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The impact of re-entrainment on the electrocyclone effectiveness

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ABSTRACT

The problem of fine particle gas cleaning is especially actual at the present time. This is due to the need to capture the desired product and waste gases cleaning. In both cases, the equipment should provide maximum collection efficiency. Cleaning of gas from thermal power plant (TPP) fly ash is serious problem. Coal-fired thermal power plants provide 27% of the total world energy consumption. Conventional TPP produce more than 700,000 tonnes of fly ash per year. Annually fly ash production only in Russia, according to various estimates, is 27–35 million tons.

Various apparatus are used to clean the gases from the fly ash. Required collection efficiency of purification units must to be 99.5–99.7% and higher. Wet scrubbers makes ash recycling more difficult. It requires ash separation from the slurry and drying.

One solution of gas cleaning problem is a electrocyclone. It provides gas purification efficiency up to 99.9% at initial ash concentration equal 50 g/m^3 and higher. An electrocyclone allows to obtain a product in dry form.

Re-entrainment is return of captured material to clean gas stream. Re-entrainment in the gas cleaning equipment is one of the negative effects. Re-entrainment reduces equipment efficiency at high gas velocities.

The present study was carried out to determine the value of re-entrainment in the electrocyclone.

The object of study was the electrocyclone of ‘pipe in pipe’ type. Aluminosilicate fly ash from thermal power plant (TPP) was the test material. Study was carried out in dry and wet modes. Re-entrainment was observed in dry operation mode. No re-entrainment was observed in wet operation mode. The value of re-entrainment was calculated. It decreases collection efficiency from 99.9% to 60%. Re-entrainment depends on aerosol velocity (range 14–27 m/s) and the aerosol concentration (range 2–30 g/m^3). It is shown, what re-entrainment can be eliminated by water irrigation of collecting electrodes.

1. Introduction

An electrocyclone is a variation of an electrostatic precipitator (ESP), in which the flow of dusty gas moves rotationally and translationally [1,2]. Many authors believe that an electrocyclone is the synthesis of a cyclone and an ESP [3–6]. The first work on electrocyclones was performed over 40 years ago [7,8]. Since then, various electrocyclone designs representing a cyclone placed in the exhaust pipe with a discharge electrode and others have been suggested [9–15].

Over the past 10 years an uncommon electrocyclone design has been suggested, a multistage electrocyclone or an electrocyclone with an active section consisting of several concentric cylinders of precipitation with discharge electrodes between them.

A very simple laboratory model of such an electrocyclone is composed of two cylinders and one system of the discharge electrodes, which will be discussed in the article (electrocyclone of the ‘pipe in pipe’ type) [16].

Quite a high degree of gas purification (up to 99.9%) in this kind of an electrocyclone from solids such as sodium percarbonate, powdered iron-vanadium concentrate, sublimates from the fumes for melting blister copper, TPS ash [17], and from liquids aerosols (transformer oil and glycerol) [18,19].

This paper will focus on the TPS ash collection.

A decrease in the degree of purification was previously shown by the experiment with the increased aerosol rate at the electrocyclone inlet of more than 15–17 m/s [20]. By increasing the gas velocity in the active section the centrifugal force increases [21], which favours the deposition of particles [22]; however, at a constant length of the apparatus the time of aerosol being in the core of the apparatus is reduced, the particle charging efficiency is reduced, and ash entrainment is increased [23–25] This means that the particles do not have time to settle on the collecting electrode, re-entrainment increases as the already settled particles, especially

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the smaller ones, are unsettled from the sediment layer in the form of large particles and turbulent eddies [26–29].

2. Experimental part

2.1. Description of the experimental setup and methods of the experiment

For the experiments, a laboratory electrocyclone of the 'pipe in pipe' type was used.

The electrocyclone diagram is shown in Fig. 1.

It consists of a housing 1, with an inlet scroll 2, the central pipe 3, corona system 4, exhaust pipe 5, hopper 6 and insulators 7.

The methods of the experiment:

A dusty gas stream goes through the inlet connection to the scroll (2), acquires a rotational motion and then moves along the annular channel of the electrocyclone active section down in a rota tional–translational manner [30]. The dust particles suspended in gas are charged in corona discharge field, and subject to the Coulomb force move in the annular channel from the discharge electrodes to the collecting electrode. Simultaneously, the particles are subject to the centrifugal forces resulting from the motion of the dust and gas flow across the curvilinear channels. These forces are directed radially from the centre to periphery.

The annular channel consists of two areas, internal and external. In the internal area, electric and centrifugal forces act in opposite directions. However, calculations show that the impact of the electric field on particles with a diameter less than 5 microns is considerably larger in size than the centrifugal force. Therefore, on the collecting electrodes of the internal area smaller particles are deposited.

The frame-type discharge electrode system is used in an electrocyclone with corona elements of the needled-rod type the needles being parallel to the collecting electrodes ('squirrel wheel'). The distance between the needles is 40 mm.

An electrocyclone is placed on the stand of the Department of Chemical Technology Processes and Devices of the UrFU Institute of Chemical Technology.

The stand (Fig. 2) includes an electrocyclone 1, a dust feeder 2, a draft and head gauge 3, a high voltage source 4, a U-shaped tube 5,

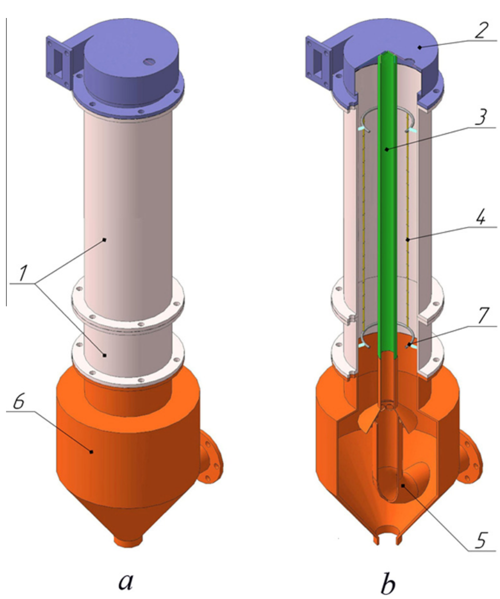

Fig. 1. Vertical electrocyclone scheme. Characters: 1 – housing (cyclone shell), 2 – inlet scroll, 3 – central pipe, 4 – corona system, 5 – exhaust pipe (vortex finder), 6 – hopper, 7 – insulators.

a bag filter 6, an inlet pipe with a collector 7, valves 8, flowmeters 9, pressure gauges 10, a filter holder 11 and a sampling tube 12.

Ash is supplied by the dust feeder in a disaggregated form through the inlet pipe to electrocyclone 1. The captured ash is collected in the electrocyclone hopper, and the purified air in the air duct is removed through a bag filter (for safe operation of the vacuum pump) into the atmosphere.

High voltage is supplied to the discharge electrodes from the power source IVNR20-10 type the housing and central tube of the electrocyclone being grounded.

The air speed in the inlet pipe of the electrocyclone is configured with a valve taking into account the pressure drop on the draft and head gauge connected to a collector on the inlet pipe. To measure hydraulic resistance, a differential pressure gauge, a U-shaped tube is used.

The concentration of ash in the purified air is determined by the gravimetric method with the absolute aerosol filter AFA-VP-20 type made of PVC fibre fixed in the filter holder. The volume of air passing through the filter is determined by the flowmeter of the RS-5 type, and the desired air flow is adjusted with a valve meeting the isokinetic sampling requirements.

Material disaggregation is achieved by supplying compressed air through the flowmeter of the RS-5 type to the dust feeder ejector. Air flow is regulated by a valve.

Tests were carried out at various air velocities in the pipe inlet of the electrocyclone without and with supplying a high voltage to the discharge electrode system in the presence and absence of the profiled elements and water film irrigation of the collecting electrode.

If no voltage was applied to the discharge electrode from the power supply source, the apparatus was operated in the cyclone mode and ash particles were deposited due to the centrifugal and inertial forces (the force of gravity may be neglected).

The ash collection experiments in a wet mode were carried out on the above stand with some optional equipment. An electrocyclone with additional tooling is shown in Fig. 3.

To irrigate the collecting electrode of the electrocyclone 1 the irrigation system in the inlet scroll consisting of a distribution ring 2 and feed tubes 3. The suspension from the hopper 4 is removed through the hydraulic lock 5 to montejus 6.

The uniform irrigation in the translational–rotational gas motion is achieved at a flow rate of 8 l/min [31]. The voltage applied to the electrode is from 0 to 17 kV.

2.2. Experiment planning

To assess the impact of the holding time and re-entrainment on decline in the particle trapping efficiency in the electrocyclone one of the factors needs to be excluded. To eliminate the re-entrainment it is necessary to irrigate the collecting electrode with a water film. Then the particles deposited on the water film cannot return into the gas stream, and will be irreversibly removed from the active section.

In order to minimise the number of required tests while maintaining the statistical reliability of the results, the experiment was planned.

The degree of gas purification is taken as an optimisation parameter. The degree of gas purification in an electrocyclone depends on many parameters. By taking some of the main ones, we obtain a general expression (1) for the response function:

$$\eta = f(U, \omega, c, l, \rho_p, \rho_{el}, a) \qquad (1)$$

where U is the operating voltage, ω is the aerosol velocity in the inlet tube, c is the aerosol concentration at the inlet of the Apparatus, l is the length of the active section, d is the particle diameter,