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Investigation into a new generation multi-channel cyclone used for removing lignin particulate matter from gas under conditions of an aggressive environment

*P. Baltrėnas, A. Chlebnikovas**

Vilnius Gediminas Technical University, Institute of Environmental Protection, Saulėtekio ave. 11, 10223 Vilnius, Lithuania

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ABSTRACT

A multichannel cyclone is new generation air treatment equipment that can remove fine stiff particles of up to 2 μm from air flow and reach the general effectiveness of 95%. The carried out research is aimed at establishing parameters for the dynamics of the gas–vapour two-phase flow in the cyclone and treatment efficiency removing stiff lignin particulate matter, i.e. under the increased humidity and temperature of the purified flow. The article describes the peculiarities of parameters for the cyclone—separator and analyses the results of the cyclones having different inner structures under conditions of an aggressive environment. The flow polluted with lignin particulate matter has been treated under simulation conditions in the laboratory, at the gas flow temperature of 28–30 °C and gas flow humidity of 85–95%. Under an average vapour-PM flow velocity of 12 m/s in the cyclone polluted with ultra-dispersive 20 μm lignin particulate matter and conditions of the aggressive environment, treatment efficiency equals 82.5%.

1. Introduction

Cyclones as air treatment equipment are most frequently used for trapping particulate matter (PM) produced in energy facilities within the combustion process. They appear as ones of the cheapest air treatment devices; however, their main disadvantage is a low trapping ratio of the stiff particles having a diameter less than 10 μm. This is particularly evident when it comes to complying with strict requirements for emitting harmful particulate emissions to air (Blachman and Lippmann, 1974; Blumberga et al., 2012; Stairmand, 1951; Widiatmojo et al., 2015). However, the advancement of the structure of the cyclone may result in the separation of 10 μm ultra-dispersive particles (Hu et al., 2005; Jakštonienė, 2012; Saltzman and Hochstrasser, 1983; Vaitiekūnas and Jakštonienė, 2010).

The treatment efficiency of the cyclone can be increased with the help of different methods–using the acoustic field exiting particulate coagulation and applying the inlet of the secondary air flow into the cyclone (Vekteris et al., 2011, 2012; Zhao et al., 2006).

A multi-channel cyclone allows producing larger output and efficiency than common cyclones. The structure of equipment is much more improved than that of regularly used analogous devices intended for separating dry stiff particles from gas-air flow (Crowe et al., 2012). A combination of dusty flow filtration and centrifugal cleaning is a new direction towards the development of centrifugal treatment equipment (Balan et al., 2000; Jakštonienė, 2012; Burov et al., 2005; Winfield et al., 2013).

The above introduced new generation multi-channel cyclones have been explored by the researchers from various

* *Corresponding author*. Tel.: +370 63693865.
E-mail address: aleksandras.chlebnikovas@vgtu.lt (A. Chlebnikovas).
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countries throughout Europe (Altmeyer et al., 2004; Baltrėnas et al., 2012; Plashihin and Serebryanskyy, 2011).

The effective trapping of particulate matter in the cyclone can be affected by mechanical, physical and chemical properties as well as by the dispersity and shape of the particulates the concentration of which has a big impact on the treatment efficiency of the cyclone. Also, the structure and geometrical parameters of the cyclone have an impact on the efficiency of trapping particulate matter (Bernardo et al., 2006; Hoffmann and Stein, 2002; Holbrow, 2013). Moreover, the efficient trapping of stiff particles in the cyclone is influenced by the properties of gas (air), including temperature, viscosity and chemical composition. The impact of gas (air) on trapping particulates in the cyclone occurs in two ways—they affect the viscosity of the gas mix, and gas equipment can change the properties of the particles thus causing their adhesion (or autohesion) (Avci and Karagoz, 2003; Sobolev et al., 2011; Van Wachem and Almstedt, 2003; Wang et al., 2006).

Regarding a simple structure of the cyclone and application possibilities, equipment for general purpose is employed not only in aspiration/ventilation systems but also under aggressive conditions. An aggressive environment is agreed as a range of different operating additional physical, chemical, etc. factors the impact of which acts negatively on the available technologies and their exploitation. In that case, the properties of materials change along with mechanical, physical, chemical, etc. processes. The purification of polluted gas frequently takes place under conditions of the aggressive environment, including increased gas temperature and humidity, the additives of chemical substances in gas flow, condensation causing evaporation, etc. Improvement in the structure of the cyclones, considering factors in the aggressive environment, should greatly expand the application of the latter ones in various industries.

Adhesion processes in the cyclones take place when particulate matter sticks to the surface of the device and thus ends in autohesion, that is inter-particle adhesion. Adhesion force value depends on particle interaction with the surface, because molecular interaction is proportional to the interaction area (Dejaguin et al., 1975). Adhesion force value is determined by the form of the particulate and surface properties. The detachment of the particle from the surface along the generated flow is a gradual process. Initially, upper larger particulates are detached from the surface layer, whereas at the later stage–smaller ones are affected by the adhesion force of the surface (Walter, 1995; Walters et al., 1998). The detachment of the upper layer of the particles is available when $F_{adh} > F_{aut}$. Particle detachment within the autohesion process is called erosion. When $F_{adh} < F_{aut}$, layer detachment occurs near the surface boundary layer. In the latter case, adhesion forces are overcome (Wall et al., 1990).

Under prediction that electric and capillary forces are not considered taking into account the real forms of particulates and other factors, adhesion force value can be expressed by dependence

$$F_{ad} = \frac{h\omega}{16\pi Z_0^2} d = \frac{hw}{8\pi z_0^2} r; \tag{1}$$

where $h\omega$—Planck constant J; z_0—spacing between the plane and particle when adhesion forces are at maximum; r—radius of the particle, m.

A number of scientists have discovered that, under the spacing of 4×10^{-10} m, adhesion force is the highest and equals:

$$F_{ad} = 2.4 \times 10^{-7} r; \tag{2}$$

Adhesion forces decrease proportionally to the square of spacing size. Thus, fine particulate matter (less than 50 μm in diameter) has a higher contact surface area compared to larger particles, and adhesion force value is higher than that of large particulates. For this reason, to detach larger particles from the surface, lower force than that needed for detaching fine particulate matter smaller than 50 μm in diameter is required (Beek et al., 2006). Consequently, the particles larger than 50 μm are detached from the surface earlier under lower air flow velocities. A possibility of detaching particulates is important for air flow movement in cyclones. Under additional barriers, the trajectory of flow movement may vary, vortices are added and the Reynolds number fluctuates (Vekteris et al., 2011).

The properties of particulate matter and medium can alter in the course of the particulate separation process. Due to the abundance of the factors influencing the efficiency of trapping particulate matter in cyclones, the assessment of the impact of all factors on the treatment efficiency of the cyclone seems to be a complex task, and therefore the number of affecting factors must be reduced thus making certain assumptions.

The carried out research is aimed at establishing parameters for the dynamics of the gas–vapour two-phase flow in the multi-channel cyclone and treatment efficiency removing stiff lignin particulate matter, i.e. under the increased humidity and temperature of the purified flow.

2. Materials and methods

Experimental research has applied for a new-generation four-channel cylindrical cyclone in which air flow passes tangentially through the inlet to the separation chamber where the circulating air flow is distributed in the channels of different curvature and filtered through air flow—the spacing of the curved channels of particulate matter. Stiff particles in the channels are affected by centrifugal forces and gravitation and are removed into the conical hopper through segmentally installed circular spaces where the most of particulate mass is eliminated. The rest of finer particulates re-enter the active zone of the curved channels through the spacing of the channels, are filtered further and approach the conical hopper. The purified air flow coherently passes through all channels and outflows from the system through the outlet. The first channel of the cyclone is restricted by a peripheral partition wall and the first curved quarter-ring. The flow from the previous channel faces the partition wall and falls into two flows—peripheral and transitional. A part of the peripheral flow enters the previous channel, and thus the filtration of the polluted flow in the direction of the reverse-flow takes place. The transitional flow moves into the following channel towards the axis of the device and outlet from the cyclone. In consequence, air flow is distributed in the channels of different curvature. Dusty air is filtered in the active zone of spacing between the channels, spacing between the quarter-rings and, as a result of the interaction between particulates themselves, under coagulation. When the structure is formed from the curved quarter-rings with folded opening slots, the created closed profiles have twice more flow distribution zones than using the curved half-rings (Jakštonienė, 2012). The opening slots folded at an