Design, Realization and Optimization of an Acoustic Levitator addressed to Condensed Matter Studies

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Abstract

This paper deals with an acoustic levitator, which has been engineering designed, optimized and then employed for performing chemical-physical analysis on levitated water mixtures of Ethylene Glycol. In particular, it is a single-axis levitator, which enables non-contact positioning and manipulation of solid and liquid samples of diameter between 0.5 and 3.5 mm versus time. Two acoustic transducers, an oscilloscope, an amplifier and a video camera forming the system that is optimized with a specific room for thermostatically regulating the temperature of the sample at a precise value and to protect the system from significant air currents, that can destabilize the levitated sample. The designed system allows to access deeply super-cooled and potentially supersaturated liquids in conditions that avoid heterogeneous nucleation by a container. Acoustic levitation can be also used for sample preparation of high concentrated mixtures starting from solutions. It can be used in many fields, especially for high added value products as it occurs, for example, in pharmaceutics. The experimental set-up can be also integrated by Infra-Red, Raman, Neutron or X-ray spectroscopy instruments. A significant example of system operation is also reported: levitated water mixtures of Ethylene Glycol sample, analyzed by an Infra-Red spectrometer. The study shows how this designed and optimized sample holder allows to follow the drying process versus time and to obtain a gel-like compound characterized by an extended chemical crosslinking. The obtained experimental findings together with their analysis allow to extract also information on the concentration values of the levitated systems.

Keywords: Acoustic levitation system, Ethylene Glycol, Infra-Red spectrometer, Sample holder, Drying processes, Super-cooled liquids. .

Introduction

Sample preparation and experimental investigation are a critical feature of research and development in advanced materials, geological systems, biology and on energy; they can take advantage by the use of contactless techniques. In particular, levitation technique eliminates container interactions and reduces contamination allowing to study samples with an high degree of control. In general, at high temperatures, reactions with crucibles limit the accessed conditions; while at lower temperatures, heterogeneous nucleation by containers limits the ability to supercool liquids below their equilibrium melting point or to make supersaturated solutions. In general, container less techniques are used to study materials such as molten oxides, liquid metals and alloys, and glasses at high temperatures [1]. By eliminating contact with container walls, sources of extraneous nucleation are kept away and it becomes possible to cool liquids to a large extent below their equilibrium melting point; moreover, due to the lower percentage of heterogeneous nucleation sites, levitated super-cooled liquids are expected to be more stable. Acoustic levitation is used to suspend and manipulate small drops and solid particles contactless in many applications fields. The first use of acoustic levitation dates back to 1933, when Bucks and Muller visualized acoustic fields throughout alcohol mists and droplets. Subsequently, in 1985 Barmatz and Collas developed techniques that use resonant cavities to create regions that can trap small samples. From a general point of view, levitation techniques enable to beget an opposing force to the gravity to keep the sample suspended, the levitator uses a single transducer and an opposed reflector to produce a simple interference. The shaping between the transducer and the reflector focuses the sound field and produces a stronger levitation force. The system, transducer and reflector, provides stable levitation but it does not enable manipulation of the sample. A single-axis levitation system uses instead, two opposed transducers that control the position of the sample by electronically adjusting acoustic phases. The distance between the two transducers is 10 wavelengths. The drive frequency is ultrasonic, usually from 20 to 70 kHz where the wavelengths are

5÷17 mm in air at room temperature. Modulation of the acoustic force can induce oscillations in low viscosity liquids by sequentially compressing and relaxing a levitated drop. In a two-transducer interference levitator, modulation can be achieved by systematically varying the power delivered to the transducers. In addition, adjusting the relative phase of the two transducers enables the levitated object to be moved along the axis of the levitator. In the present work an acoustic levitator, enables non-contact positioning and manipulation of solid and liquid samples of diameter between 0.5 and 3.5 mm versus time, was engineering designed, optimized and was performed physical analysis. Then an example of system operation was reported. The study on levitated water mixtures of Ethylene Glycol sample, analyzed by an Infra-Red spectrometer, showed how this designed and optimized sample holder allows to follow the drying process versus time and to obtain a gel-like compound characterized by an extended chemical crosslinking. Data analysis allowed to extract also information on the concentration values of the levitated systems.

Engineering design of the system and physical analysis

In an acoustic levitator, see figure 1a, an acoustic wave that is generated by a piezoelectric crystal is reflected creating a standing wave when the distance between transducer and reflector is an integral multiple of the half wavelength. Pressure nodes and antinodes appear at fixed points separated by a distance of $\lambda/2$. Small liquid samples can be levitated near the pressure nodes.

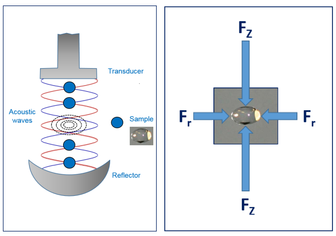

Figure 1: *a) Sound pressure and sound particle velocity in a standing acoustic wave, b)Radial and axial levitation forces.*

The levitation forces have influence on the droplet shape. While the axial forces are mainly responsible for compensating the gravitational force, the radial forces hold the sample in the pressure node. The axial and radial levitation forces lead to a deformation of the sample as shown in figure 1b.
The designed system was formed by three main component represented by the levitation apparatus, the ultrasonic power amplifier, and the acoustic controller circuit:

- The levitation apparatus used two transducers, on a rigid vertical support of 38 mm of diameter that was bolted to an optical breadboard, mounted facing each other along a vertical axis. The transducers were mounted in aluminum tubes, using two split ring clamps that were fastened around the motor and lower part of the horn, respectively, and were located on a metal stand. They operate at a frequency of 22 kHz and can produce sound pressure levels produced is not exceeding to 160 dB. The horn of the transducer was firmly fixed to a piezoelectric motor, formed by four lead zirconium titanate disks sandwiched between two cylindrical aluminum stubs, and the conductive electrodes were placed between the piezoelectric disks to drive them in parallel, in order to energize the motor. The lower transducer was fixed, while the upper one could be moved to adjust the separation and precisely align the components. Two acoustic absorbing foam disks of diameter about 50 mm were glued onto the face of the transducer horns to reduce unwanted reflections that can cause instabilities in the levitated sample

- The ultrasonic power amplifier was the capacitive load of the two transducers, that varies with frequency (minimum $\sim 70\Omega$at resonance). The power supply was formed by a push-pull amplifier and a matching transformer and the power output transistors was powered from a ± 40 V rail. There was a series resistor of 1 Ω value, that enable the current supplied to the transducer to be measured with an oscilloscope. The levitation system required 125 V ac and 10 A electric power. The amplifier was connected to the transducers using a shielded twisted pair cable

- The acoustic controller circuit provides the drive signal to the ultrasonic power amplifier, hooks the resonant frequency of the transducers with a phase lock loop and maintains near zero the phase angle between the drive current and voltage. It also enables control of the drive power, relative phase between the transducers, balance of drive power to the transducers, and modulation of the acoustic power. The circuit was printed on a card, housed in a rack-mount chassis together with the power supply and the conditioning hardware. The acoustic controller circuit allowed manual adjustment of the acoustic drive signal, relative phases of the power supplied to each transducer and the amplitude. The modulation was accomplished throughout an external signal generator, connected to the controller.

The modulation signal was a sine wave. The levitator was set up on a flat horizontal surface in a specific room for thermostatically regulating the temperature of the sample at a precise value and to protect the system from significant air currents, that can destabilize the levitated sample. The power supply the voltage to current phase to the transducers was adjusted, so to be in phase. In this way, will be present the maximum acoustic output for the drive power and reduced heating of the transducers that leads to a drift in frequency. An oscilloscope monitored the current signals from the amplifier and the frequency of the phase lock loop was set as a compromise between the resonant frequencies of the two transducers. The relative phase of the two transducers was adjusted in order to control the vertical position of the sample and the balance control was adjusted to achieve similar drive signal levels to both the transducers. The voltage-to-current phase was automatically maintained near-resonant frequency operation by the phase lock loop. The movable transducer was also adjusted slightly to determine the most stable levitation conditions. The acoustic power, phase, and balance were finely adjusted to achieve the most stable levitation. In figure 2 the acoustic levitator technical parameters are reported.

Frame and levitator system dimensions	30 x 45 x 60 cm
Controller dimensions	60 x 45 x 20 cm
Total weight	30 Kg
Electrical specifications	100/120V 60 Hz, 15A 230 V 50/60 Hz, 15A
Nominal resonant frequency	22 kHz
Sound pressure levels	160 dB
Transducers distance	150 mm

Figure 2: *Acoustic levitator technical parameters.*

A 30 Hz frame rate video camera equipped with a macro lens was focused onto the sample position so that an image of the levitated sample could be observed and recorded in a Toughbook pc, to continuously monitor the levitated sample. The whole system is optimized with a specific room to thermostat the temperature of the sample at a precise value. Samples are introduced into the sound field using a micropipette injection and can be translated by adjusting the phase between the transducers or squeezed by modulating the acoustic levels with variable frequencies. The acoustic levitator can be operated in conjunction with Infra-Red, Raman, Neutron or X-ray spectroscopy to study materials in-situ. In this case, it is coupled with an Infra-Red spectrometer. A FTIR Vertex 70 v by Bruker Optics spectrometer was employed to collect absorption spectra. Each spectrum is composed by 128 runs, which furnish a spectral resolution of 4 cm-1. Spectra corrections for atmospheric water background, baseline and area normalization were performed. OPUS/Mentor software interface was used to process data. The first line of figure 3 shows a sequence of images of drops levitated with increasing acoustic force. The vertical position of the levitated drop could be adjusted over a distance of about 7 mm by changing the relative phase of the transducer drive signals. Experiments using drop modulation showed the feasibility of inducing oscillation in liquids. The other lines of figure 3 shows, instead, the images of water drops excited with a sinusoidal variation in acoustic force, obtained using a shutter speed of 1/200 s. The images of levitated samples were selected to show representative drop shapes. It was found that a small amplitude modulation at a frequency of about 20 Hz resulted in very stable levitation of 3 mm diameter water drops. At certain frequencies, the magnitude of the drop oscillation increased markedly as resonant frequencies were excited. The maximum amplitude occurred over a frequency range of about 5 Hz and outside this range, the drops were quiescent.

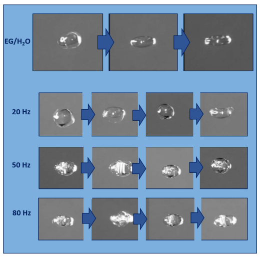

Figure 3: *Levitated EG mixtures drops excited by varying the acoustic forces using a sine wave function (first line) and images of levitated water drops excited by varying the acoustic forces using a sine wave function.*

After approximately 1 h of operation at constant power, the transducer temperature stabilized and their subsequent performance remained practically unchanged over long periods of time. The phase lock loop controller in the acoustic power supply maintained operation at resonance during warm up and once the temperature had stabilized.

Results and Discussion

An example of system operation was reported. In particular, Ethylene Glycol (EG), manufactured by Aldrich-Chemie and double-distilled water were used in this study [2]- [3]. The solutions were prepared by mass, using an analytical balance with $\pm 0.01 mg$ accuracy. The surface tension measurements were carried out using a standard thermostated stalagmometer, which was calibrated with distilled water (σ= 72.8 mN/m at T = 20°C). A constant temperature water bath was used to control the temperature of the solutions to an accuracy of ± 0.1°C. Measurements for each solution were repeated four times. Ancillary density measurements were performed by standard pycnometer technique. The surface tension of a liquid mixture is an important property, which plays an important role in affecting the mass and heat transfer at the interface. In the chemical field applications, it determines the product quality (i.e. coatings, paints, detergents, cosmetics and agrochemicals) and affects different production processes such as catalysis, absorption, distillation and extraction. Measured surface tensions of pure EG as a function of temperature and of water mixtures at T=25°C show that the surface tension of pure EG decreases linearly with the temperature and in a quadratic way with concentration. It may be suggested that the presence of extensive intermolecular H-bonding between EG molecules and EG and water molecules could be responsible for decreasing surface tension with increasing temperature and EG concentration.

In figure 4 the InfraRed absorbance spectra of levitated EG, in aqueous solutions at T=20°C for the initial concentration value of ϕ = 0.50 as a function of time are reported, i.e. at 15m, 30m, 45m and 60m.

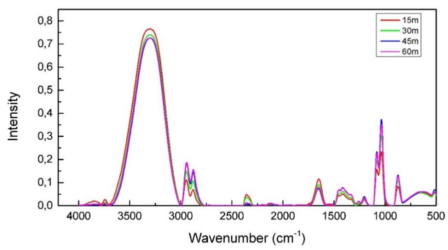

Figure 4: *IR absorbance spectra of levitated EG aqueous solutions at T=20° C for the concentration values ϕ = 0.50 as a function of time, i.e. 15m, 30m, 45m and 60m.*

In figure 5a the OH stretching contribution area of non levitated aqueous solutions at T=20°C are reported. As it can be seen the intensity of the OH stretching contribution decreases with the increasing of the EG concentration and in figure 5b the OH stretching contribution area of levitated aqueous solutions at T=20°C are reported as a function of time. As it can be seen from figure 4, the intensity of the OH stretching contribution decreases with the increasing of the levitation time reaching a plateau value after 60 minutes. From the comparison between the data reported in figures 4a and 4b one can infer that the concentration value is 0.647 after 15m, 0.787 after 30m, 0.918 after 45m and 0,953 after 60m

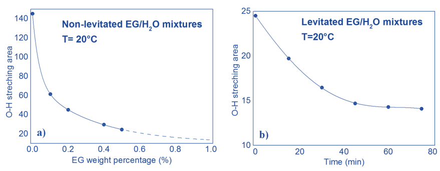

Figure 5: *a) O-H streching area of IR absorbance spectra of levitated EG aqueous solutions at T=20° C for the concentration values ϕ = 0.50 as a function of time; b) O-H streching area of absorbance multiple spectra of non-levitated EG aqueous solutions at T=20° C.*

Conclusions

In the present paper, the acoustic levitation technique has been used in combination with InfraRed spectroscopy to collect data on levitated water mixtures of EG in a wide concentration range; the study also includes ancillary surface tension and density data determinations. The obtained experimental findings together with their analysis allow to extract information on the concentration values of the levitated systems. Acoustic levitation can stably levitate 1 - 3 mm diameter drops of water and aqueous solutions. This provides a means to access deeply supercooled and potentially supersaturated liquids in conditions that avoid heterogeneous nucleation by a container

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Global Climate Changes and Global Warming: Effects Related to Extreme Weather Events on Local Scale

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Abstract

The attention towards environmental issues is today stimulated by a significant increasing of extreme weather events. The scientific and socio-political interest about phenomena such as flash floods, strong winds and storm surges has grown as a result of the impact caused on the daily life. Just to mention a few, landslides, mudslides, damage of buildings, loss of cultivations and in the most tragic circumstances, loss of human lives. In this work the global warming effects on a local scale, with specific reference to the frequency increase of extreme weather events are dealt. In this framework the most important findings obtained by using the WRF model (specially configured for Sicily) which allowed to analyze as a study case the flood that struck Messina on 10th October 2015 are reported. Furthermore an innovative monitoring system for the prevention of weather connected territory injuries is described.

Keywords: weather forecast, Interfacing Weather station-Arduino YUN, WRF model, heavy rain, extreme weather events, complex horography.

Introduction

The global climate changes and their impact on global scale represent one of most important issues nowadays. In recently years, the understanding of the climate changes, through the studies of ice ages and interglacial ages have intrigued many scientists and researchers. Studying the last million years, a periodicity ranging between 40 and 100 thousand of years for an average temperature fluctuation of 10 K has been found. Assuming the average temperature of the Earth as a fundamental variable and disregarding the contribution of the atmosphere, through the global energy balance theory we have:

$$C\frac{dT}{dt} = P_{in} - \alpha P_{in} - P_{out}$$

where C is the heat capacity of the Earth, and P_{in} is the incoming radiation given by $P_{in} = \pi R^2 S$. P_{in} it is independent on Earths temperature but affected by the time as function of astronomical modulations. In the last relation, $S \simeq 1370 W m^{-2}$, is the solar constant and πR^2 represents the surface perpendicular to the solar rays. P_{out} is the emitted radiation by the surface of the Earth estimated through the Stefan-Boltzmann law for the black body at T temperature: $P_{out} = 4\pi R^2 \sigma T^4$ ($\sigma \simeq 5.6710^{-8} W m^{-2} K^{-4}$ Stefan-Boltzmann constant). Finally, α is the average albedo of the Earth (typically of the order to 0.3). The climatic fluctuations are related with the astronomical variations of the terrestrial orbit (cycles of Milankovitch), but at global level, the variations of insolation alone cannot explain the variation of 10 K observed in climate data. Therefore, an amplification mechanism to move from small solar modulation to the great climate change, is to be taken into account. According to G. Parisi et al. [1], this mechanism is governed by positive feedback induced in the albedo. A further amplification is due to stochastic resonance induced by the weather fluctuations. When treating with physical phenomena that involve variables with different time scales, it is possible to consider the faster ones as perturbations acting on the slower. Climate changes such as the global warming, are important not only from a scientific point of view. They can have implications also in social, economic and political environments. In fact, on December 2015 (Paris) at the United Nations conference on climate change (COP21) has been decided that before the end of century the global warming must be kept less of $2°C$. During this meeting was discussed about the area known as Stretto di Messina which is one of most interesting area from climate point of view.