American Journal of Mechanical and Materials Engineering
2021; 5(4): 71-77
http://www.sciencepublishinggroup.com/j/ajmme
doi: 10.11648/j.ajmme.20210504.13
ISSN: 2639-9628 (Print); ISSN: 2639-9652 (Online)

Electron-ion Technology Modular Fine Gas Cleaning Apparatus

Kashcheev Mikhail Anatolievich[1], Vladi Valery Alexandrovich[2], Kashcheev Evgeny Mikhailovich[3], Manzenko Sergey Vyacheslavovich[2], Rudenko Nikolay Romanovich[1], Kvashin Vladimir Anatolyevich[2]

[1]Department of Metallurgy of Ferrous Metals, Dneprovsky State Technical University, Kamenskoe, Ukraine
[2]"Design Bureau VAV", Kamenskoe, Ukraine
[3]LLC "Pridneprovsky Mechanical Plant", Kamenskoe, Ukraine

Email address:
18rudenko@gmail.com (R. N. Romanovich)

To cite this article:
Kashcheev Mikhail Anatolievich, Vladi Valery Alexandrovich, Kashcheev Evgeny Mikhailovich, Manzenko Sergey Vyacheslavovich, Rudenko Nikolay Romanovich, Kvashin Vladimir Anatolyevich. Electron-ion Technology Modular Fine Gas Cleaning Apparatus. *American Journal of Mechanical and Materials Engineering*. Vol. 5, No. 4, 2021, pp. 71-77. doi: 10.11648/j.ajmme.20210504.13

Received: November 22, 2021; **Accepted**: December 7, 2021; **Published**: December 24, 2021

Abstract: For the process gases cleaning from dust in sinter production, different types and designs of apparatus are used. These are battery multicyclones and electrocyclones, bag filters, as well as electrostatic precipitators of various designs. However, only electrostatic precipitators have clear advantages. The purpose of this article is to improve the design of an electrostatic precipitator by increasing the efficiency of collecting dust, using electronic-ion technology with the combined movement of dusty gases and reducing the size. The improvement is based on the task of introducing a new architecture for constructing an electrostatic precipitator. The use of this improvement will contribute to the creation of lighter and more compact electrostatic precipitators, will make it possible to regulate the resistance of the apparatus, which affects the efficiency, depending on the dust load and the dispersion composition of the solid component. Computer modeling was carried out in order to establish the mechanism of the aerodynamic forces influence of the gas flow and to determine the dependence of the drift velocity and the direction of movement of charged dispersed particles on the velocity of the medium being purified during the combined course of gases in the electrostatic precipitator. The problem is solved by the fact that the electrostatic precipitator has a modular structure and consists of a voltage unit, a charging unit with a system of crown needle electrodes made in the form of needle plates 0.2... 0.5 m long and 0.020... 0.030 m wide, connected to the deposition unit, in which the deposition electrodes are installed perpendicular to the gas flow with the possibility of regulation and fixation at any angle to the direction of movement of the gas flow. The technical result is an increase in the density of the corona charge, the efficiency of the deposition process, a decrease in the overall dimensions of the electrostatic precipitator, and a decrease in the time of its manufacture, adjustment and installation. A gas cleaning apparatus of modular type “MV-2” has been developed, in which a new modular layout and technology of gas cleaning are applied. The device makes it possible to provide the required emission standards in a much smaller size in the range of 20... 50 mg/m^3, depending on the parameters of the dust and gas flow entering for cleaning and the fractional composition of dust.

Keywords: Electrostatic Precipitator, Charging Unit, Deposition Unit, Precipitating Element, Module, Emission Standards

1. Introduction

The problem of effectively collecting solid or liquid particles during the purification of process gases has become very relevant in recent years, because the degree of collecting used by traditional electrostatic precipitators for a number of insurmountable drawbacks is at a very low level - about 95% [1], this ultimately results in an excess of established European emission standards in various industries: power engineering, ferrous and non-ferrous metallurgy, construction materials, chemical and petrochemical industries.

In the applied electrostatic precipitators [2-5], the classical process of electro-gas cleaning is fulfilled, in which charged particles are removed from the gas phase by collecting in the boundary laminar sublayers near the surface of the collecting electrodes. The loss of collected particles is replenished as a result of the moving of charged particles and the rest of the interelectrode space under the action of a strong electric field and due to the entrainment of particles by pulsations of a turbulent gas flow. The efficiency of classic electrostatic precipitators is calculated, as a rule, in the form [6]:

$$\eta=1 - \exp \times (- w\kappa L/vd)$$

where:

η - efficiency;

w - the drift velocity of charged particles, m/s;

κ - coefficient of non-uniform distribution, reflecting the displacement of ash particles into laminar sublayers;

L - the length of the working fields of the electrostatic precipitator, m;

v - the speed of flue gases in the intervals between the collecting and corona electrodes, m/s;

d - the distance between the collecting and corona electrodes, m.

It follows from the above expression that traditional approaches to solving the problem of effective dust collection by reducing the speed of flue gases in electrostatic precipitators change the probability that all dust particles can end up in laminar sublayers and will be collected in them, especially their highly dispersed fractions. Although, on the other hand, a highly turbulent gas flow results in the separation of already collected dust particles and their agglomerates from the surface of the collecting electrodes. At the same time, increased speeds of 2... 3 m/s reduce the time spent in active intervals to 4... 5 seconds.

The main contribution to the efficiency of the electrostatic precipitator is still made by the heterogeneity coefficient of dust concentration distribution in the gas and, accordingly, the drift velocity of charged particles, which is determined [7]:

$$w=qE_{oc}\ (1+A_k l_m/r_ф)/6\ \pi\mu r_ф k_ф$$

where:

q - the charge acquired by the particle, C;

E_{oc} - the electric field strength at the surface of the collecting electrodes, V/m;

A_k - a constant characterizing the properties of the particle surface;

l_m - free path of dispersed particles, m;

$r_ф$ - the radius of the equivalent sphere of the particle, m;

$k_ф$ - the shape factor of the equivalent sphere of the particle;

μ - the viscosity of the gas phase, m^2/s.

As can be seen, the main criteria for increasing the drift velocity of dust particles are the charge and the strength of the electric field at the surface of the collecting electrodes. For the efficiency of trapping dust particles, it is necessary to maintain a sharply inhomogeneous field and ensure stable electron-ion processes in the corona discharge sheaths, which are concentrated in a narrow area near the discharge protrusions of the corona elements. However, the stamped needles in tape-needle corona elements, which are widely used, after 1-2 years of operation turn into oval protrusions due to electroerosion. Worn-out discharge protrusions exclude the formation of a sharply inhomogeneous strong electric field and do not provide a corona discharge density of 0.2... 0.5 mA/m^2 of the deposition surface acceptable for dust electroplating.

In addition, the proposed effective conditions for charging and collecting dust particles in a strong electric field should be provided by power units, the operation of which is focused on maintaining a certain frequency of spark discharges in automatic mode (50... 250 sparks/minute at a voltage of 40... 50 kV). In this case, the automatic control parameter is the load current feedback signal. And all the elements of the regulator are designed for optimal currents in the supply fields of the electrostatic precipitator. The design currents must be at least 50... 100% of the agreed rated load of the power supply unit of the specified standard size. Since the power supply protection circuit is also designed for the same load, the manual mode of power supply is not allowed with modern units. In the process of operation, the above-mentioned electroerosive destruction of corona protrusions and overgrowing of collecting electrodes with outdusted deposits result in a sharp drop in current loads - less than 30% of the nominal load of the power unit. Under these conditions, the automatic mode of the power unit tries to deduce the design indicators due to arc discharges. The manual mode does not allow reliable control of power thyristors. In the aggregate, the operation of an electrostatic precipitator leads to constant overvoltages in the high-voltage power supply circuit, which explains the failure of its individual elements. And in the low-voltage primary circuit, even power thyristors fail. Thus, instabilities and surges in the power supply results in an unjustified overconsumption of electricity and a further decrease in the operational efficiency of the electrostatic precipitators.

Technically and ecologically, the most promising solution to the problem of efficient dust collection is the use of intensive electron-ion technology with combined gas movement in electrostatic precipitators [8]. The basic physical principles of the combined flue gas cleaning technology are as follows:

1) ensuring the charging of the entire aggregate of ash particles to the limiting values by organizing a highly turbulent flow and staying of dust particles in areas with the highest intensity in corona discharge sheaths;
2) use of aerodynamic forces of gas pressure for forced movement of all charged particles into the trapping cells of gas-permeable collecting electrodes;
3) effective collection of charged dust particles in laminated layers near precipitation elements.

Intensive electron-ion technology with combined gas flow when implemented in electrostatic precipitators at power units of thermal power plants provides the following advantages:

a) ensuring European standards of emissions into the atmospheric air of cities;
b) metal consumption and specific energy costs for electric cleaning have the lowest values;
c) the design of active elements guarantees MTBF favorable for the power industry, which can be eliminated without the use of special equipment.

1.1. Simulation Stages

The SolidWorks software was used to simulate the technological scheme to determine the main parameters and efficiency, industrial instrumental measurements. The main stages of simulation are following:

1. Selection of components.
2. The choice of aerodynamic parameters for the main blocks of the cleaning device.
3. Calculation of the parameters of the gas cleaning apparatus.
4. Creation of a flow sheet.
5. Collecting results from the simulated environment.
6. Modeling the trajectories of dusty gas flows in the dust deposition system of an inertial apparatus.

1.2. The Simulation

A feature of metallurgical production is the formation of a significant amount of contaminated gases. In order to establish the physical mechanism of the electric gas cleaning technology with a combined gas flow, the possibility of separating and cleaning up to 400 thousand m^3/hour of contaminated gases from 0 to 6 g/m^3 of solid dust particles was modeled.

Particular attention was paid to the modeling process of deposition. A model of the deposition unit chamber was created, which is a dust chamber with a gas-permeable precipitator placed inside, made of shaped elements, and a dust deposition hopper.

The configuration and mutual arrangement of the elements made it possible to direct the flow along a complex trajectory between the elements of the precipitator (Figure 1).

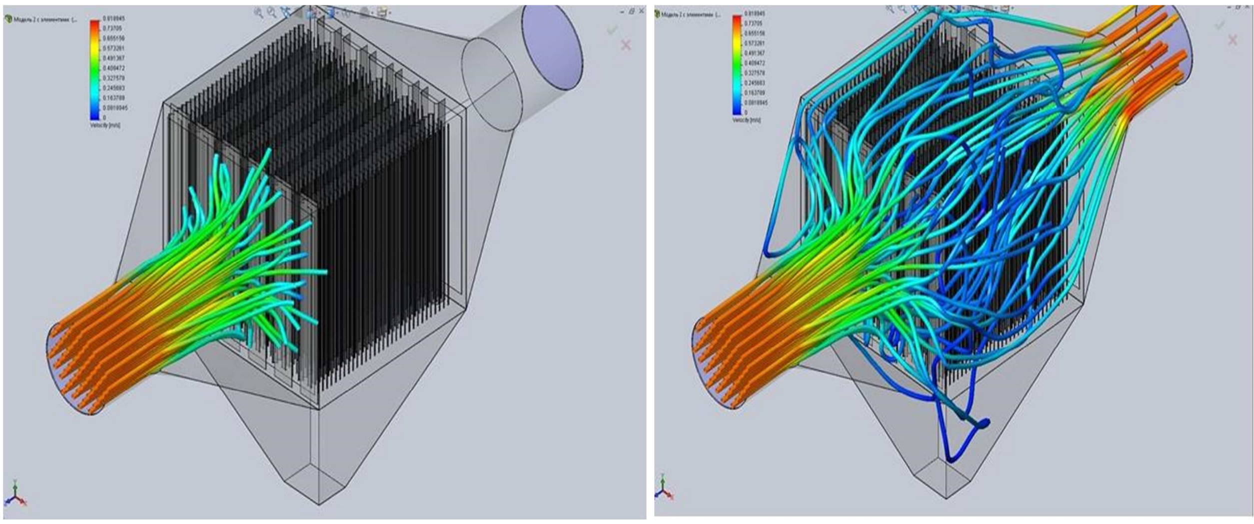

Figure 1. *Modeling the trajectories and velocities of dusty gas flows in a dust deposition system at various stages of movement.*

2. Result and Discussion

Industrial research has established the dependence of the effective (calculated) drift velocity of charged dispersed particles on the speed of the medium to be purified in the classical process of electro-gas cleaning and combined gas flow in electrostatic precipitators [8] (Figure 2).

It was found that in the electrostatic precipitator of the classical process of electro-gas cleaning, the increase in speed from 0.5 to 1.5 m/s, the drift of charged particles is intensified from 5 to 12 cm/s. However, further increases in velocity reduce the drift velocity of charged particles (Figure 2). Intensive electron-ion technology with combined gas flow provides an increase in the drift velocity of charged particles up to 22 cm/s.

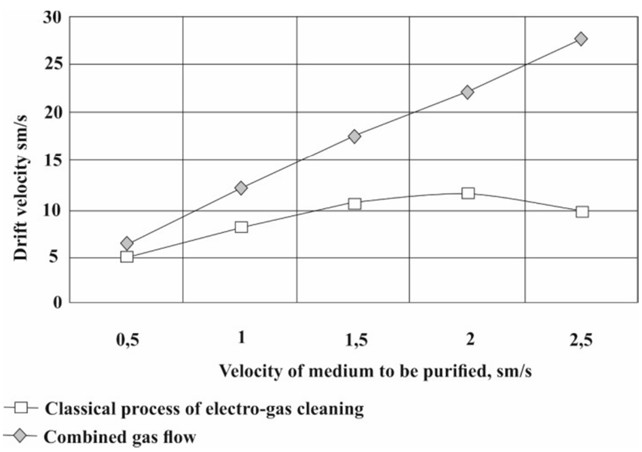

Figure 2. *Dependences of the efficiency of the drift velocity of charged dispersed particles in electrostatic precipitators.*

The data of a comprehensive survey also show that with an increase in the velocity of the medium to be purified in the electrostatic precipitator, the efficiency of dispersed particles collecting according to the classical electro-cleaning process significantly decreases, and in implementing the combined path of gases in the interelectrode gaps it increases ((Figure 3).

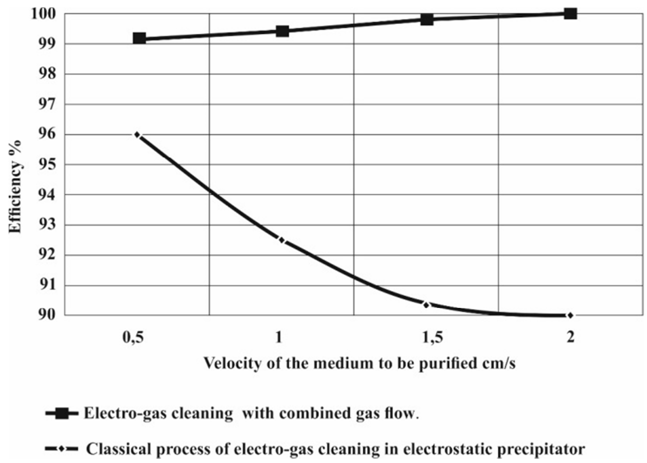

Figure 3. *Dependence of the efficiency of electrostatic precipitators on the velocity of the medium to be purified.*

However, when implementing a combined gas flow in electrostatic precipitators, collecting rod elements have a number of disadvantages: their cylindrical surface does not create conditions for laminar movement and active deposition of charged particles near the collecting surface. Collecting rod elements do not have developed aerodynamic shadow zones.

As a result of experimental studies, the mechanism of the influence of the aerodynamic forces of the gas pressure on the drift velocity of charged particles with the combined flow of gases has been established. This makes it possible to intensively turbulize the gas flow in the zone with the maximum values of the electric field strength and electric wind density. This ensures the maximum level of suspended particles charging, especially their finely dispersed fractions with a media diameter of up to 10 microns.

The aerodynamic forces of the gas flow transport the entire set of the charged medium into the cells, between the precipitation elements. When changing the direction of movement between the collecting plates, the value of the lateral displacement increases. This results in a sharp increase in the residence time of charged particles in the collecting cells [9, 10] where the electrostatic deposition of suspended particles in the laminar layers occurs.

The studied velocity spectra of the medium to be purified made it possible to generate designs of precipitation elements with a developed surface for the deposition of dispersed particles. The most optimal is the design of collecting elements in the form of a flat face with edge bends in the form of a circle not closed at 85... 95° and the ratio of the flat face to the radius of edge bends is 2... 7 units, depending on the electrophysical properties of the collecting particles [11].

In electrostatic precipitators with a combined gas flow of a new generation, profiled elements with a wide side are installed in the longline of the collecting electrode at certain angles at which the free cross-section of the perforated collecting electrode is 65….85%. Moving along the surface of the collecting electrodes the turbulent gas flow changes direction and breaks up into separate currents. Due to a sharp increase (more than 10 times) of the spreading area, the gas jets have a significantly lower velocity than the core of the main flow. Such spreading has a beneficial effect on the process of collecting charged dispersed particles, and also excludes their secondary carrying out. In the collecting cells between adjacent deposition elements, the conditions for a laminar flow of gas jets around their surface are provided. In this case, charged dispersed particles fall into the aerodynamic shadow zones formed by edge bends and are not directly exposed to gas jets [11, 12]. Taken together, the efficiency of collecting charged dispersed particles under the influence of Coulomb forces of an electric field in electrostatic precipitators with a combined gas flow will be determined:

$$\eta = l - [\exp(-w_{кхг} L/vd)](w_{кхг} L_э/v_э d_э)$$

where:

$w_{кхг}$ is the drift velocity of charged particles in the combined flow of gases, m/s;

$L_э$, $d_э$ is respectively, the width and pitch of installation of the profiled collecting electrodes, m;

$v_э$ is the speed of gas jets in the collecting cells, m/s.

At the same time, based on the results of investigations of the spectra of the velocities of the gaseous medium in the models of new electrostatic precipitators, the optimal free cross-sections of aerodynamic partitions were determined to ensure favorable conditions for charging suspended particles and uniform distribution of the cleaned flow through the collecting cells [12].

Based on the above, a new generation of gas cleaning equipment has been developed, based on innovative developments in the field of KEIT (combined electronic-ion technology for cleaning gases), as well as in the field of transformation and control of cascade energy of aerodynamics of turbulent and laminar flows during inertial deposition of dispersed suspensions of flue gases. One of the representatives of this equipment is a modular-type gas-cleaning apparatus "MV-2" ((Figure 4).

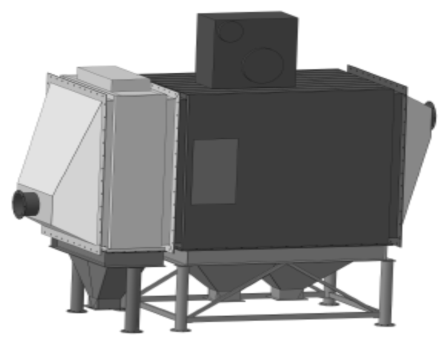

Figure 4. *Electron-ion technology modular fine gas cleaning apparatus.*

The main advantage, in contrast to traditional bulky electrostatic precipitators, is the applied new modular construction and new technology of gas cleaning in the MV-2 apparatus, which allows:

1) constructively manufacture them in much smaller dimensions, while ensuring the same parameters in terms of the volume of gases to be cleaned;
2) efficiently combine in one building of a gas cleaning unit sequentially located modular blocks of various gas cleaning technologies, through which passing flue gases are successively purified from dispersive suspensions and harmful gaseous elements such as CO, SO_2, as well as CO_2 (option).
3) ensure the purification of industrial or aspiration emissions (gases, dust, etc.) from dispersion suspensions at the exit from the apparatus into the atmosphere no more than 20 mg/m^3;
4) to completely assemble the MV-2 apparatus at the manufacturing plant, which determines, first of all, the high quality of the assembly of the internal equipment, to carry out preliminary adjustment (70% of the adjustment work) of the internal equipment in laboratory conditions and to supply the apparatus to the consumer with assembly modules;
5) at the installation site, only a large-unit modular assembly of the device, which significantly saves the customer's funds on installation and contract supervision.

Application area:

The device "MV-2" is designed for highly efficient cleaning of process gases and aspiration air from solid or liquid particles with a cleaning efficiency of 95.0... 99.9%, emitted during technological processes in various industries: power engineering, ferrous and non-ferrous metallurgy, materials of construction, chemical and petrochemical industry.

The design possibilities of assembly and application of "MV-2" have a wide range of productivity in terms of the volume of purified gases from 10,000 m^3/hour to 1,000,000 m^3/hour and more.

Apparatus "MV-2" covers a wide range of applications in the general arrangement of a gas cleaning plant, which includes several stages of gas cleaning. The modular arrangement of "MV-2" makes it possible to efficiently complete the design of the apparatus (to combine various technologies for gas cleaning in one common body), in order to use it as a main cleaning stage, with the cleaning reaching no more than 20 mg/m^3 at the outlet, and a preliminary cleaning stages, for example in front of a bag collector.

Apparatus "MV-2", as a preliminary cleaning of gases in a joint arrangement in front of a bag collector, has significant advantages in efficiency:

Gas cleaning apparatus "MV-2", unlike bag collectors, effectively neutralizes harmful gaseous (CO, SO_2) due to the innovative cleaning technology applied in it.

Apparatus "MV-2" effectively performs a very important function for a bag collector- spark suppression function in the labyrinths of precipitating systems;

Apparatus "MV-2" extends the service life of the filtering materials of the bags in the bag collector several times;

It reduces moisture content in gases entering the bag collector for cleaning.

Specific features of the MV-2 equipment set.

Depending on the parameters of the dust and gas flow entering for cleaning (gas volume - m^3/h, temperature - C°, dust content - g/m^3, composition of microconstituents in the gas component (for example: CO - up to 0.1 g/m^3), average chemical composition -% Fe_2O_3, etc., fractional composition -% µm.), as well as the parameters required by the Customer at the outlet of the gas cleaning unit, the MV-2 apparatus is equipped with appropriate modular units to ensure the required degree of cleaning in terms of dispersion and gas components of the dust and gas flow.

The gas cleaning apparatus can include the following modular blocks of a separate technology for cleaning a dust and gas stream:

1. Unit №1 of combined electronic-ion technology of gas cleaning (Figure 5);
2. Due to the unique design of the arrangement of the internal equipment, corona and precipitation elements, the achieved corona discharge density is 10 times higher compared to traditional designs of electrostatic precipitators, and the power consumption is significantly lower.
3. Unit №2 for conversion and control of cascade energy of aerodynamics of turbulent and laminar flows of inertial deposition of dispersive suspensions ((Figure 6);
4. The special design of the precipitating elements, the order and density of their arrangement, allows you to achieve the maximum effect of deposition of charged particles on the surfaces of the elements. In the small internal dimensions of the block body (length 2.6 m, width 1.78 m, height 2.2 m), the total deposition area of dispersed suspensions is 336 m^2.
5. Unit №3 for harmful gaseous constituents cleaning (CO, SO_2).

Due to the innovative technology applied in this modular unit, depending on the degree of contamination of the gas component of the dust and gas flow, the efficiency of neutralizing such gaseous gases as CO, SO_x can be from 10 to 90%. (Optional: CO_2 neutralization efficiency from 5%).

Technical and operational characteristics of "MV-2"

The total weight and dimensions of separate modular units of the apparatus, with a dust collection hopper, no more than:

1. Unit 1: - length 0.75 m, height 3.7 m, width 2.0 m. Weight up to 1.5 tons.
2. Unit 2: - length 3.0 m, height 3.7 m, width 2.0 m. Weight up to 5 tons.
3. Unit 3: - length 0.75 m, height 3.7 m, width 2.0 m. Weight up to 2 tons.

Each unit is designed for a capacity of 30,000 m^3/hour in terms of gas volume at a temperature not exceeding 300°C. (The design of a high-temperature device up to 600°C is possible) Depending on the volume of the gas flow and the required degree of purification, "MV-2" is equipped with the necessary number of modular units with the appropriate purification technology (for example, Figure 7).

Resistance: no more than 400 Pa, not depending on the number of modular units in the general arrangement.

Energy consumption: up to 0.3 kW/h per 1000 m^3

Vibration regeneration system: regeneration mechanisms (vibrators) are located outside the core of the apparatus.

High-voltage equipment: The set of the device includes a power supply unit for electrodes, a control cabinet for a power supply unit and a mechanism for shaking electrodes. Depending on the volume of the gas flow and the required degree of cleaning, "MV-2" is completed with the required number of power units, regeneration mechanisms, control cabinets and other high-voltage equipment.

Dust unloading devices are included in the kit only at the request of the customer.

Confuser, diffuser and additional equipment are in accordance with the binding project.

Figure 5. *Unit №1.*

Figure 6. *Unit №2.*

Figure 7. *Combined arrangement of gas cleaning unit "MV-2-30".*

From left to right: Unit №1 of the combined electronic-ion technology of gas cleaning.

Unit № 2: conversion and control of cascade energy of aerodynamics of turbulent and laminar flows of inertial dispersion suspensions deposition.

3. Conclusion

1. Computer simulation of the movement of dusty gas flows through the dust deposition system has been carried out. The dependence of the velocity, movement direction of the gas flow, the size of dust and the performance coefficient of the cleaning apparatus, depending on its resistance, has been defined.
2. The physical mechanism of the electro-gas cleaning technology with the combined gas flow has been determined.
3. A gas-cleaning electric apparatus of the modular type "MV-2" has been developed, in which a new modular arrangement and technology of gas cleaning are applied.
4. Apparatus "MV-2" allows, in significantly smaller dimensions, to provide better parameters in volume of gases to be cleaned, to efficiently combine modular units of different gas cleaning technologies in one body, through which passing flue gases are successively cleaned from dispersion suspensions (no more than 20 mg/m^3) and harmful gases such as CO, SO_2, as well as CO_2 (option), completely assemble "MV-2" at the manufacturing plant, which determines the high quality of assembly of internal equipment and supply the device to the consumer with mounting modules.
5. The solution to the problem of effective dust collection in flue gases is to implement an intensive electronic-ion technology with a combined gas flow in electrostatic precipitators.

References

[1] Richter L. A. Ways to improve the efficiency of electrostatic precipitators // Heat power engineering №5, 1991, p. 5-9.

[2] Aleksandrov M. REDECAM equipment for dust removal and gas cleaning systems (REDECAM Group S.r.s Italy) Interbranch scientific and technical journal "Dust gas cleaning" № 7, 2014, p. 13-19.

[3] Myslivets D. K. Use of highly efficient gas cleaning equipment manufactured by INTENSIV INFASTA CIPRES FILLTR (Sweden) in the metallurgical industry during new construction and reconstruction (SovPlym CJSC) Interbranch scientific and technical journal "Dust gas cleaning" № 5, 2013, p. 10-12.

[4] Cao RJ, Tan HZ, Xiong YY, Mikulcˇic ´ M, Wang X, et al. Improving the removal of particles and trace elements from coal-fired power plants by combining a wet phase transition agglomerator with wet electrostatic precipitator. J Clean Prod 2017; 161: 1459-65.

[5] Yang Z, Zheng C, Chang Q, Wan Y, Wang Y, Gao X, et al. Fine particle migration and collection in a wet electrostatic precipitator. J Air Waste Manage Assoc 2017; 67 (4): 498-506.

[6] Fundamentals of electro-gas dynamics of disperse systems/I. P. Vereshchagin, V. I. Levitov, T. Z. Mirzabekyan, M. M. Pashin, M.: Energiya, 1974, 480 p.

[7] Baranov L. P., Vereshchagin I. P., Belousov V. V. The process of collecting high-resistance dust of ferroalloy production in an electrostatic precipitator with limiting the reverse corona // Izvestiya VUZ Ferrous metallurgy, 1991, № 3, pp. 31-38.

[8] Baranov L. P., Vereshchagin I. P. Electrostatic precipitators with intensive electronic-ion technology // Application of electronic-ion technology in the national economy: Abstracts of reports IV All-Union Conference - M.: 1991, p. 14-15.

[9] Antonov M. V., Baranov L. P. Intensification of the cleaning process in electrostatic precipitators with increased rates of gases to be cleaned // Environmental protection from emissions from ferrous metallurgy enterprises - Moscow: Metallurgy, 1988, p. 72-75.

[10] Baranov L. P., Golodnova T. S., Golodnov N. N. Experimental determination of the physical velocity of particle drift in the model of an electrostatic precipitator // Ecological problems of the trans-Dnieper-Donetsk region: Conference Abstracts - Zaporozhye, 1995, pp. 9-10.

[11] Baranov L. P., Golodnova T. S., Konovalov N. A., Lakhno N. I., Golodnov N. N. Film and photo recording of the motion of highly dispersed particles in two-phase flows // Environmental problems of the trans-dnieper-donetsk region: Conference Abstracts - Zaporozhye, 1995, p. 7-8.

[12] Patent (USSR) 1820877 A3 B03C 3/45 Electrostatic precipitation electrode/L. P. Baranov, N. N. Golodnov, T. S. Golodvanova and others - application № 4928174/26, announced on 04.16.91, Publ. 06/07/93 Bulletin № 21.