Two-Level Electrostatic Filter for Fine Cleaning

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Abstract. In the given paper, we consider the original design of an electrostatic filter [2], which, in addition to precipitation of unburned hydrocarbon fuel particles (soot), allows to fulfill the fine cleaning of the waste flue gases. The design consists of two parts, each of which carry out respectively a coarse and fine cleaning of the smoke passing through the filter. The application of this filter allows to solve the problem of smoke emissions in certain industries and the national economy, where until now the using of the electrostatic cleaning method encountered some difficulties and was insufficient. The compact construction of vertical design does not require the special place for its location and can be placed as a superstructure of the working pipe or inside it. The self-cleaning system at each filter level allows to minimize the influence factor of maintenance personnel on the work process, improves the safety level and increases the service life of the cleaning system between current repairs.

1. Introduction

The main sources of pollution of atmosphere as well as water and soil are various energetic stations designed for generation of the required type of energy and using for this purpose mainly hydrocarbon-based fuel [1, 2, 3]. The work of given stations in addition to obtaining of useful amounts of energy is also associated with emissions of solid fractions and gaseous substances. If we consider coal as fuel, then a boiler plant with an installed capacity 1 MW emits about 21 tons of solid fractions per year [4]. The concentration of substances in emissions varies depending on the type of fuel, the deterioration of the using equipment, its operating mode, etc.

For the neutralization of these emissions in large plants, various cleaning systems are used, mainly destined for removing of soot particles from the smoke emissions produced at the working. To reduce the negative effect of emissions at the fuel combustion in mobile devices, in particular in cars, the systems whose work based on a catalytic cleaning system are used.

2. Formulation of the problem

The using of purifying devices able to remove black smoke from the chimney by trapping of soot particles does not allow to neutralize the accompanying gases, which also are formed at the fuel combustion. The process of operation of such devices is also very special and requires periodic disconnection of individual elements for cleaning, which leads to increasing of sizes and cost. The catalytic cleaning system allows to reduce the concentration of toxic gases, but it is sensitive to soot emissions, which can lead to complete or partial failure.
Strengthening of requirements, indicated at annual world climate conferences, oblige states to reduce emissions on their territory. As a rule, implementation of these requirements leads to a reducing in of the amount of burned fuel, which will inevitably lead to decreasing of economic indicators, or the introduction of new technologies for cleaning of flue gas.

3. Solving of the problem

The satisfaction of the requirements of gas cleaning increasing is possible with the using of a two-level vertical electrostatic filter, proposed by the authors, whose originality is confirmed by patents for inventions [5]. Given filter differs from other existing constructions by a paired construction consisting of two levels (Fig. 1), where at the first level, primary flue gas cleaning is carried out using a system of rotating cylindrical precipitation electrodes (CPE). This level consists of four zones, where area 1 is characterized by an area of dense smoke, with soot particles coming directly from the furnace of the boiler. The size of the particles, their agglomerations and the nature of the formation of these particles depends on the type of using fuel and the deterioration of the equipment. In zones 2 to 4, the primary and main precipitation of soot particles is carried out under the action of an electrostatic field of high voltage [6]. The efficiency of cleaning of the passing smoke flow depends on the number of precipitation electrodes. In this case the using of cylindrical electrodes solves the problem of the compactness of the system and the problem of maintaining the proper efficiency of flue gas cleaning, taking into account the constant presence of a clean surface in the precipitation zone.

At the second level, fine cleaning of the exhaust gases is carried out by the honeycomb catalytic collector (Fig. 3) made of a heat-resistant dielectric with self-cleaning function. The catalytic filter installed in zone 5 performs fine cleaning of the flue gases coming in without soot particles. At this stage, direct purification of gases containing in their composition NO₂, NO, CO etc. is carried out. The self-cleaning function of the catalyst allows to prevent the "clogging of the main channels". Zone 6 is characterized by the cleaned flue gases coming out of the chimney.

At the first level, the process of precipitation of particles on the surface of the CPE is carried out under the action of electrostatic field forces and aerodynamic resistance. Cleaning of the precipitation surface at its turning is carried out mechanically in the withdrawal sleeves, which are separated from the flue cleaning zone by a heat-resistant dielectric barrier. The pressure in the precipitation zone during operation is equal to the pressure in the withdrawal sleeves. This separation does not allow particles of soot, removed from the CPE, to enter again in the cleaned smoke stream. The particles under their own weight are lowered into the dust collector intended for their collection and utilization. Thanks to this, it is possible to clean the surface of the precipitation electrodes continuously, in an automatic mode. The using of the withdrawal sleeves and the precipitation electrodes of a cylindrical shape allows to abandon the cyclic mode of voltage applying to the electrodes and the mechanical action necessary to shake the precipitation electrodes of the classical construction. Fixed corona electrodes placed along the perimeter of the CPE, at a certain distance from each other, forming an active gap δ, have a needle structure. For creation of an inhomogeneity of the field, the needles of each subsequent corona electrode cover the gap between the needles of the preceding corona electrode (Fig. 1) in order to equalize the fields of action of the electric field strength and to increase the cleaning efficiency of the smoke flow passed through the filter. The installation of the construction of the considered filter is performed directly on the pipe of the existing chimney or the filter is installed inside the pipe, which allows to reduce financial and labor costs, since the necessity of a separate site for its placement is excluded.

The cleaning of the smoke is carried out as follows: the flow, passing through the electrostatic filter, bypasses the CPE and comes into the region of action of the electrostatic field of high voltage created between the precipitating electrodes and corona electrodes. Particles of soot, ionized at the coming into this field, precipitate at the surface of the CPE, which at the rotating transfer the precipitated particles to the withdrawal sleeves. Scrapers, installed in the withdrawal sleeves, remove a layer of precipitated particles that fall into the dust collector. The cleaned surface of the CPE in time of its further rotation enter again in the area of precipitation of the electrostatic filter, which
contributes to a reliable and efficient process of precipitation of particles and working of the electrostatic filter as a whole.

The soot particles, contained in the smoke and formed at the combustion of fuel in the furnace, being in a common smoke stream, interact with each other, creating agglomerations of various sizes and masses \((m_1, \ldots, m_4)\), which leads to their precipitation at different stages (different CPE) of the cleaning in the filter (Fig. 1), which also is confirmed by the model \([6]\). The precipitation of particles mainly is carried out at the area "x" of each CPE, it characterizes the zone located opposite the corona electrodes. Particles with a mass of \(m_4\), eventually passed through the first level of the electrostatic filter, are a percentage of the error of the electrostatic filter, which also includes particles which have detached from the side walls of the electrostatic filter. The mass of these particles significantly exceeds the value of the mass assuming at the calculation.

The precipitation process in areas "x" is characterized by significant changing of the magnitude of the electric field strength, which is also confirmed by the results of experimental studies \([6]\).

Thus, knowing the type of fuel, as well as other parameters of the boiler house for which the electrostatic filter is designed, it's possible to optimize the proposed filter design for the considered type of boiler house varying the number of CPEs, the corona electrodes, the active gap \(\delta\) between them and the voltage applied to them.

![Figure 1. Construction of the two-level electrostatic filter.](image)

Analyzing the data of experimental researches, consisting in cleaning of the smoke flow, formed at diesel fuel combustion and passing through the experimental device, that imitates the first level of the smoke filter, one should note the presence of soot particles precipitated on the surface of the CPE in the "x" zone. On the surface there is a discernable boundary of precipitation of soot particles, for case when the electrode did not rotate, but operated in a static mode \([6]\).

When a smoke stream passes through an electrostatic filter, part of the particles precipitates, simply colliding with the surface of the electrode (this is observed mainly in zone 2), the remaining particles, bypassing the CPE, come within the region of the electrostatic field of high voltage, where, in addition to the main forces acting in the electrostatic filter, such as force of traction \(F_m\), induction forces, coulomb force \(F_k\), the centrifugal forces \(F_u\), which are amplified by the electric field, begin to act \([7, 8]\). Their appearance is characterized by the design of the electrostatic precipitator (Fig. 2).
Figure 2. Forces in the electrostatic filter.

\[ F_u = \frac{mv^2}{R} \]  

(1)

where: \( m \) is the mass of soot particles; \( v \) is the velocity of the soot particles; \( R \) is the average radius of the electrode, taking into account the air gap, over which the bypassing of the CPE is carried out.

Thus, the first filter level, at the passing through it the combustion products, ensures removing of the most part of the soot particles. However, it should be noted that incomplete oxidation of the fuel during combustion leads to the formation of not only particles of soot, but also toxic gaseous impurities. If coal is used as fuel, flue gas contains carbon monoxide (CO). At the combustion of petroleum products, emissions also include various types of hydrocarbons (C\(_x\)H\(_y\)) and nitrogen oxidation products NO\(_x\), which are very harmful to the environment. Therefore, in order to carry out purification in accordance with modern standards, it is also necessary to use a second filter level, which is a catalytic converter, a device for preventing the emission of toxic gaseous impurities into the atmosphere. Due to special catalytic blocks in the neutralizer, the harmful components of combustion products, such as carbon monoxide, hydrocarbons and nitrogen oxides, are converted to environmentally friendly products: carbon dioxide, water and elemental nitrogen.

For the solving of this problem, it is proposed to use a honeycomb block based on the aluminum ceramics obtained by the Boreskov Institute of Catalysis. The ceramics is one of the forms of the crystal lattice of aluminum oxide Al\(_2\)O\(_3\).

The dielectric catalyst is made in the form of a honeycomb monolith.

The experimental researches showed a high degree of purification of the combustion products and a long service life of the catalyst (see Table 1).

A significant advantage in comparison with analogues is the cheapness of the raw materials and technologies for obtaining the catalyst.

**Table 1.** The efficiency of the catalytic block.

| №  | Combustion products  | Degree of purification, % |
|----|----------------------|----------------------------|
| 1  | Carbon monoxide      | 80-90                      |
| 2  | Organic compounds    | 70-80                      |
| 3  | Soot                 | 60-70                      |

As experimental studies showed, the efficiency of neutralizing poisonous substances listed in Table 1 remains stable during more than 2000 hours of operation. These numbers exceed the values of similar indicators for platinum catalysts.

However, despite all the above advantages of the obtained aluminum-ceramic catalyst, for it, as for other types of catalysts, there are problems, such as a decrease of efficiency with decreasing temperature of the emissions.
For increasing of the efficiency of catalytic cleaning of combustion products, it is proposed to use a system of two groups of opposite charged electrodes, which are nested into the channels of the catalytic block of the honeycomb structure (Fig. 3). Since the material of the catalyst has dielectric properties, at a certain value of the voltage applied to these electrodes, a barrier discharge arises that ensures the appearance of ozone molecules and a significant increasing of the purification efficiency. Ozone generation directly in the dielectric-catalyst layer initiates highly efficient ozone-catalytic oxidation of hydrocarbons and other volatile organic compounds.

**Figure 3.** A catalyst of honeycomb structure with electrodes located in the channels of the block.

It has been found that under this condition the effective oxidation of various organic compounds such as alcohols, ketones, aromatic compounds and chlorinated hydrocarbons is provided.

In particular, as studies have shown [9] at the using of a catalytic material containing 5% MnO$_2$/γ-Al$_2$O$_3$, 10% MnO$_2$/γ-Al$_2$O$_3$, γ-Al$_2$O$_3$ the maximal toluene removal efficiency close to 100% was reached.

On the other hand, it's important to pay attention to the fact that the interaction of ozone with the material of the catalytic block also leads to a significant acceleration of the process of decomposition of ozone itself in accordance with the following chain of reactions:

\[ O_3 + \bullet \rightarrow O + O_2; \]
\[ O_3 + O \rightarrow 2O_2 + \bullet. \]  

In the first stage, the ozone molecule is activated on the surface of the catalyst and dissociates into atomic oxygen (in the adsorbed state) and the molecular oxide released into the gaseous environment. In the second stage, the adsorbed atomic oxygen reacts with ozone from the gaseous environment to form molecular oxygen. The efficiency of ozone decomposition according to this mechanism reaches 98%, which prevents its unwanted release into the atmosphere.

The optimal choice of the geometric parameters of the catalytic block, the shape of the cells and embedded electrodes, the frequency and voltage of the supply plays an important role in achievement of high cleaning efficiency. Optimization of these parameters is possible on the basis of the developed mathematical models of the distribution of the electric field in the inhomogeneous dielectric of the catalytic block, which were experimentally confirmed in the process of the studies carried out jointly with the Boreskov Institute of Catalysis [10-12].

The foregoing allows us to conclude that the development of devices providing direct formation of ozone in heterogeneous catalyst layers is an actual problem. The using of this type of device leads to a combination of processes of formation of highly active atomic oxygen and complete oxidation of undesirable organic impurities to carbon dioxide and water.
4. Conclusion

Thus, on base of the results of the analysis of this construction and simulation data, it can be said that the applying of an electrostatic filter of the considered design, characterized by the using of precipitation electrodes of cylindrical shape, allows:

- provision of a constant mode of voltage supplying to the electrodes, simplifying the power supply system of the electrostatic filter;
- abandon the mechanisms of shaking electrodes in the electrostatic filter, that reduces its metal consumption, sizes and simplifies the design;
- Implement the automatic electrode cleaning system.

The using of catalytic block of a honeycomb structure with electrodes nested in channels as the second level of the filter allows to efficiently oxidize such toxic components of combustion products as carbon monoxide, hydrocarbons and oxides of nitrogen to environmentally friendly carbon dioxide, water and nitrogen.

The obtained research results can significantly facilitate the solution of the problems of flue gases cleaning of medium and low-power boiler houses, the cost of cleaning the exhaust gases of the boiler houses, and also can be useful at the development of purification devices, ozone generators, etc.

5. References

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