Experimental Investigation of Influence of Acoustic Wave on Vapour Precipitation Process

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Abstract—**The measurement results of acoustic field parameters above electroplating bath, in presence of water vapour, are analyzed in this work. Suction was created by means of side exhausters. It is obtained that the sound field generator generated a sound level of 130–140 dB at frequency interval between 1 and 10 kHz. It is shown that aerosol coagulation and precipitation processes are intensified under the mentioned conditions. The concentration of vapour and other aerosols in removal air decreases as a result, therefore air cleaning equipment costs can be reduced and cleaning efficiency increased.**

Keywords: aerosol; water vapour; exhauster; acoustic coagulation; sound frequency; sound level

I. INTRODUCTION

Electroplating processes are widely used in a variety of industries; the number of such technologies constantly increases. These processes are performed in electroplating bathes by means of electrolysis. Small hydrogen, oxygen and other gas bubbles are formed at the electrodes during such processes as a result of electrochemical and chemical reactions. These bubbles then get released from the electroplating solution. Electroplating solutions contain hazardous substances concentration of which at the workplace can‘t exceed permissible according hygiene norm. To reduce the concentration of these substances electroplating lines are equipped with powerful local ventilation systems. According to their position in respect to the pollution source, exhausters can be divided to the following groups: open, side and close. Their purpose is to collect and remove pollutants from the vaporized surface of electroplating bath and to control the concentration of pollutants at the workplace [1, 2]. The additional air flow (from blowers) which directs polluted air towards the exhauster can be used to improve air cleaning efficiency. Such exhausters are called side activated. The amount of evaporated substance depends on the chemical composition of the solution, the temperature of the solution, the vaporized surface area, time and characteristics of the motion of the environmental air [3, 4]. If some amount of pollutants was successfully returned back into the steaming liquid, thus reducing the concentration of the pollutants, it would be possible to reduce the energy consumptions of the air cleaning equipment. Therefore it is proposed to generate an acoustic field above the bath solution surface, thus causing acoustic coagulation of aerosol particles. This would allow a reduction of the concentration of pollutants (aerosols) in the polluted air flow; i. e. air will be cleaned before being removed. The Hartmann generator [5, 6] can be used to generate high-pressure acoustic waves.

Gravitational coagulation follows acoustic coagulation. The scheme of this phenomenon is presented in Figure 1. A particle which radius R is bigger than the radii of the neighbor particles comes into the gravitational field, its falling velocity increases and the particle collides with some of the smaller particles (which radii are r) as the result [3]. The coagulation rate or air cleaning efficiency depends on the following parameters of the acoustic field [7, 8]: intensity, frequency and exposure time. It is established [9] that 4–5 s are enough for aerosol precipitation. Increasing time to 30 s and more doesn‘t lead to improved coagulation efficiency. In accordance with Parker and Brandt [10] experiments concentration depends exponentially on time and a parameter called coagulation coefficient.

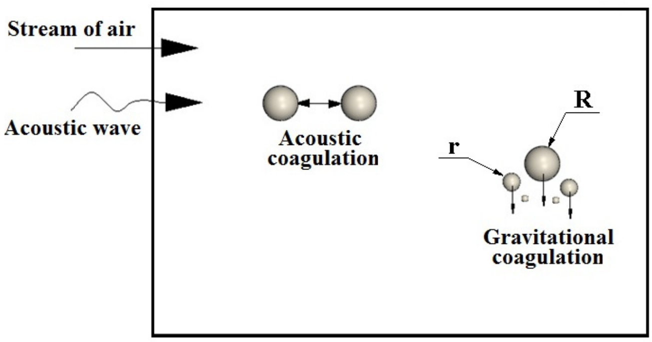


Fig. 1. Aerosol particles coagulation process

The first experimental data dealing with the impact of acoustic fields on coagulation process [7, 10] was obtained at low sound frequencies. For example, Stokes in experiments with smoke soot obtained optimal frequency interval between 3 and 4 kHz [7]. For zinc oxide smoke (particle size about 5 μm) and sulphuric acid mist (particle size was varied from 5 to 100 μm) optimal frequency was about 1 kHz. In case of smaller particles which size is less than 10 μm sound pressure level should not exceed 137 dB and Reynolds number should be less than 0.4. Specific velocity can be taken as 0.32 m/s.

In the present work, the indirect parameter –air humidity at different temperatures-was proposed to evaluate the coagulation efficiency.

II. Analysis

The dependence of particle and flow amplitudes ratio on frequency and particle size is presented in Figure 2. This dependence is described by the following formula:

$$\frac{x_p}{x_f} = \frac{1}{\sqrt{\left(\frac{4\pi\rho_p r^2 f}{9\mu_m}\right)^2 + 1}} \quad (1)$$

where x_p is the amplitude of the particle, x_f is the amplitude of the medium (gas mix), r is the radius of the particle, ρ_p is the density of the particle, f is the frequency of the acoustic field, μ_m is the dynamic viscosity of the flow.

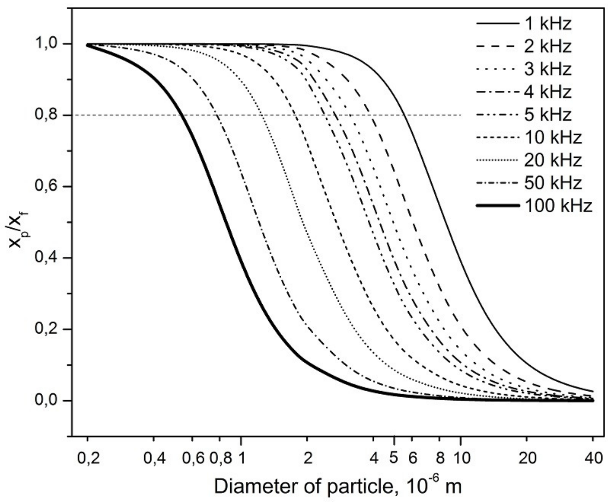
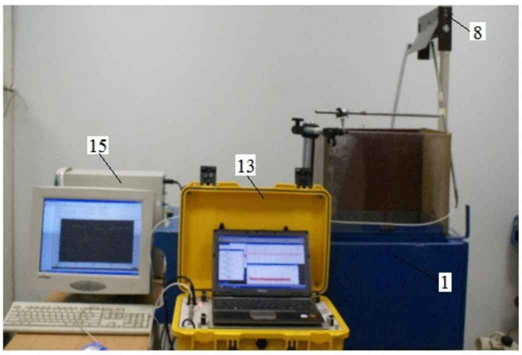


Fig. 2. Amplitude ratio as a function of the frequency of the acoustic field and the diameter of particles

In accordance with Figure 2, oscillations of particles which diameter is bigger than 10 μm are hardly observed when frequency varied from 1 to 100 kHz. Oscillations of smaller particles are observed in whole range of frequencies. Optimum value of the ratio is about 0.8.

It can be stated that not only aerosol properties (for example initial concentration in the air) influence the coagulation process, but also the parameters of the acoustic field. When particle size increases, frequency must be reduced to excite oscillations of the particles in the flow.



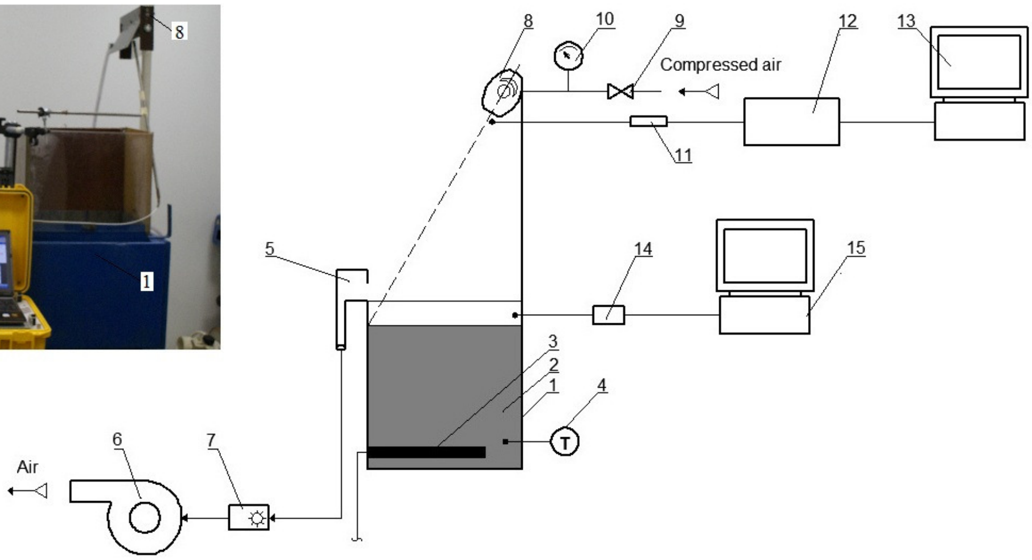


Fig. 3. Experimental stand: 1 – bath, 2 – liquid, 3 – heater, 4 – thermometer, 5 – side exhauster, 6 – fan, 7 – variable-frequency drive, 8 – blower and acoustic wave generator, 9 – valve, 10 – pressure gauge, 11 – hydrophone, 12 – data storage, 13, 15 – computer, 14 – temperature and humidity meter

III. EXPERIMENTAL STAND

A special experimental stand was designed and built. This stand is shown in Figure 3. Liquid 2 was heated in electroplating bath 1 by means of heater 3. Temperature was monitored by thermometer 4. Vaporized liquid was removed by means of side exhauster 5 which was attached to the edge of the bath and connected to fan 6. Air flow rate was controlled by variable-frequency drive 7. Special construction blower – acoustic wave generator 8 was mounted above the liquid surface as shown in Figure 3. Acoustic wave was generated due to the compressed air flow pulsations. Air flow was directed at the liquid surface near the edge of the bath as it can be seen in Figure 3. Compressed air was supplied through valve 9, and its pressure was controlled by pressure gauge 10. Acoustic field parameters were measured by hydrophone 11, measured data was stored in data storage 12 and then processed by means of computer 13. Air humidity was measured by temperature and humidity meter FHT 70 DataLog 14, measurement results were processed by means of computer 15.

Aerosol concentration in the air was reduced due to precipitation above the formation zone. A specially designed blower – acoustic wave generator was used to intensify the mentioned process. Its scheme is presented in Figure 4. It consists of hollow collector 1 which has nozzles 2 connected to collector‘s holes. Spherical resonators 3 were placed against nozzles 2 to direct the flow to the outlet. The air flow leaving the nozzle 2 collides with the air from the resonator, thus sound (standing acoustic wave) was generated.

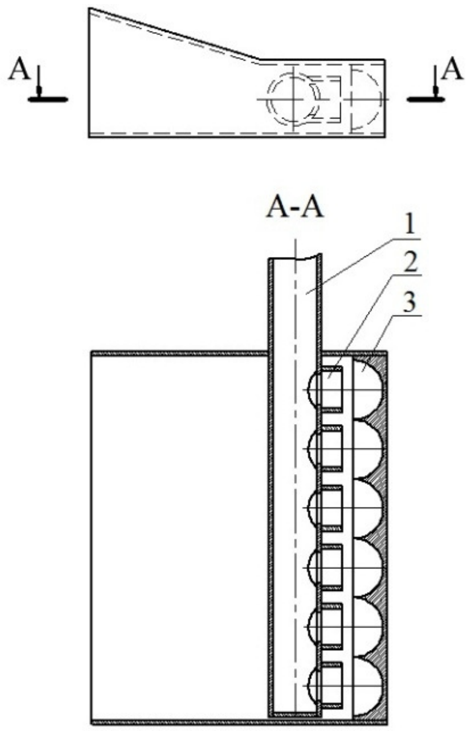


Fig. 4. Scheme of the acoustic wave generator: 1 – collector, 2 – nozzle, 3 – resonator

IV. EXPERIMENTAL TECHNIQUE AND RESULTS

The primarily parameters of the acoustic field generated by the acoustic wave generator were measured. When air compressed to 4–5 bar pressure was supplied to the generator, the sound pressure amplitude reached 154 Pa. Sound pressure level at frequency interval between 1 and 21 kHz didn't drop less than 120 dB, i.e. minimal value required for dispersed droplets coagulation [11].

In order to ensure the optimal parameters of acoustic field the ratio of the nozzle diameter d and resonator diameter D was varied. Results of measurements are presented in Figure 5. It can be seen from Figure 5, that if diameters ratio equal to 1:2, 130–140 dB sound pressure level is achieved at 1–4 kHz frequency interval. If the ratio is equal to 1:5, sound pressure level above 130 dB is achieved at 6–9 frequency interval (Figure 5 b). The shift toward the limit of audibility is evident.

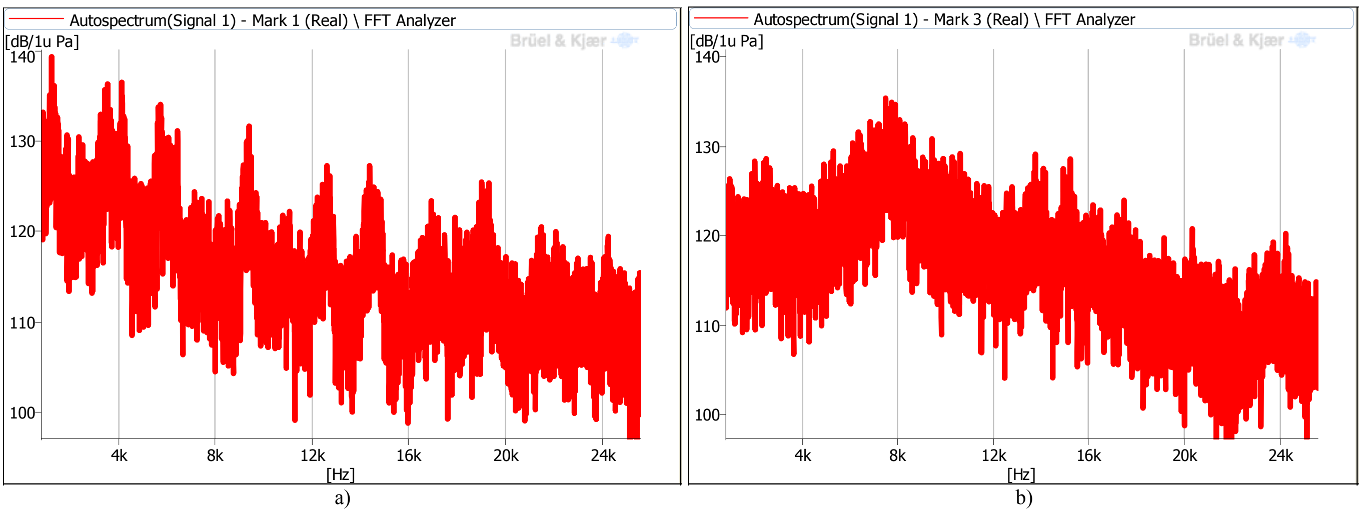


Fig. 5. Sound pressure level spectrum of acoustic wave generator when nozzle and resonator diameters ratio was equal to: a) – 1:2, b) – 1:5

Next, the air humidity above the vaporized liquid was measured. It was tried to establish its dependence on the temperature of the liquid and the distance from liquid surface.

In order to compare results four cases were analyzed:

- when vapour from the liquid surface raised freely and removal equipment was turned off.
- when vapour was removed from the liquid surface by means of the side exhauster.
- when vapour was removed from the liquid surface by means of the activated side exhauster (with additional air flow which directs polluted air towards the exhauster, acoustic wave generator was used as conventional blower).
- when vapour was removed from the liquid surface by means of the side exhauster with the use of the acoustic wave generator.

Temperature of the liquid was varied from 50 to 85°C. Results of humidity measurements are presented in Fig. 6. These results were obtained when distance from liquid surface was varied from 0 (bath edge) to 300 mm.

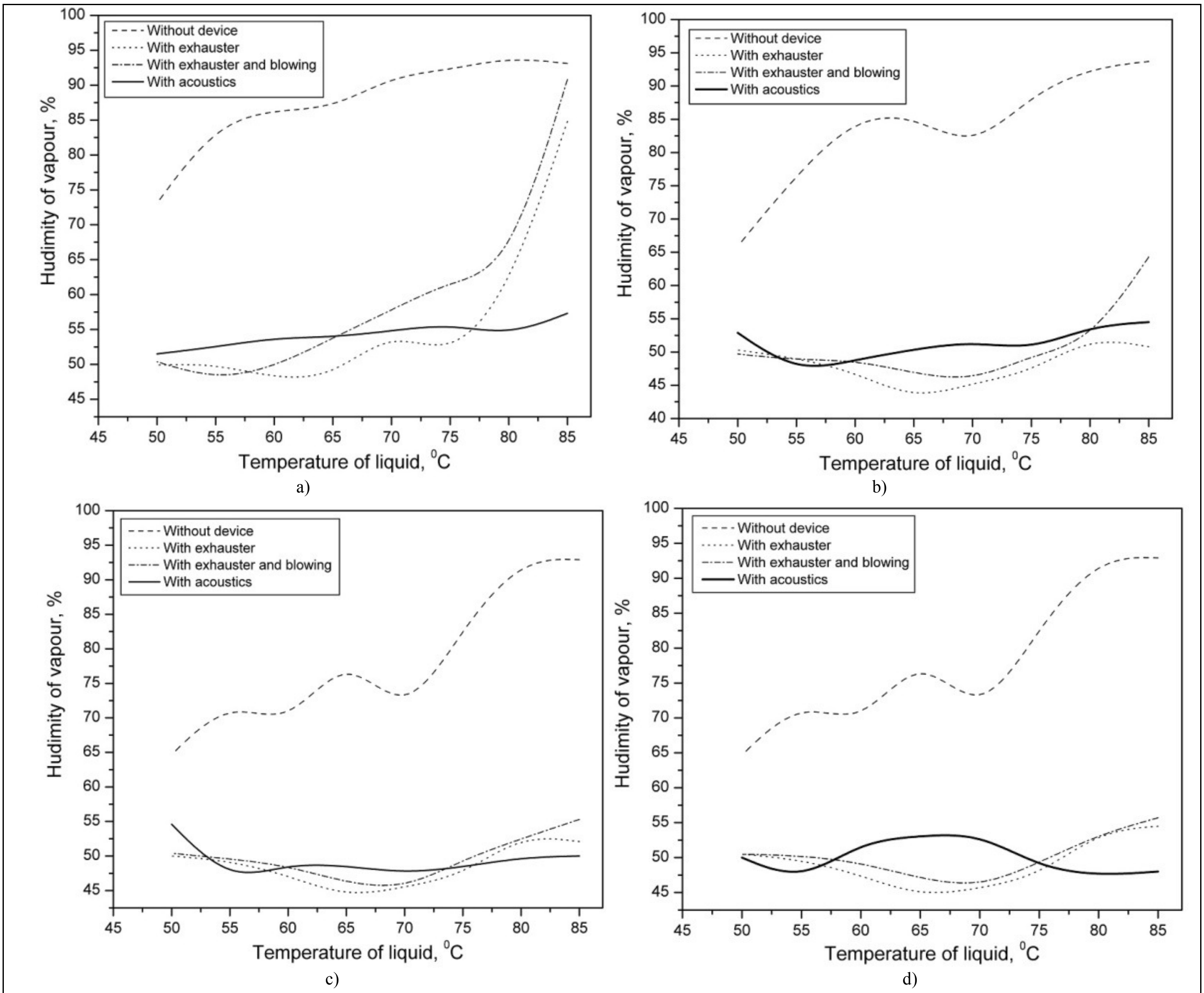


Fig. 6. Humidity of air measured at different distances from liquid surface as function of the liquid temperature and air removal method: a) – 0 mm distance (edge of the bath; b) – 100 mm distance above the bath; c) – 200 mm distance above the bath; d) – 300 mm distance above the bath

It is evident from Figure 6 that the precipitation process is intensified in the presence of the acoustic field. When the temperature increases humidity increases also. As it can be seen from Figure 6, air humidity doesn‘t depend on the distance from the liquid surface when temperature reaches 80 °C value. At such temperatures, the impact of the acoustic field on the coagulation process becomes most apparent. In other words, acoustic coagulation equipment becomes more effective with the increase of the initial concentration of the aerosol particles.

V. CONCLUSIONS

1. It is obtained that lower acoustic field frequencies between 1 and 4 kHz are more effective for small particles with diameter less than 10 μm.
2. Acoustic field positively impacts the coagulation process of dispersed in air drops and mist (aerosol) particles.
3. It is obtained that acoustic field frequency and sound pressure level are the main parameters of the acoustic field that influence the aerosol coagulation process.
4. Obtained experimental data shows that acoustic coagulation efficiency increases with the increase of the initial concentration of the aerosol particles in air.

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