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Original Research Paper

Experimental investigation of processes in acoustic cyclone separator

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ABSTRACT

This paper presents air flow velocity profiles obtained in conventional and acoustic cyclone separators. It is shown that vortex air flow is created in acoustical cyclone separator in presence of secondary countercurrent air flow. It is obtained that in acoustic cyclone separator air pressure pulses occur at frequency of 8 kHz and pressure amplitude reaches a value of 170 dB. Separation efficiency of acoustic cyclone separator was established experimentally.

1. Introduction

Processes occurring in cyclone separators are quite complex and depend on many factors [1]. Particles rotating with the air flow are affected by gravitational, centrifugal and resistance forces. Gravitational and resistance forces are relatively low, therefore it can be stated that particle separation process in cyclone separators is based on the centrifugal force acting on particles. However, flow characteristics of ultrafine particles differ from those of the coarse, non-adhesive particles. The interaction forces between ultrafine particles are much greater than gravitational or inertia forces [2]. To separate such particles from the air, it is necessary to increase their size or to agglomerate them. Besides electrostatic, gravitational and thermal agglomeration methods there is highly efficient acoustic method when cleaning air is affected by acoustic field [3]. This method is called acoustic agglomeration.

Acoustic agglomeration is a process in which high intensity sound waves produce relative motions of particles suspended in gaseous media. These motions cause particle collisions in which particles stick together and form larger structures called agglomerates. Then particle agglomerates continue to connect with each other and become larger and heavier. Usually the sound pressure level of 140–160 dB is used to acoustically agglomerate particles which size is less than 1–5 μm. The Reynolds number should be less than 0.1–0.5 [4].

Within a short period of time (about 1 s), due to the action of acoustic field, particles increase to a size large enough to be caught by traditional air cleaning equipment [5]. Acoustic particle agglomeration method has indisputable advantages compared to other particle agglomeration techniques [6]. In order to acoustically agglomerate particles, special cyclone separators with separate acoustic column can be used [7]. Such equipment is bulky and requires special maintenance. In addition, the acoustic column does not ensure complex motion of polluted air flow and acoustic field is used inefficiently.

Next, cyclone separators with integrated ultrasonic generator [8] are used to acoustically agglomerate particles and separate them from air. However, such systems have limited industrial application, because it is difficult to apply ultrasonic field in large ventilation system ducts. In addition, the ultrasonic source control systems are complex [9].

In order to agglomerate ultrafine particles acoustic cyclone separator with secondary countercurrent flow [10] was developed. It allows to significantly increase separation efficiency and reduce energy demands. These aims were achieved by placing the acoustic generator inside the conical section of cyclone separator, at the narrowest place. The special plates were fixed to the reflector of acoustic generator; these plates were inclined at an angle α to the axis of cyclone separator. The vertex of an angle pointed in the opposite direction to the direction of polluted air flowing through inlet of cyclone separator.

According to Nicholson [11], primary ultrafine particles moving freely and colliding into each other stick together under the action of weak adhesion forces (for example, van der Waals or electrostatic). Then particles affected by forces join together forming rigid

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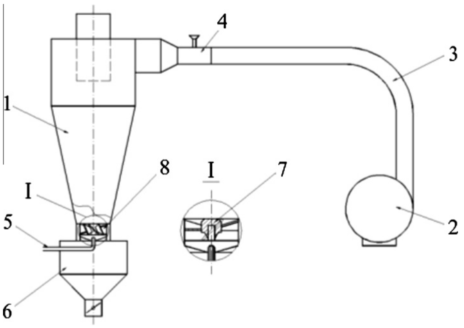

Fig. 1. The experimental setup: 1 – acoustic cyclone separator; 2 – fan; 3 – air inlet pipe; 4 – dispenser; 5 – compressed air inlet pipe; 6 – dust bin; 7 – Hartmann-type acoustic generator; 8 – stationary blades.

agglomerates, they join by strong covalent, ionic, metallic, and other bonds [12,13].

According to Kinloch [14] contact adhesion of two particles can be divided into six types. In dispersive adhesion, two particles are held together by van der Waals attraction forces. Electrostatic adhesion occurs when conducting materials pass electrons to form a difference in electrical charge at the join. This results in a structure similar to a capacitor and creates an attractive electrostatic force between the particles. Chemical adhesion arises due to the bonding at a molecular level, where two particles join and form ionic or covalent bonds upon contact and hold together. Hydrogen bond adhesion takes place when oxygen, nitrogen or fluorine atoms of the particles share a hydrogen nucleus leading to the weak hydrogen bonding. Diffusive adhesion occurs when atoms and molecules of particles diffuse from one particle to another. Particles merge and form a new material at diffusion. Finally, in mechanical adhesion, adhesive materials fill the pores of the surfaces and hold surfaces together by interlocking [2].

In addition to the above-mentioned six types of adhesion, some special types of adhesion also were observed. For example, liquid-bridge adhesion which occurs due to the action of attractive capillary forces developed as a result of the formation of liquid bridges between contacting particles in presence of vapours (e.g., water vapour) in the gas phase [15]. Interaction adhesion occurs when two particles are joined together between the liquid and gaseous phases and attract one another by capillary force developed due the deformation of surfaces [11].

Particle atoms interact with one another via non-bonded potentials that affect electrostatic (Coulomb) and dispersion (van der Waals) forces as well as repulsive interactions occurring between atoms in molecules [16]. The Lennard–Jones potential is the most commonly used potential of non-bonded interactions.

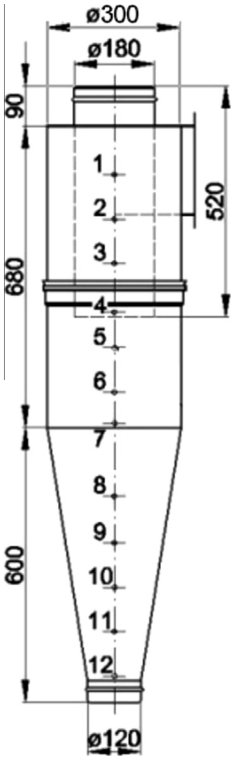

Fig. 3. Arrangement of holes drilled in the wall of cyclone separator.

As long as the distance between the particles is significantly greater than the particle size, the adhesion forces are very small and can be neglected. However, they become significant when two or more particles collide, then they become stronger than gravitational and inertia forces.

In addition to the interactions with each other, fine particles interact with their surroundings such as flow, external temperature, electric, magnetic and acoustic fields. Unlike the adhesion forces, these interactions do not require a particle collision condition to be satisfied.

Moreover, particles cause various perturbations in air flow, electric, acoustics and thermal fields, these perturbations affect the mutual interaction forces acting on particles. Such forces acting on particle fields can cause attraction between particles, their collisions and adhesion [2].

Industrial polluted air usually contains particles (or their aggregates) whose shape is far from regular sphere. Therefore, during the design of acoustic cyclones, it is necessary to assess the actual

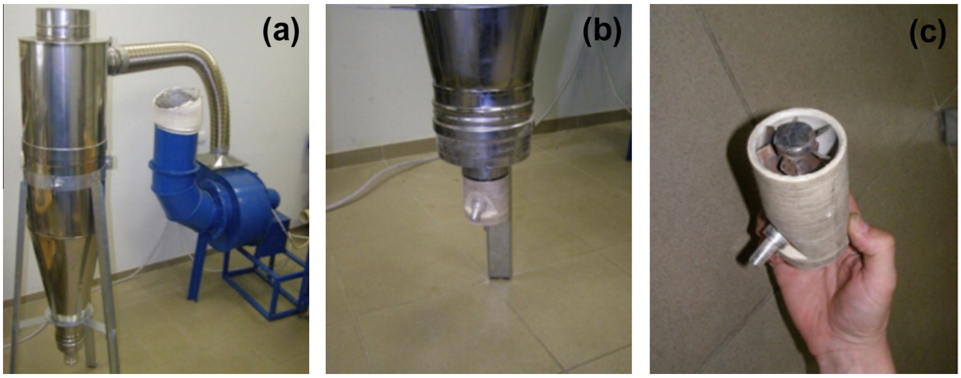

Fig. 2. Photo of the experimental setup: (a) overall view; (b) Hartmann-type acoustic generator; (c) stationary blades.