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Generation of Monodisperse Particles

S.H. Harutyunyan*, L.E. Khachikyan, G.A. Harutyunyan

Institute of Applied Problems of Physics NAS RA
25 Hr. Nersissian Str., 0014, Yerevan, Republic of Armenia
*E-mail seyran@iapp.sci.am

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Abstract: A laboratory device for generation of monodisperse particles (droplet and solid particles) of variable size and generation frequency is presented. The solid particles are formed by drying of droplets of different solutions in the glass tube. Experimental investigation has been performed in order to create periodical structures using these micro crystals. For focusing and "trapping" thermophoretic force affect on particles trajectory is applied.

Keywords: monodisperse droplets, solid particles, periodic structures

1. Introduction

Monodisperse aerosol particles (droplets and solid particles with the narrow size distribution) with a known size and chemical composition are used in different applications such as instrument calibration, fundamental aerosol research applications, creation of artificial periodic structures (known as photonic crystals). Different methods for generating of monodisperse droplets are known [1]. The generation of droplets is based on the phenomenon of formation of satellite droplets in capillary breakup [5] of vibrating meniscus in the space between two identical capillary nozzles. The solid particles are formed as a result of drying of initial droplets of water solvable crystals ($NaCl, LiIO_3$) in the glass tube with the controllable conditions of evaporation process and crystal particle formation. The droplets and particle were sized by using both direct microscope measuring and the diffraction patterns obtained by the superposition of diffraction patterns from the large number of single particles of uniform size chaotically distributed on the glass plate. The size range of droplets is 10 to $100 mcm$ in diameters and 2 to 25 mcm for solid particles (solid particle size depends on solution concentration). Experimental investigation has been performed in order to create periodical structure using these micro crystals. For focusing and "trapping" the particles thermophoretic force affect on particle trajectory is applied.

2. Generation of monodisperse droplets

The principle of droplets generation is shown schematically in Fig.2 Generator includes a reservoir 1 for the liquid, an atomizer 3 and a source 2 of mechanical vibrations. The atomizer is made in the form of two L-shaped capillary nozzles 3 disposed towards each other in a small variable distance. The generator is also equipped with an elastic membrane 4 mounted above the surface of the liquid and connected to the source of mechanical vibrations 2. The output ends of the capillary tubes 3 are cut off at an angle θ.

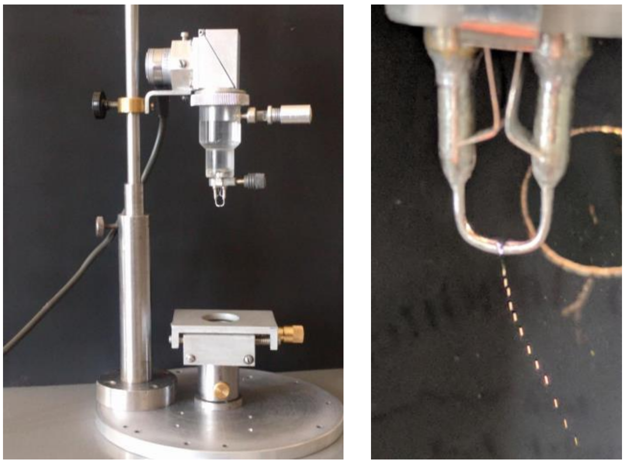


Fig. 1. Generator of monodisperse droplets

The source of mechanical vibrations 2 by means of the elastic membrane 4 creates periodically changing pressure on the surface of the liquid, which leads to the periodic coalescence and breakup of the menisci formed at the output ends of the capillary tubes 3. (Fig. 2. a,b,c,d,e). With the reverse flow of liquid through the capillary tubes 3 the meniscus decreases and a filament is formed (Fig.2.d) which breaks up in the zones of instability .The liquid filament (satellite droplet) due to the surface forces takes a spherical form and falls at a certain initial velocity depending on the cutting angle. The droplet size dependence on the distance between atomizer nozzles for capillary diameter $D = 600mcm$ and generation frequency $f = 15$ is shown in the graph in Fig.3.

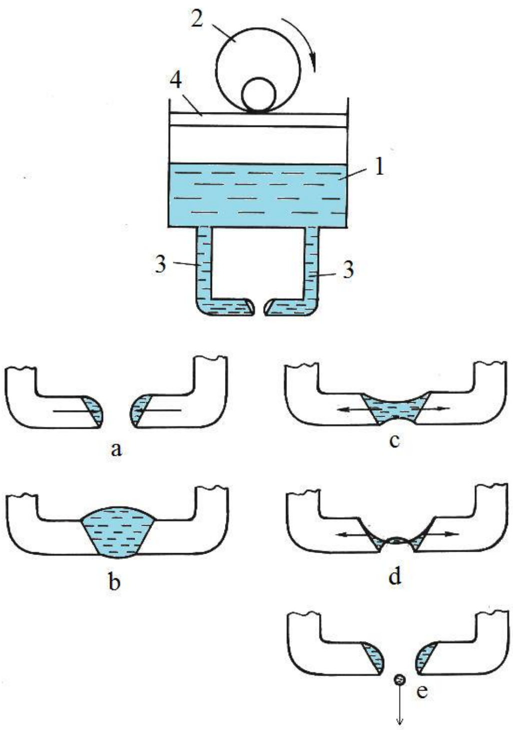


Fig.2. Principle of droplets generation

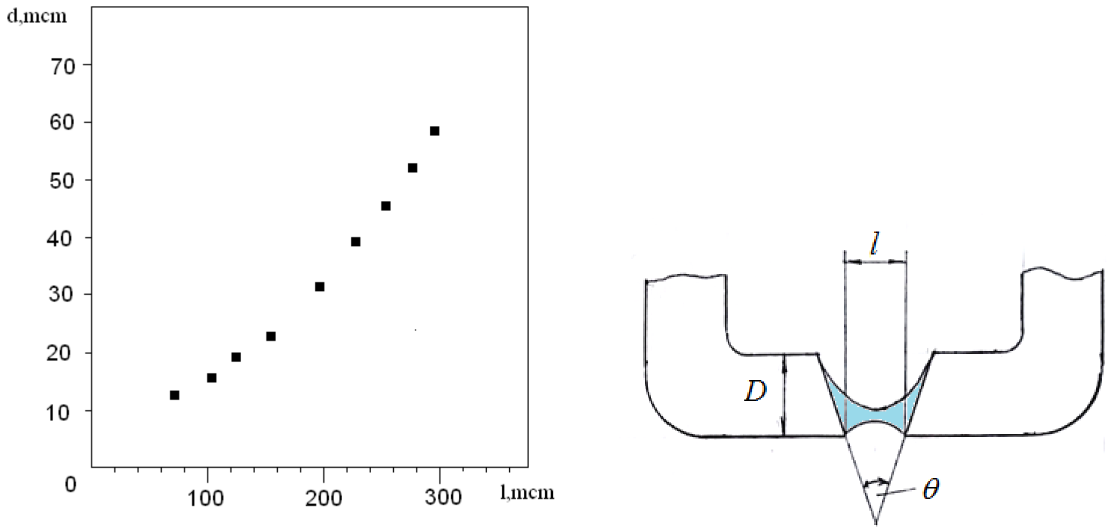


Fig.3. The droplet size (d) dependence on the distance (L) between atomizer nozzles

3. Solid particles

To obtain solid particles (micro crystals), various solutions of water-soluble crystals ($NaCl, LiIO_3, KDP,$ etc.) are used.

Crystallization of the generated droplets is carried out using the dry technology by evaporation [2] of the initial droplets in the crystallization chamber (a glass tube with controllable conditions of relative humidity and temperature inside).

The process of sold particles formation from the initial droplets is schematically shown in Fig.3. (a-e)

Inside the glass tube the particles move vertically with the sedimentation velocity. Simultaneously the evaporation of the solvent (water) takes place until the saturation of droplet solution is achieved after which the process of formation of crystal particle begins. Due to the droplet motion the evaporation intensity becomes higher in the front zone of droplet since the relative humidity is lower here that means that the concentration of solution is higher in this zone and the nucleation starts (most probably) just in the front zone of the droplet and the crystal particle grows [6] in the shape illustrated In Fig.4.e.The photographs of crystal particles of $NaCl$ and $LiJO_3$ are shown in Fig4 a,b.

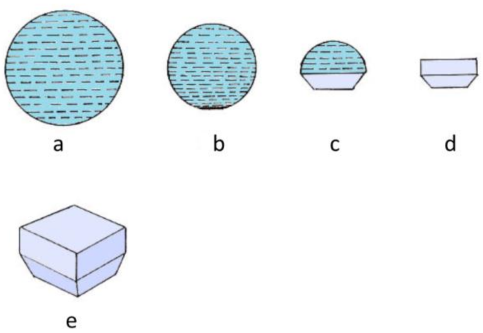
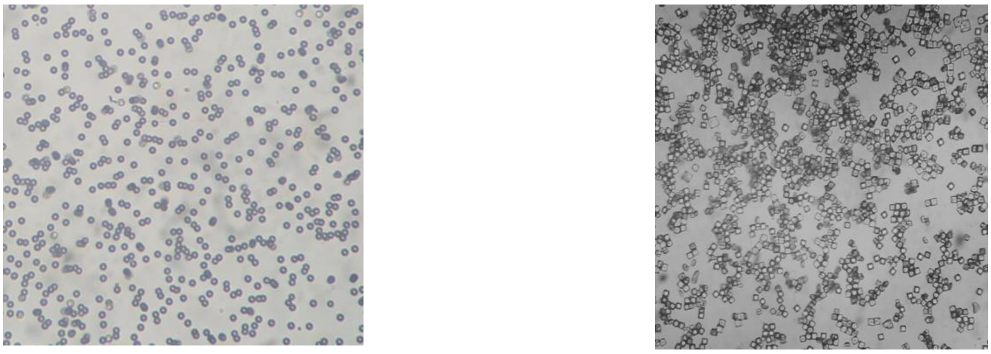


Fig.4. Schematic of solid particle (NaCl) formation



a b

Fig.5 a, b Photographs of crystal particles NaCl and LiJO3

4. Particle size measuring

The diffraction pattern observed on the screen (Fig. 6) is the result of a superposition of diffraction from the large number of individual obstacles (micro crystals) chaotically spread on the glass plate. The nature of the intensity distribution in each ring depends on the diameter of the beam, the size of the micro crystals, and their bulk shape.

Since the laser beam has a negligible small angle of divergence, we can assume that the plate is illuminated by a practically parallel beam of light.

If a large number N of micro crystals enters the beam region, the intensity of diffracted light is N times greater than the intensity created by a single particle. Since the diameter of the laser beam is very small, all particles that are in this region give very close-up diffraction patterns on the screen, a system of alternating wide light and dark concentric rings.

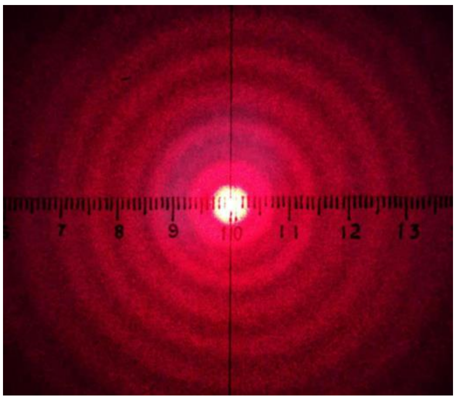


Fig.6. Diffraction pattern

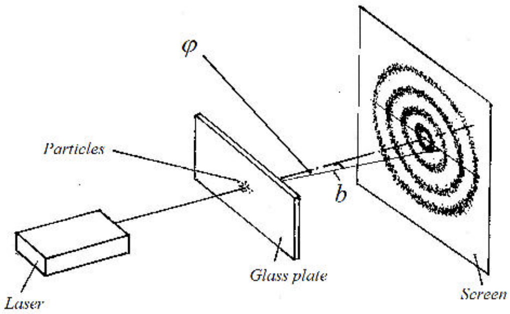


Fig.7. Particle size determining scheme

In the case of Fraunhofer diffraction the calculation formula for determining the particle size d can be written as

$$d = \frac{k_i \lambda}{\cos\left[arctg\left(\frac{D_i}{2b} \right) \right]}$$

where D_i notes the diameter of $i-$th ring, b is the distance between sample and screen, $\lambda-$ light wavelength, k takes the values $1.22; 2.22; 3.24-$ for odd dark rings $(i=1,3,5)$ and $1.64; 2.70; 3.72-$ for even light rings $(i=2,4,6)$, respectively.

5. Periodic structures

In order to create periodic distribution of particles on the substrate, masks with different size and periods of holes were used (Fig. 8) Masks are mounted directly on the surface of the glass plate, and particles (micro crystals) passing through the holes are distributed on the substrate along the corresponding micro-holes. However, the role of the mask is not limited only to the function of mechanical separation of particles. They are also used to create a temperature gradient inside the micro holes (by heating), and the particle falling into the hole region, under the influence of thermophoretic forces [3] moves to the central region of the cell. The mask is heated by a diode laser beam. Photographs (Fig. 9 and Fig. 10) show the results of applying of the mask. Laser beam diffraction pattern from this structure is shown in Fig.11.

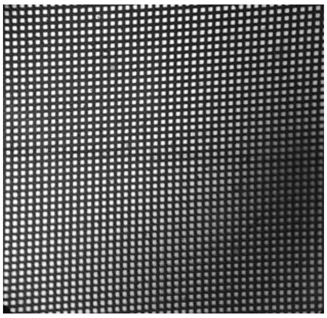


Fig.8. Mask

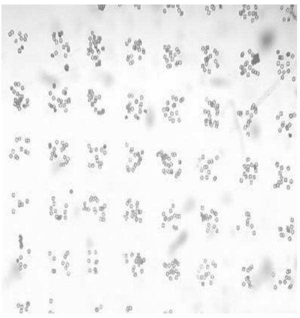


Fig.9. Periodically arranged groups of particles

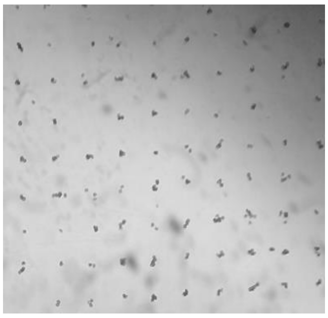


Fig.10.

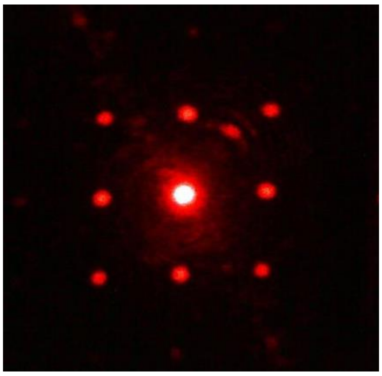


Fig.11. Difraction pattern from the periodic structure in Fig.10

Acknowledgments

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Conflict of interest

There is no conflict of interest

Author contributions

S.H. Harutyunyan invented and developed the method of monodisperse droplets generation, constructed the laboratory device; L.E. Khachikyan and G.A.Harutyunyan performed experimental investigations**.**

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