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INVESTIGATION OF ACOUSTIC AGGLOMERATION EFFICIENCY USING DIFFERENT WORKING CONDITIONS OF ACOUSTIC CHAMBER

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Abstract. Particulate matter pollution is one of the main factors of atmospheric pollution. Due to its negative impact on both human health and the environment, it has become an actual problem in Lithuania and around the world. This paper will present a method for reducing the concentration of ultrafine particulate matter present in the atmosphere and causing pollution using different parameters of the acoustic chamber. Fine particles with an aerodynamic diameter of less than 2.5 μm are usually more saturated with toxic heavy metals and other pollutants due to their large surface area and strong surface activity. These particles go deep into the lungs and can cause lung cancer and other heart and lung diseases. Acoustic agglomeration is one of the most promising pretreatment technologies. Before using traditional particulate removal technologies, the ultrafine particles in the exhaust gas are exposed to a high-intensity sound wave, which promotes the relative motion of the aerosol particles and increases their agglomeration rate. Given results approved the high effect of reducing the amount of ultrafine particulate matter by agglomeration, thus, the reducing of the finest 0.3 μm particles is equal to more than half time at frequency of 34.75 kHz, 0.5 μm – more than half and more than three times at both frequencies of 20.06 kHz and 34.75 kHz respectively.

Keywords: acoustic agglomeration, acoustic chamber, sound pressure direction.

Introduction

Environmental particulate matter (PM) emissions remain a global concern in the 21st century due to their associated cardiovascular mortality and high cost to society. Reported health problems appear to be mostly caused by the smallest particles, as they are able to spread deep into the respiratory tract, where lung clearance is less efficient. Indeed, PM with an aerodynamic equivalent diameter of less than 2.5 μm (also known as PM2.5), commonly known as fine particles (FP), has the greatest impact on human health. A number of experimental studies have already demonstrated the pulmonary toxicity of FP and may be associated with the development and/or exacerbation of chronic lung diseases, including lung cancer (Abbas et al., 2019; Leclercq et al., 2018).

Research has also focused on PM with an aerodynamic equivalent diameter of less than 0.1 μm (also called PM0.1), also called ultra fine particles (UFP), which can comprise more than 70% of total number of particles. Due to their high specific surface area, UFPs are likely to be more reactive with target tissues and are largely responsible for the reported adverse effects of FPs. Their nanometer scale increases their deposition efficiency and retention in the respiratory tract, as well as their cellular uptake and systemic distribution.

In recent years, the issue of atmospheric quality has received much attention from researchers (Liu, 2021). One of the effective ways to improve the quality of the atmosphere is to remove harmful aerosols by technical means (Agarwal et al., 2013; Dass et al., 2021; Dyakov et al., 2021; Meng et al., 2021). Because of its safety, acoustic agglomeration technology has great potential for the removal of fine particles (Haig et al., 2014; Sun et al., 2020; Zhang et al., 2018; Zhou et al., 2016). Particulate matter pollution is one of the main factors of atmospheric pollution. Due to its negative impact on both human health and the environment, it has become an actual problem in Lithuania and around the world. This paper will present a method for reducing the concentration of ultrafine particulate matter present in the atmosphere and causing pollution using different parameters of the acoustic chamber. Fine particles with an aerodynamic diameter of less than 2.5 μm are generally more saturated with toxic heavy metals and other pollutants due to their large surface area and strong surface activity. These particles go deep into the lungs and can cause lung cancer and other heart and lung diseases (Bi

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et al., 2007; Fenger, 2009). Acoustic agglomeration is one of the most promising pretreatment technologies. Before using traditional particulate removal technologies, the ultrafine particles in the exhaust gas are exposed to a high-intensity sound wave, which promotes the relative motion of the aerosol particles and increases their agglomeration rate (Hoffmann, 2000; Riera et al., 2015; Zhou et al., 2016).

The quantitative evaluation of the acoustic agglomeration characteristics of suspended particles and the determination of the optimal acoustic frequency and SPL are of great importance for the optimization of the agglomeration efficiency (Kilikevičienė et al., 2020).

Applying a high-intensity acoustic field to an aerosol can initiate a process known as acoustic agglomeration or ultrasonic agglomeration of suspended particles. Various mechanisms have been proposed for this process. It is now generally accepted that the dominant mechanisms are orthokinetic and hydrodynamic interactions, and other effects such as radiation forcing, acoustic flow, and turbulence may play an important role in driving these interactions (Garbarienė et al., 2021; Ng et al., 2017; Song et al., 1994; Yan et al., 2016; Zhang et al., 2018). Orthokinetic interaction occurs between two or more suspended particles of different sizes when they are at a distance approximately equal to the displacement amplitude of the sound field in the suspending medium and their relative motion is substantially parallel to the direction from the source of vibration (Amiri et al., 2016; Fredericks & Saylor, 2019; Zhang et al., 2020; Zhou et al., 2016). Differential fluid and inertial forces cause particles to vibrate at different amplitudes and phases, and such differential motion greatly increases the probability of collision and thus agglomeration (Kilikevičienė et al., 2020).

The work analyzed the created acoustic agglomeration stand for studying the particle agglomeration process in the presence of a sound field of different characteristics.

Methodology

The essence of the ongoing experimental study is that fine particles in the air can be pre-enlarged using acoustic agglomeration to facilitate subsequent removal by air filtration in chimney systems. The general view and scheme of the experimental research bench are presented in Figure 1. The test bench simulates airborne particulate matter in a system (similar to a stack element) with pre-acoustic particulate agglomeration prior to particle measurement. As shown in Figure 1a, the main part of the device consists of: housing and particulate dosing equipment (positions 1 and 1.1 in Figure 1a); part of the acoustic field generation

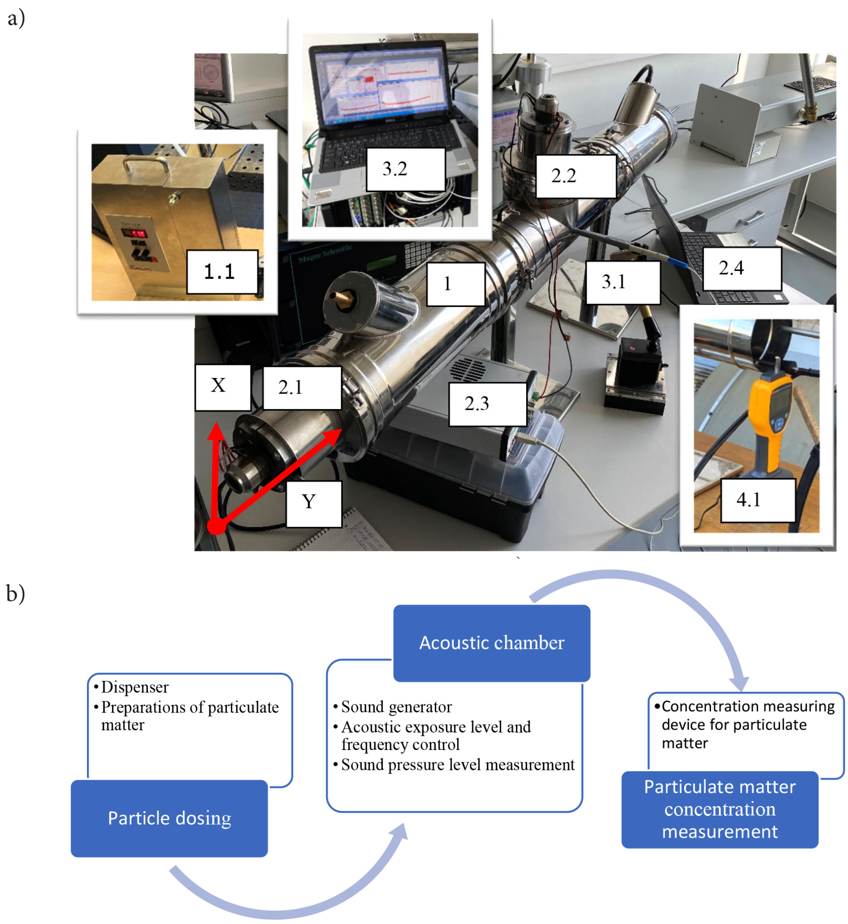

Figure 1. General view (a) and diagram (b) of the experimental research bench

(consisting of the piezo generator and its control (positions 2.1, 2.2, 2.3 and 2.4 in Figure 1a)); acoustic parameters measurement part (hydrophone and data acquisition and processing equipment (Figure 1a, positions 3.1 and 3.2)); particle measurement equipment. A Fluke 985 six-channel particle counter with an isokinetic sampling probe (Figure 1a, position 4.1) was used to determine the numerical concentration of particles. The particle size range of the device is (0.3, 0.5, 1.0, 3.0, 5.0 and 10.0) μm. The sample flow rate is 2.83 L/min.

The target of this method is to achieve a sound pressure level of at least 140 dB, which is recommended by other authors in the field in order to achieve the agglomeration of particles in the presence of an acoustic field in a chamber. The study uses the same design, changing only the operating conditions and thus the acoustic space. The acoustic chamber does not change in terms of any design or/and geometry, but the space is changing itself, when the sound parameters change.

The scheme (Figure 1b) shows that the experimental studies consist of three stages: 1. Particle dosing using the selected type of particles; 2. An acoustic chamber, in which an acoustic field is created by an acoustic generator (which is controlled using a piezodrive feedback controller), and the parameters of the created acoustic field are measured using a hydrophone, from which the received signal is analyzed in the data collection and processing equipment; 3. Measurement of the concentration of particulate matter.

Results and discussion

Using the experimental research bench, sound pressure measurements were performed at different operating directions of the piezo generator (along the flow when the piezo generator is used in Figure 1a, position 2.1, and perpendicular to the flow when the piezo generator is used in Figure 1a, position 2.2) and at different exposure frequencies (20.06 and 34.75 kHz). The obtained sound pressure measurement results are presented in Figure 2 (red curve background measurements, blue when the piezo generator is on).

Given the sound pressure level measurement results (Figure 2), it was determined that the sound pressure level at 20.06 kHz was 145.8 dB in the acoustic chamber, and the sound pressure level at 34.75 kHz was 146.8 dB in the acoustic chamber. In research on acoustic agglomeration, it has been found that in order to observe changes in particle size distribution, the recommended sound pressure level must be above 140 dB to observe any changes in particle size distribution, and particle drift towards nodes is favored by standing waves.

Given the control parameters of the piezo generator using the piezodrive controller with software (Figure 3). The PDUS210 piezodrive generates a pure sine wave output, which is ideal for operation at parallel electrical resonance that is close to the mechanical resonance frequency, but is less sensitive to changes in load dissipation when constant vibration amplitude is desired. Current and power control is also provided to adjust the oscillation amplitude in the resonance mode.

In Figure 3 presented the adjustment graph of the piezoacoustic oscillator whose settings are withstood during the test. Between the part of a and b in Figure 3, the difference is the change in frequency, the other parameters serve only as auxiliary parameters. The presented results (Figure 3) show that when the resonant frequency of the piezo generator was 20.06 kHz, the following electrical parameters were used: voltage 200 (peak-peak) V; impedance 337 ohms; RMS current 239 mA. Accordingly, when the resonant frequency of the piezo generator was 34.75 kHz, the following electrical parameters were used: voltage 190 (peak-peak) V; impedance 42 ohms; RMS current 1.6165 A.

The results of measuring the concentration of particulate matter at different operating directions of the piezogenerator (along the flow, marked 1Y and 2Y, and perpendicular to the flow, marked 1X and 2X) and different impact frequencies (20.06 kHz, marked 1Y and 1X, and 34.75 kHz, marked 2Y and 2X) are presented in Figure 4). In summary, 1X (red curve) is the acoustic effect in the direction perpendicular to the flow at a frequency of 20.06 kHz; respectively, 1Y (blue curve) is the acoustic effect in the direction coinciding with the flow

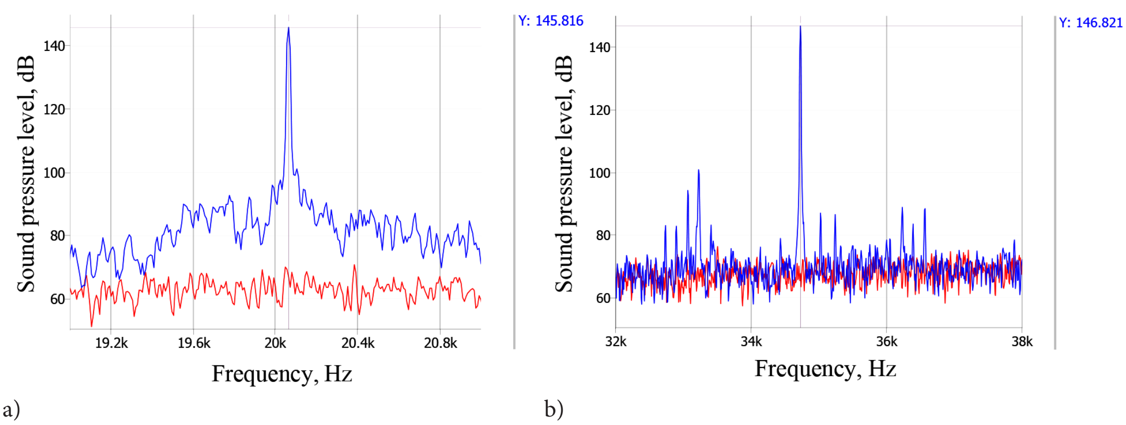

Figure 2. Sound pressure distribution at different excitation frequencies 20.06 (a) and 34.75 (b) kHz in the frequency domain

a) b)

Figure 3. Control parameters of a piezo generator using piezodrive

at a frequency of 20.06 kHz; respectively, 2X (red curve) is the acoustic effect in the direction perpendicular to the flow at a frequency of 34.75 kHz; respectively, 2Y (blue curve) is the acoustic effect in the direction coincident with the flow at a frequency of 34.75 kHz; black curve without acoustic effect.

The presented results show that acoustic agglomeration occurs with all considered acoustic exposure options and starts when the particle sizes are between 1 and 2 μm (Figure 4). Evaluating the agglomeration efficiency results in Figure 4b. it can be seen that the acoustic effect along the flow reduces the amount of particles with a diameter of 0.3 μm from 32 (at a frequency of 20.06 kHz) to 53% (at a frequency of 34.75 kHz), respectively, it reduces the amount of particles with a diameter of 0.5 μm from 60 (at a frequency of 20.06 kHz) to 225% (at a frequency of 34.75 kHz), and reduces the amount of particles with a diameter of 1.0 μm from 38 (at a frequency of 20.06 kHz) to 118% (at a frequency of 34.75 kHz). When evaluating the acoustic effect of particles larger than 1.0 μm in diameter along the flow, it was found that their number increases. The acoustic effect along the flow increases the amount of particles with a diameter of 2.0 μm from 21 (at a frequency of 20.06 kHz) to 25% (at a frequency of 34.75 kHz), respectively, it increases the amount of particles with a diameter of 5.0 μm from 11 (at a frequency of 20.06 kHz) to 15% (at a frequency of 34.75 kHz). frequency), and increases the amount of particles with a diameter of 10.0 μm from 50 (at a frequency of 20.06 kHz) to 65% (at a frequency of 34.75 kHz). Accordingly, the acoustic effect of the vertical flow reduces the amount of particles with a diameter of 0.3 μm from 69 (at a frequency of 20.06 kHz) to 91% (at a frequency of 34.75 kHz), respectively, it reduces the amount of particles with a diameter of 0.5 μm from 60 (at a frequency of 34.75 kHz) to 130% (at a frequency of 20.06 kHz frequency), and reduces the amount of particles with a diameter of 1.0 μm from 35 (at a frequency of 34.75 kHz) to 68% (at a frequency of 20.06 kHz). When assessing the acoustic effect of the vertical flow on particles larger than 1.0 μm in diameter, it was found that their number increases. Vertically, the acoustic effect of the flow increases the amount of particles with a diameter of 2.0 μm from 27 (at a frequency of 34.75 kHz) to 33% (at a frequency of 20.06 kHz), respectively, it increases the amount of particles with a diameter of 5.0 μm from 22 (at a frequency of 20.06 kHz) to 30% (at a frequency of 34.75 kHz). frequency), and increases the amount of particles with a diameter of 10.0 μm from 56 (at a frequency of 20.06 kHz) to 71% (at a frequency of 34.75 kHz).

Summarising the results obtained for particulate matter concentrations for aerosol flow in the perpendicular and longitudinal direction of the acoustic flow at 20.06 and 34.75 kHz, it is found that the number of particles up to a diameter of 1 μm decreases for all acoustic exposure options. The greatest reduction in particle number was observed at 34.75 kHz and at the longitudinal exposure direction. It can be argued that the highest efficiency of acoustic agglomeration of particulate matter is achieved when the acoustic exposure is along the flow, thus resulting in longer exposure times, and that the higher agglomeration efficiency at higher acoustic excitation frequencies confirms the results reported in the scientific literature (Kačianauskas et al., 2018), which show that higher excitation frequencies provide better conditions for agglomerating smaller particles.

Two variations of the high-frequency sound wave and their effect on the process of particle agglomeration

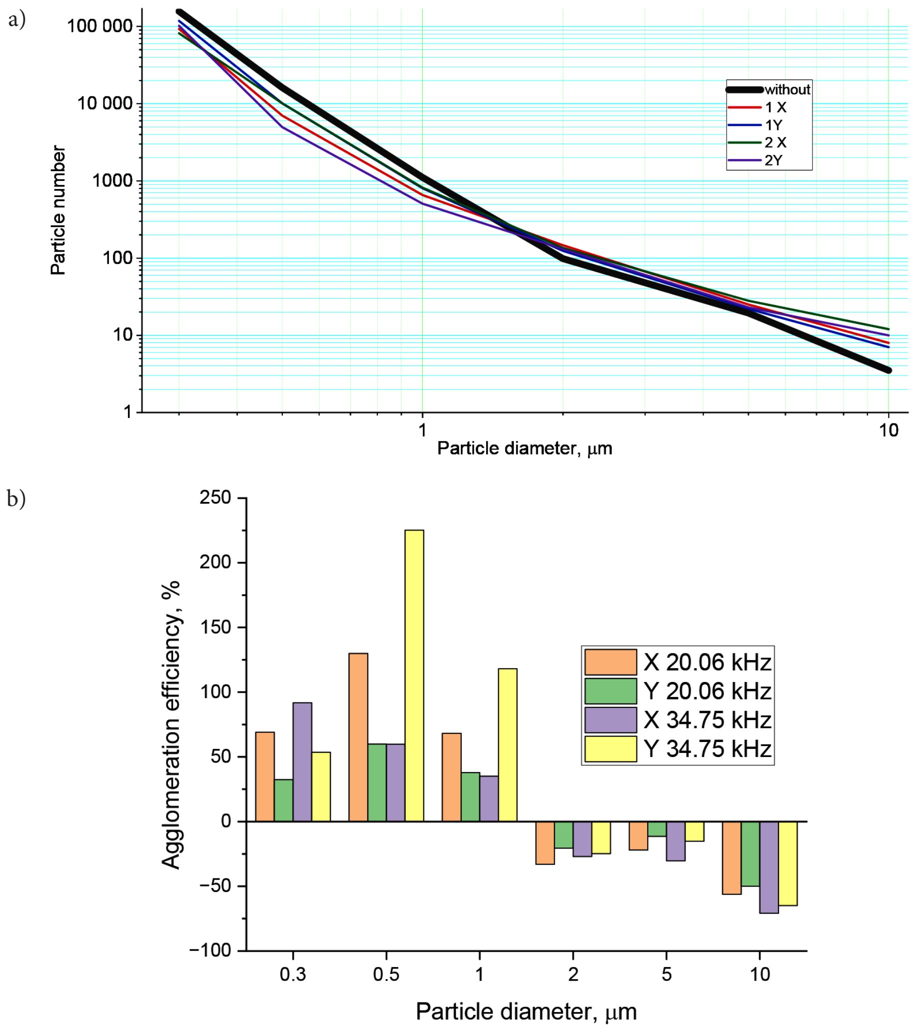

Figure 4. Measurement results of particulate matter concentration (a) and agglomeration efficiency (b) at different operating directions of the piezo generator (along the flow, marking 1Y and 2Y, and perpendicular to the flow, marking 1X and 2X) and at different exposure frequencies (20.06 kHz, marking 1Y and 1X, and 34.75 kHz, designation 2Y and 2X)

in the process of studying their concentration before and after the acoustic field were studied. Due to the results obtained it will be possible to analyze in more depth other solutions using other frequencies of the sound wave to reduce the emission of solid particles, namely changing their dispersion in favor of increasing it.

Conclusions

The article analyzed the created acoustic agglomeration stand for studying the particle agglomeration process in the presence of a sound field with different characteristics. Using the experimental research bench, sound pressure and particulate matter concentration measurements were performed at different operating directions of the piezo generator (along the flow and perpendicular to the flow) and at different exposure frequencies (20.06 and 34.75 kHz). When performing the sound pressure level measurement results, it was determined that the sound pressure level at 20.06 kHz was 145.8 dB in the acoustic chamber, and the sound pressure level at 34.75 kHz was 146.8 dB in the acoustic chamber. The design was investigated, but due to technical considerations and limitations, it only allowed to reach the above frequencies of sound waves. In the future, taking into account the data obtained, the possibilities will be considered to create a layout in which other frequencies will be studied, or this studied interval will be expanded.

When evaluating the results of acoustic agglomeration, it was found that the amount of particles with a diameter of 0.3 to 1.0 μm decreases, and the amount of particles with a diameter of 2.0 to 10.0 μm increases accordingly.

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