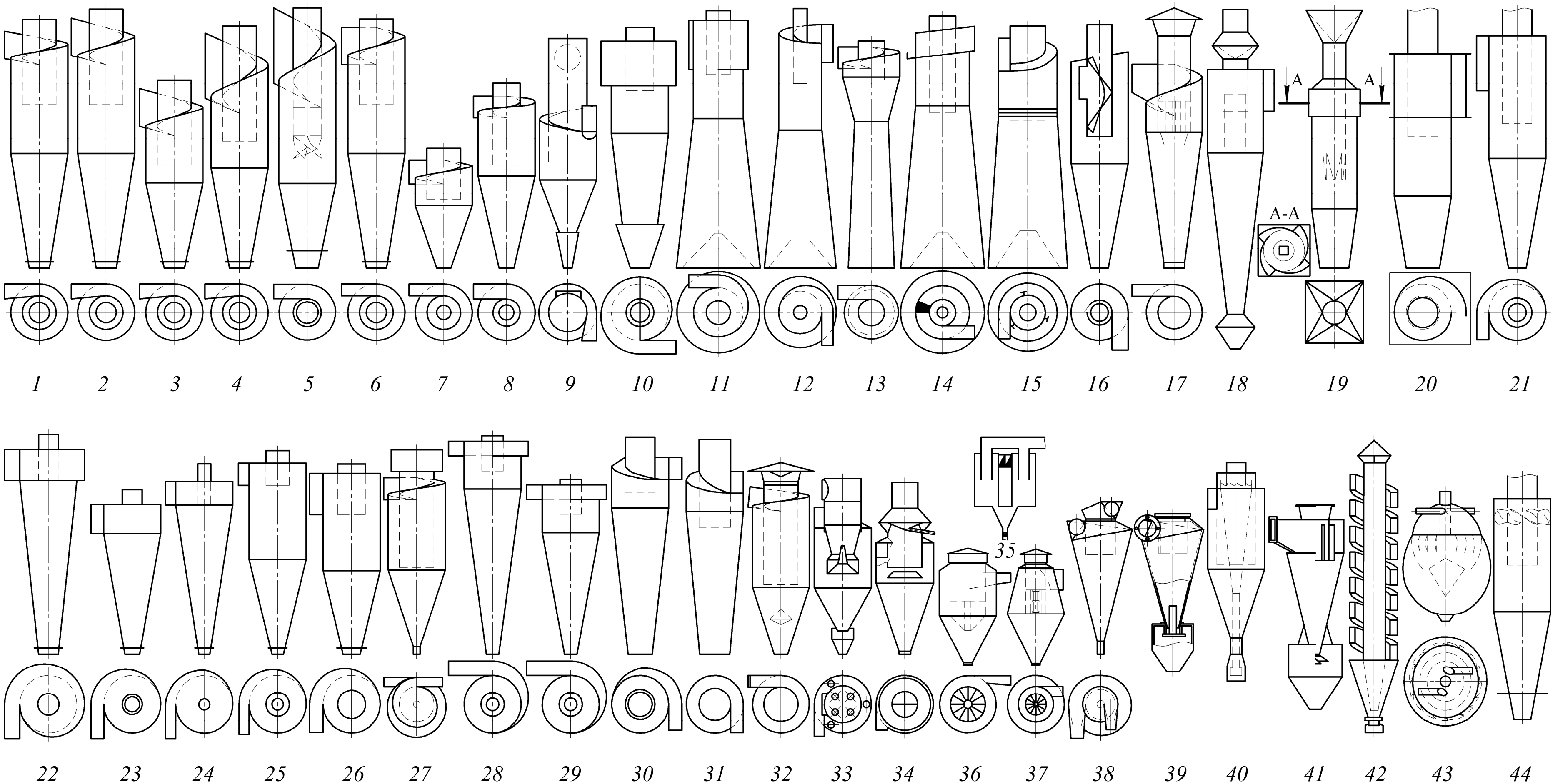

Fig. 1. Cyclones made in the CIS countries:
1 – TsN-11; *2* – TsN-15; *3* – TsN-15U; *4* – TsN-24; *5* – TsMS-27; *6* – TsR; *7* – TsRk; *8* – LTA; *9* – TsP-2; *10* – TsPN-50;
11 – TsOK (VTsNIIOT); *12* – TsM (universal TsOK); *13* – RISI (TsKK); *14* – RTs; *15* – RTsP; *16* – TsVR;
17 – Ts design of Giprodrevprom (Merkusheva); *18* – GDPTs; *19* – element of BTs-512;
20 – element of PBTs, BTsU, BTsU-M, “Energougol”-512; *21* – element of TsBR-150u; *22* – SDK-TsN-33; *23* – SK-TsN-34;
24 – SK-TsN-22 (SK-TsN-34M); *25* – STsN-40; *26* – STsN-50; *27* – LIOT; *28* – UTs (design of Drevprom);
29 – UTs-38 design of VNIIZ (Melstroia); *30* – UTsM; *31* – OTI; *32* – TsOL; *33* – TsKKB; *34* – K (OEKDM “Klaipeda”);
35 – monoprofile with the flat bottom (NIPIOTstrom); *36* – design of Giprodrev; *37* – design of Promstrojproekt;
38 – SIOT; *39* – SIOT-M; *40* – “Nested doll”; *41* – KTsE; *42* – spiral (Sirkina); *43* – spherical; *44* – element of BTs-2, TsB-254R

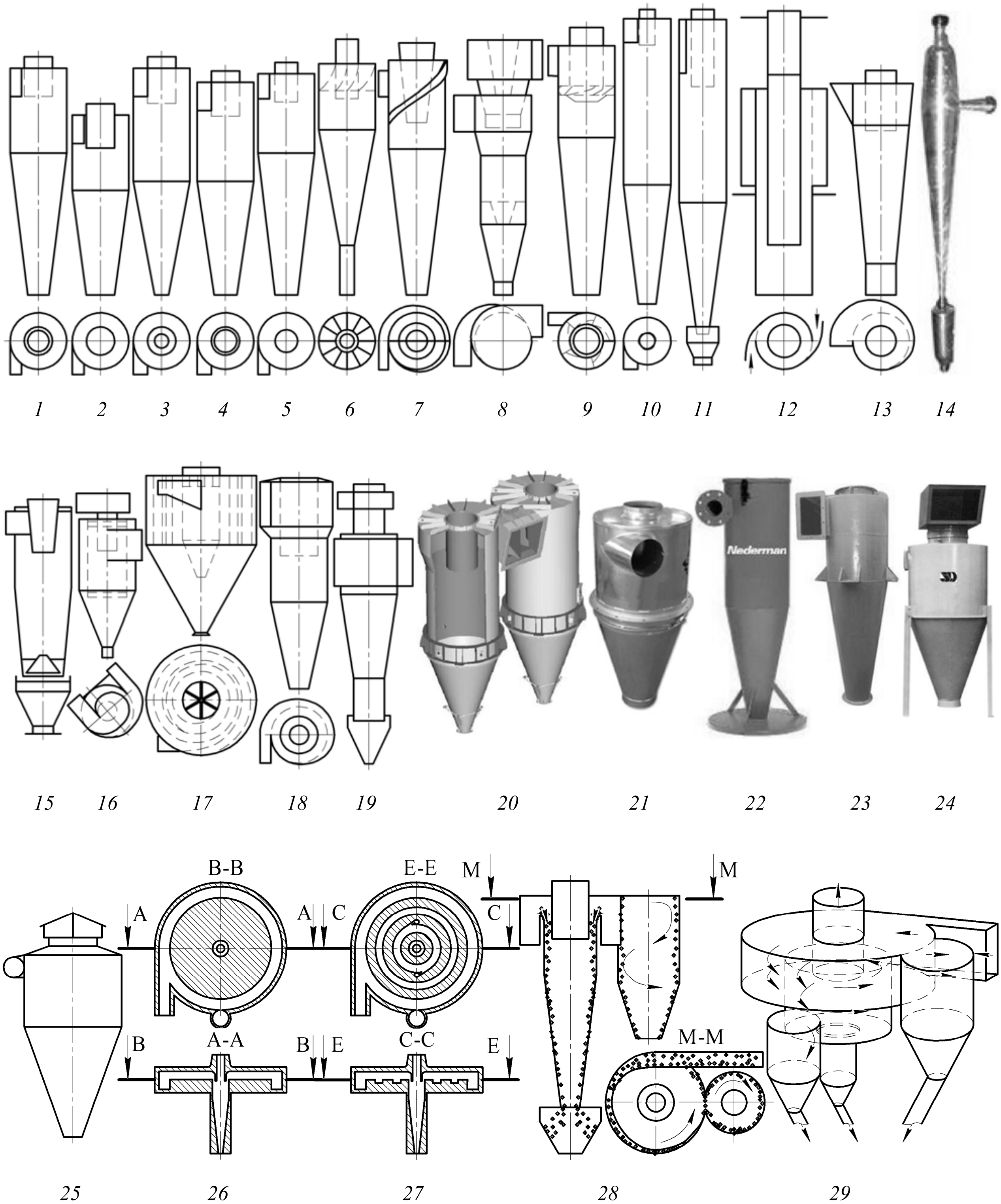

Fig. 2. Foreign cyclones:
1 – Stairmand (high efficiency); *2* – Peterson andWhitby (general purpose);
3 – Lapple; *4* – Swift (general purpose); *5* – Swift (high efficiency);
6 – made in the Czech Republic; *7* – Van Tongeren; *8* – Davidson; *9* – Corso;
10 – Dirgo and Leith; *11* – *T*-4/63; *12* – Prat-Daniel; *13* – "Beth" (Germany);
14 – "S. Bose" (India); *15* – Kreisel; *16* – Van Tongeren (with dust contour); *17* – Polysius;
18 – "Svenska Flaktfabriken" (Sweden); *19* – Feifel;
20 – high efficiency cyclone (HEC) A TEC (Austria); *21* – "Oneida air systems" (USA);
22 – "Nederman" (India); *23* – PABD; *24* – "Samsoud" (France); *25* – PACK;
26 – MK.I; *27* – MK.II; *28* – MK6A; *29* – MK6C

Adjustable cyclone RTs (Fig. 1 poses. *14*) has a return cone, it is supplied with the spiral-screwed twisting device and the regulating device. This cyclone is recommended to be applied to dust catching with the increased humidity or the oiliness inclined to a adherence, containing very large-dispersed fraction, possessing increased abrasivity, and in need of regulation of an operating mode of the device.

Regulating cyclone with redistributing shovels RTsP (Fig. 1 poses. *15*) is developed on the basis of a RTs cyclone and differs from it existence on an exhaust pipe of redistributing shovels.

Cyclone with internal recirculation TsVR (Fig. 1 poses. *16*) is intended for catching of a soya dust and other types of a dry not sticking together fine-dispersed dust.

Cyclones of Giprodrevprom design (Fig. 1 poses. *17*) are offered for catching of a wood dust in pneumatic conveying systemsand aspiration installations.

Cyclones STsN-40 (Fig. 1 poses. *25*) are suitable for cleaning of gas and aspiration air from a fine- and medium-dispersed dust, and also for catching of an abrasive dust in chemical and allied industries. They are recommended for application as a portable step of cleaning in installations of catalytic cracking.

LIOT cyclones (Fig. 1 poses. *27*) are developed for catching of a large dry, not fibrous, not sticking together dust with particle size more than 25 μm.

Cyclones UTs of Drevprom design (Fig. 1 poses. *28*) are used as cleaning of technological emissions of woodworking productions of not sticking together, not fibrous dust, and also dust mixes with dry sawdust and shaving, and also in aspiration systems of a woodworking when catching a grinding dust.

Cyclones UTs-38 of VNIIZ design (Fig. 1 poses. *29*) are developed for catching of a fine-dispersed dust in pneumatic conveying systems and aspiration installations in flour-grinding, formula-feed and other industries (for example, in grinding and hulling compartments of flour-grinding and cereals plants).

UTs cyclones with body diameter less than 850 mm are applied in amylogenic, oil and fat branches to single and multi installations. They are characterized by high pressure drop. UTsM cyclone is developed for decrease in pressure loss (Fig. 1 poses. *30*), which differs from UTs cyclone a spiral-screwed inlet.

OTI cyclones (Fig. 1 poses. *31*) are used at the grain processing and food enterprises generally at group installation. Advantage of these cyclones is their considerable stability to change of gas velocity on an entrance ±35% that is important for the systems working with a variable mode.

TsOL cyclones (Fig. 1 poses. *32*) are suitable for catching of a large grain dust in aspiration installations of elevators, etc. at the enterprises for storage and grain processing in the flour-grinding industry.

Cyclones K (Fig. 1 poses. *34*) are developed for catching of a wood waste in aspiration systems of woodworking shops at the small maintenance of a wood and grinding dust.

Monoprofile cyclones with the flat bottom (Fig. 1 poses. *35*) are used in cement industry.

Giprodrev's cyclones (Fig. of 1 poses. *36*) are developed for catching of large wood particles (shavings, sawdust) by the size more than 40–60 μm. Also it is possible to apply a barrel-like cyclone Promstroyproyekta (Fig. 1 poses. *37*) to rough air cleaning-from not fibrous dust and a wood waste.

SIOT type cyclones (Fig. 1 poses. *38*, *39*) are used for catching of a dry, not fibrous, not sticking together dust in mechanical engineering and light industry.

Comparative tests of the variouscyclones, executed in NIIOGAZ and its Semibratovsky branch, and also at the LIOT and NIISTO institutes showed that the nomenclature of devices of considered type recommended for use can be limited to cylindrical and conic cyclones of NIIOGAZ [32].

Cylindrical cyclones NIIOGAZ are the most widespreadon territory of the CIS countries, among which in turn the devices of the TsN-15 type providing rather high extent of cleaning at moderate pressure drop [34, 35] are used more often. However at identical efficiency the highest technical and economic indicators have cyclones TsN-11 [36]. In this regard this type of cyclones was included by Glavpromstroyproyektom Gosstroya of the USSR in the unified row of the dust removal equipment as the most economic, effective and convenient for configuration in groups [13, 34, 37].

Separation efficiency of cyclones depends on their diameter. Centrifugal force and consequentlyseparation efficiency decreases with increasing in cyclone diameter. Therefore when cleaning significant amounts of gases they are united in group with the general gas inlet and outlet and the bunker, i.e. in a so-called group cyclone, or multicyclones (paraclones) are used.

Multicyclones represent the dust removal device made of a large number ofcyclonic elements established in parallel and united in one body both having the general gas inlet and outlet, and also the bunker. Multicyclones can be made by the usual and direct-flow cyclonic elements. The last possess smaller efficiency and consequently as independent steps of cleaning are used seldom. More often they are applied to preliminary gas cleaningbefore such highly effective devices, as electrical filters, bag filters, etc. At that direct-flow multicyclones are built in a settling chamber of the corresponding device, forming with it a uniform design of a two-level deduster.

Multicyclones with counter-flow elements find wide application as dust extraction plant for cleaning of smoke gases of the boiler plants burning low-cindery fuels, recirculating gases of coppers from ashes, drying gases of pulverized-coal system from an in explosive coal dust, and also for gas cleaning from other industrial dust [32].

Operating experience of multicyclones with elements of different diameter shows [32] that the devices made of a large number of cyclonic elements of small diameter without a suction of gases from the dust bunker work effectively and reliably contrary to theoretical reasons. The overall collection efficiency is deduced by 20–25% in comparison with separation efficiency of elements. It is caused by overflows of gases from elements with big pressure drop in elements with smaller pressure drop.

The attempts to reduce pressure drop in cyclone dust collectors at simultaneous reduction of dimensions and receiving a number of other advantages have led to development of direct-flow cyclones (Fig. 3) [32].

TsKTI cyclones (Fig. 3, *a*–*c*) are intended for preliminary cleaning of smoke gases before electrical filters in ash collecting systems, and also as the first step of cleaning in any industries where the high initial dust content takes place, especially at existence at a dust of abrasive properties.

The direct-flow conic cyclone with the bottom gas outlet NVGK (Fig. 3, *d*) is developed for dust catching at the second step of gas cleaning in chemical and allied industries.

Direct-flow cyclone with intermediate selection of a dust PTsPO (Fig. 3, *e*) is a deduster for common industrial purpose.

As a rule, at the accounting of all technical and economic indicators taken into account at a choice of the dust removal device, direct-flow cyclones don't maintain comparison with usual cyclones because of smaller separation efficiency. Nevertheless in a number of special cases their application appears justifiable. It is convenient to put a fettling on direct-flow cyclones of big diameter and they have small pressure drop. In this regard vertical lined direct-flow cyclones were recommended byTsKTI as the first step of cleaning for a number of ash collecting systems [32].

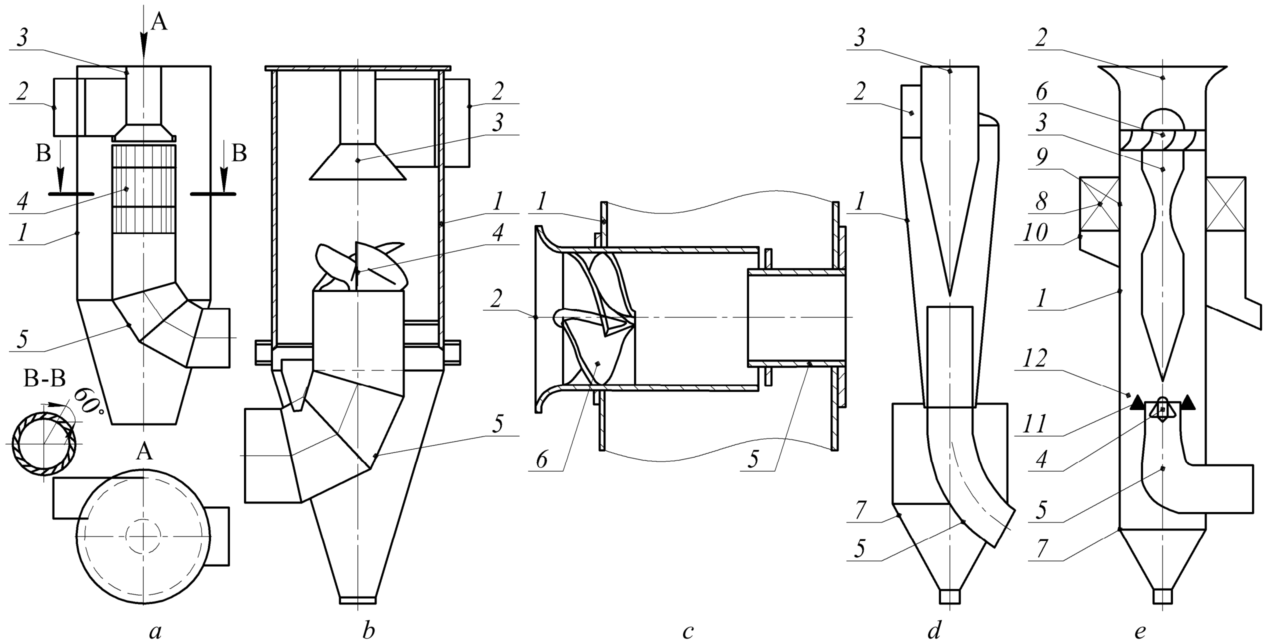

Fig. 3. Direct-flow cyclones:
a – TsKTI [14, 32]; *b* – TsKTI [14]; *c* – cyclonic element TsKTI [14, 32];
d – NVGK (the direct-flow conic cyclone with the bottom gas outlet) [14];
e – PTsPO (direct-flow cyclone with intermediate selection of a dust) [14]:
1 – body; *2* – inletbranchpipe; *3* – flow displacer (cowling); *4* – untwisting device;
5 – outlet branch pipe; *6* – axial distributor; *7* – bunker; *8* – radial plates;
9 – windows for intermediate selection of a dust; *10* – bunker for intermediate selection of a dust;
11 – biconical dedusting washer; *12* – annular slot for second selection

According to the possibility of wide applicationin engineering practice of gas cleaning design direct-flow cyclones essentially concede to counter-flow cyclonesfor the following reasons [14]:

– considerably smaller study of technical characteristics;

– insufficient number of data on industrial application;

– absence or inaccessibility necessary technical documentation for their inclusion in projects and for manufacturing.

Vortical dust collector (VDC or vortical dedusters) were developed much later cyclones (at the beginning of the 60th of the XX century). Lately a number of designs of VDC (Fig. 4) was created. Many articles about positive results of researches and industrial application of these designs are published. At the same time publications quite often contain discrepant and not consistent among themselves the data even belonging to the same authors [14].

Vortical dedusters VZP (Fig. 4, *a*) and VZP-M (Fig. 4, *b*) are intended for dust catching (including fibrous, average and very coherent) in pneumatic conveying and aspiration systems; for carrying out heat-and-mass transfer processes (drying, granulation, etc.) in various industries.

Vortical dedusters VZP-B (Fig. 4, *c*) are developed for cleaning of smoke fumes from ashes and for catching of a fine-dispersed dust in power installations.

Vortical dedusters MIHM (Fig. 4, *d*) are intended for dust catching in pneumatic conveying and aspirationsystems in chemical and allied industries.

Vortical dedusters "Vihr" (Fig. 4, *e*) are devices for common industrial purpose.

The main advantages of vortical dedusters in comparison with cyclones are the following [14]:

1) more intensive separation of particles on device height;

2) more effective catching of afine-dispersed dust (less than 5 microns);

3) a wide range of loadings on gas and a disperse phase;

4) smaller power consumption.

Application of vortical dedusters using for creation of an external spiral clean air, is perspective for high-temperature gas cleaning as isolates device walls from influence of dusty hot gases [38].

Vortical dedusters catch a fine dust more effectively and are preferable when catching particles less than 3 μm [39, 40]. For larger particles it is expedient to use traditional cyclones.

For the purpose of minimization of energy consumption and increase of efficiency of catching of solid particles at cyclonic gas cleaning we developed advanced designs of the most widespread and universal TsN cyclones NIIOGAZ (Fig. 5) [41–45].

In the cyclones fitted with the blade untwisting device (Fig. 5, *a*) the kinetic energy of the rotary motion of the vertical upward flow is transformed into potential energy of the static pressure that reduces the general pressure loss. At the same separation efficiency pressure drop in such cyclones is reduced by 26–30% in comparison with standard cyclones of TsN type.

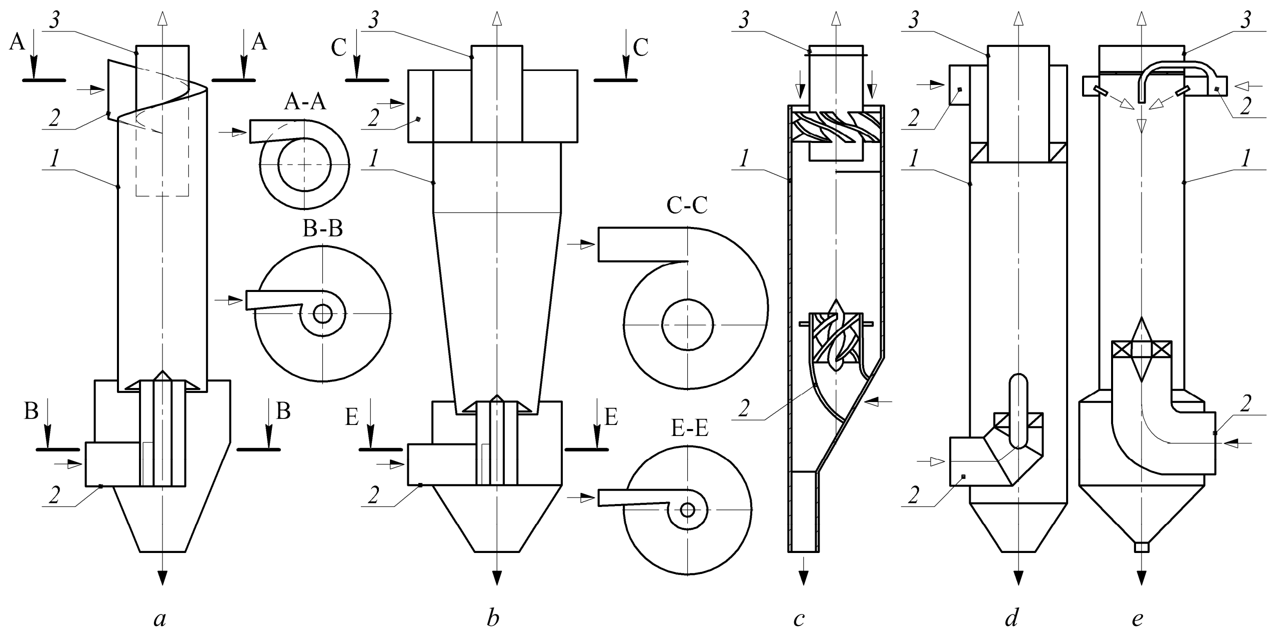

Fig. 4. Vortical dust collectors:
a – VZP; *b* – VZP-M; *c* – VZP-B; *d* – MIHM; *e* – "Vihr":
1 – body; *2* – inletbranch pipe; *3* – outlet branch pipe

The internal recirculation of the flow most concentrated by a dust from the exhaust pipe into the bunker and transformation of kinetic energy of the rotary motion of the vertical upward flow into potential energy of the static pressure are carried out in the cyclones fitted with the untwisting device with flow recirculation (Fig. 5, *b*). These cyclonic apparatus in comparison with standard cyclones of TsN type are characterized by bigger separation efficiency and lowered pressure drop by 19–23%.

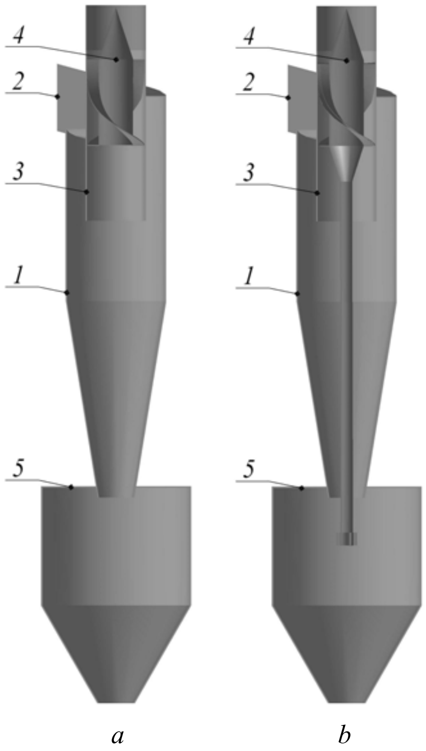

Fig. 5. Advanced designs of TsN cyclones:
a – with the blade untwisting device;
b – with the untwisting device with flow recirculation:
1 – body; *2* – inletbranchpipe; *3* – exhaust pipe;
4 – untwisting device; *5* – bunker

Conclusion. Having analysed existing designs of cyclone dust collectors, it is possible to draw the following conclusions:

1. Continuous improvement of cyclone dust collectors have led to creation of very wide number of designs of these devices which can be divided into counter-flow cyclones, direct-flow cyclones and vortical dedusters.

2. Direct-flow cyclones are rational for using at the lowered requirements to separation efficiency for catching of a big dispersed dust and minimization of power inputs for carrying out the process.

3. Vortical dedusters have the highest efficiency of catching of a finedust, however they are more difficult structurally. Their application is justifiable when catching dust with the big maintenance of small fraction.

4. The counter-flow cyclones are the most widespread equipment as dry dust collectors among whichcyclones TsN-15 are the most universal apparatus possessing rather high separation efficiency at moderate pressure drop. Modern counter-flow cyclones allow catching rather effectively a dust with 10 microns and more particles size.

The use of the advanced designs of TsN cyclones will allow to reduce power inputs of carrying out processes of gas cleaning and to increase efficiency of catching of solid particles.

References

1. Асламова, В. С. Прямоточные циклоны. Теория, расчет, практика / В. С. Асламова. – Ангарск: Ангарская гос. техн. акад., 2008. – 233 с.

2. Ужов, В. Н. Подготовка промышленных газов к очистке / В. Н. Ужов, А. Ю. Вальдберг. – М.: Химия, 1975. – 216 с.

3. Пирумов, А. И. Обеспыливание воздуха / А. И. Пирумов. – 2-е изд., перераб. и доп. – М.: Стройиздат, 1981. – 296 с.

4. Щелоков, Я. М. Повышение эффективности циклонных аппаратов / Я. М. Щелоков // Промышленная энергетика. – 2008. – № 8. – С. 44–45.

5. Карпов, С. В. Высокоэффективные циклонные устройства для очистки и теплового использования газовых выбросов / С. В. Карпов, Э. Н. Сабуров; под ред. Э. Н. Сабурова. – Архангельск: Изд-во Архангельского гос. техн. ун-та, 2002. – 504 с.

6. Greenfield, R. R. High efficiency cyclone dust collector / R. R. Greenfield // Filtration and separation. – 1989. – Vol. 26, № 4. – P. 272–274.

7. Завьялов, С. В. Новое газоочистное и пылеулавливающее оборудование в Республике Беларусь: справ.-информ. материал / С. В. Завьялов, Д. Н. Абрамович. – Минск: БелНИЦ «Экология», 2003. – 94 с.

8. Газоочистное оборудование: каталог / сост.: Н. М. Васильченко [и др.]. – М.: ЦИНТИхимнефтемаш, 1988. – 120 с.

9. Тимонин, А. С. Инженерно-экологический справочник: в 3 т. / А. С. Тимонин. – Калуга: Изд-во Н. Бочкаревой, 2003. – Т. 1. – 917 с.

10. Швыдкий, В. С. Очистка газов: справ. изд. / В. С. Швыдкий, М. Г. Ладыгичев. – М.: Теплоэнергетик, 2002. – 640 с.

11. Тимонин, А. С. Основы конструирования и расчета химико-технологического и природоохранного оборудования: справочник: в 3 т. / А. С. Тимонин. – Калуга: Изд-во Н. Бочкаревой, 2002. – Т. 2. – 1025 с.

12. Завьялов, С. В. Газоочистное и пылеулавливающее оборудование, выпускаемое за-

водами-изготовителями Российской Федерации: сб. справ.-информ. материалов / С. В. Завьялов, Д. Н. Абрамович; Министерство природных ресурсов и охраны окружающей среды Республики Беларусь. – Минск: РУП «БелНИЦ «Экология», 2006. – 174 с.

13. Старк, С. Б. Газоочистные аппараты и установки в металлургическом производстве: учеб. для вузов / С. Б. Старк. – 2-е изд., перераб. и доп. – М.: Металлургия, 1990. – 400 с.

14. Лазарев, В. А. Циклоны и вихревые пылеуловители: справочник / В. А. Лазарев. – 2-е изд., перераб. и доп. – Н. Новгород: Фирма ОЗОН-НН, 2006. – 320 с.

15. Зиганшин, М. Г. Проектирование аппаратов пылегазоочистки / М. Г. Зиганшин, А. А. Колесник, В. Н. Посохин. – М.: «Экспресс – 3М», 1998. – 505 с.

16. Эриксон, С. Е. История развития циклонов / С. Е. Эриксон // Применение гидроциклонов на зарубежных обогатительных фабриках: сборник переводных статей / под ред. А. И. Поварова. – Л., 1961. – Вып. 130. – С. 17–24.

17. Сабуров, Э. Н. Теория и практика циклонных сепараторов, топок и печей / Э. Н. Сабуров, С. В. Карпов; под ред. Э. Н. Сабурова. – Архангельск: Изд-во Архангельского гос. техн. ун-та, 2000. – 568 с.

18. Откуда пошло слово «циклон» // Наука и жизнь. – 1969. – № 5. – С. 149.

19. Jackson, R. Mechanical equipment for removing grit and dust from gases / R. Jackson. – Leatherhead: The British Coal Research Association, 1963. – 281 p.

20. Сабуров, Э. Н. Циклонные устройства в деревообрабатывающем и целлюлозно-бумажном производстве / Э. Н. Сабуров, С. В. Карпов; под ред. Э. Н. Сабурова. – М.: Экология, 1993. – 368 с.

21. Процессы и аппараты нефтегазопереработки и нефтехимии: учеб. для вузов / А. И. Скобло [и др.]. – 3-е изд., перераб. и доп. – М.: ООО «Недра-Бизнесцентр», 2000. – 677 с.

22. Владимиров, А. И. Основные процессы и аппараты нефтегазопереработки: учеб. пособие для вузов / А. И. Владимиров, В. А. Щелкунов, С. А. Круглов. – М.: ООО «Недра-Бизнесцентр», 2002. – 227 с.

23. Скрябин, Г. М. Пылеулавливание в химической промышленности / Г. М. Скрябин, П. А. Коузов. – Л.: Химия, 1976. – 63 с.

24. Коузов, П. А. Очистка газов и воздуха от пыли в химической промышленности / П. А. Коузов, А. Д. Мальгин, Г. М. Скрябин. – 2-е изд., перераб. и доп. – СПб.: Химия, 1993. – 320 с.

25. Стабников, В. Н. Процессы и аппараты пищевых производств / В. Н. Стабников, В. М. Лысянский, В. Д. Попов. – 4-е изд., перераб. и доп. – М.: Агропромиздат, 1985. – 503 с.

26. Вентиляция, кондиционирование и очистка воздуха на предприятиях пищевой промышленности: учеб. пособие для студентов вузов / Е. А. Штокман [и др.]; под ред. Е. А. Штокмана. – 2-е изд., испр. и доп. – М.: Изд-во АСВ, 2007. – 632 с.

27. Ситтиг, М. Защита окружающей среды в целлюлозно-бумажной промышленности / М. Ситтиг; пер. с англ. Б. М. Гуткина. – М.: Лесная пром-сть, 1981. – 278 с.

28. Пылеулавливание в металлургии: справ. изд. / В. М. Алешина [и др.]; под ред. А. А. Гурвица. – М.: Металлургия, 1984. – 336 с.

29. Банит, Ф. Г. Пылеулавливание и очистки газов в промышленности строительных материалов / Ф. Г. Банит, А. Д. Мальгин. – М.: Стройиздат, 1979. – 351 с.

30. Балтренас, П. Б. Обеспыливание воздуха на предприятиях стройматериалов / П. Б. Балтренас. – М.: Стройиздат, 1990. – 184 с.

31. Красовицкий, Ю. В. Обеспыливание промышленных газов в фаянсовом производстве / Ю. В. Красовицкий, А. В. Малинов, В. В. Дуров. – М.: Химия, 1994. – 272 с.

32. Справочник по пыле- и золоулавливанию / М. И. Биргер [и др.]; под общ. ред. А. А. Русанова. – 2-е изд., перераб. и доп. – М.: Энергоатомиздат, 1983. – 312 с.

33. Коузов, П. А. Сравнительная оценка циклонов различных типов / П. А. Коузов // Обеспыливание в металлургии: сборник / под ред. Я. А. Штромберга. – М., 1971. – С. 185–196.

34. Ладыгичев, М. Г. Зарубежное и отечественное оборудование для очистки газов: справ. изд. / М. Г. Ладыгичев, Г. Я. Бернер. – М.: Теплотехник, 2004. – 694 с.

35. Юдашкин, М. Я. Пылеулавливание и очистка газов в черной металлургии / М. Я. Юдашкин. – 2-е изд., перераб. и доп. – М.: Металлургия, 1984. – 320 с.

36. Циклоны НИИОГАЗ. Руководящие указания по проектированию, изготовлению, монтажу и эксплуатации / под науч. ред. В. Н. Ужова. – Ярославль: Верх.-Волж. книж. изд-во, 1970. – 95 с.

37. Коузов, П. А. Указания по расчету циклонов А6-52: методические материалы для проектирования / П. А. Коузов, Ф. М. Гулишамбаров, А. Я. Мозгов; под ред. А. Я. Мозгова. – М.: ВНИИОТ ВЦСПС, 1971. – 53 с.

38. Кирсанова, Н. С. Новые исследования в области центробежной сепарации пыли / Н. С. Кирсанова. – М.: ЦИНТИхимнефтемаш, 1989. – 56 с. – (Обзорная информация. Серия ХМ-14, Промышленная и санитарная очистка газов).

39. Медников, Е. П. Вихревые пылеуловители / Е. П. Медников. – М.: ЦИНТИхимнефтемаш, 1975. – 44 с. – (Обзорная информация. Серия ХМ-14, Промышленная и санитарная очистка газов).

40. Сажин, Б. С. Пылеуловители со встречными закрученными потоками / Б. С. Сажин, Л. И. Гудим. – М.: НИИТЭХИМ, 1982. – 46 с. – (Обзорная информация. Серия ХМ-14, Охрана окружающей среды и рациональное использование природных ресурсов. – Вып. 1 (38)).

41. Мисюля, Д. И. Применение лопастного раскручивателя в циклонных пылеуловителях / Д. И. Мисюля, В. В. Кузьмин, В. А. Марков // Труды БГТУ. – 2011. – № 3: Химия и технология неорган. в-в. – С. 162–169.

42. Мисюля, Д. И. Новая конструкция лопастного раскручивателя циклонного аппарата / Д. И. Мисюля, В. В. Кузьмин, В. А. Марков // Энергетика – Изв. высш. учеб. заведений и энерг. объединений СНГ. – 2010. – № 5. – С. 57–60.

43. Мисюля, Д. И. Устройство для снижения энергопотребления циклонов / Д. И. Мисюля, В. В. Кузьмин, В. А. Марков // Экология и промышленность России. – 2010. – № 9. – С. 20–22.

44. Мисюля, Д. И. Влияние раскручивающего устройства на эффективность очистки в циклонах / Д. И. Мисюля, В. В. Кузьмин, В. А. Марков // Промышленная энергетика. – 2011. – № 4. – С. 37–39.

45. Мисюля, Д. И. Разработка и исследование раскручивающего устройства для снижения сопротивления циклонов / Д. И. Мисюля, В. В. Кузьмин, В. А. Марков // Труды БГТУ. Сер. III, Химия и технология неорган. в-в. – 2010. – Вып. XVIII. – С. 202–205.

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