engineering proceedings

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Proceeding Paper

Transient Thermal Characterization of Small Particles in Fluidic or Acoustic Levitation †

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† Presented at the 17th International Workshop on Advanced Infrared Technology and Applications, Venice, Italy, 10–13 September 2023.

Abstract: Putting small particles in levitation and in transient thermal imbalance in a gas has several advantages. This avoids chemical and thermal pollution through contact with a solid wall. The large exchange surface between the particle and the surrounding gas and the small volume can be considered as microfluidic situations with acceleration of surface transfers, rapidly isothermal particles, low-cost thermal cycling, rapidly isothermal situations and extreme temperature conditions facilitated. Several results related to thermal characterization in the case of fluidic and acoustic methods of levitation are presented. It consists of recording and comparing the transient temperature response by using an infrared thermography device to a step convective or radiative heating.

Keywords: fluidic or acoustic levitation; transient thermal characterization; infrared thermography

Citation: Batsale, J.-C.; Aouali, A.; Achchaq, F.; Sommier, A. Transient Thermal Characterization of Small Particles in Fluidic or Acoustic Levitation. *Eng. Proc.* **2023**, *51*, 50. https://doi.org/10.3390/engproc2023051050

Academic Editors: Gianluca Cadelano, Giovanni Ferrarini and Davide Moroni

Published: 4 July 2024

1. Introduction

Analysis of the thermal behavior of small particles in levitation in a gas makes it possible to study chemical or phase transformations without polluting contact with a solid support. The small size of the particle, with a large exchange surface compared to the volume, makes it possible to assume that the particle is isothermal with very fast thermal response times and possible extreme heating conditions.

The potential applications can touch many fields such as the evaporation of aerosols [1], the phase change of candidate peritectic materials [2], or even cases of combustion [3] or violent chemical reactions by contactless transport of particles [4].

The characterization of thermophysical properties in such situations needs first to analyze a temperature response to calibrated heating. The heating of such particles can be ensured by laser irradiation, allowing high densities of radiative flux (of the order of a few tens of Watt) [5], or simple radiative and convective heating with simple lamps or dryers. The temperature response is easily approached with IR thermography devices, even if the particle is unstable or in light motion.

This kind of experimentation can be complementary to more traditional methods such as DSC (Differential Scanning Calorimetry) or even microfluidic experiments in microchannels (See [6–8]). Methods such as DSC require larger volumes, and therefore slower experiments, of contact with a solid wall.

A disadvantage of levitation methods is that the shape of the particles is not always perfectly controlled, can evolve over time, and has variations in emissivity, mass and chemical constitution. In order to be able to at least carry out comparative tests, it is necessary to develop reference situations with particles which remain homogeneous, without chemical reaction or phase change. We show some results related to these reference methods.

2. Bernoulli's Levitation

Bernoulli's method consists of placing a spherical particle in a laminar flow. This type of levitation is obtained by rudimentary experiments consisting in creating a flow of air around a reference particle. A table tennis ball with a diameter of 4 cm and a mass of 2.7 g (see [9,10]) is frequently used. At short times, we can assume that the thin wall of the Celluloid is isothermal and that the gas inside of the ball is sufficiently insulating to ensure adiabatic conditions at a short time.

The first step is to place the ball in the cold airflow and then turn on the dryer heater. The measurement of the temperature of the wall of the ball is ensured simply using an infrared camera which makes it possible to note that the temperature field is uniform on the surface of the ball and which also makes it possible to follow the object even if it is not stable in the flow. The setup is shown in Figure 1.

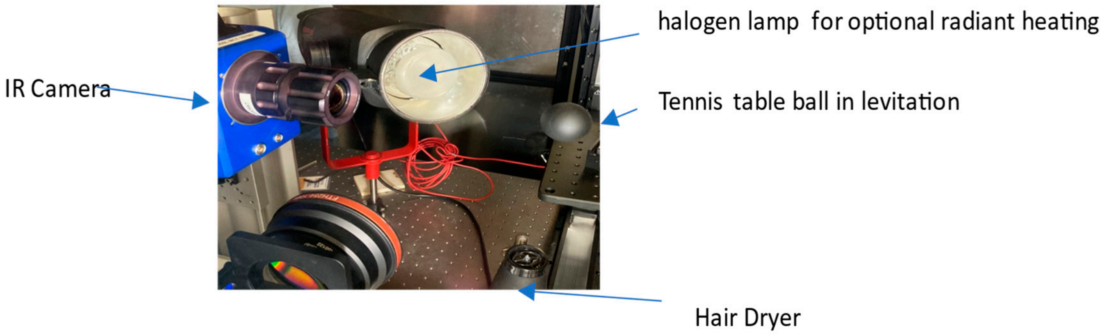

Figure 1. Setup for the tennis table ball levitation.

The results in Figure 2 show that this type of experiment is practical for comparing complex situations of drying a previously moistened ball with a reference situation of heating a dry ball. It can be seen that after a similar temperature rise phase in the dry or wet case, the drying phase gives an almost linear temperature evolution, which can be assimilated to a constant evaporation of surface water. It can also be seen that this evolution of global temperature hides a great complexity of the local temperature field due to the non-uniformity of the drying. A modeling of the transfers in the dry ball by taking into account the mass of the specific heat of the ball, the internal gas and the absolute temperatures should make it possible to complete these preliminary results.

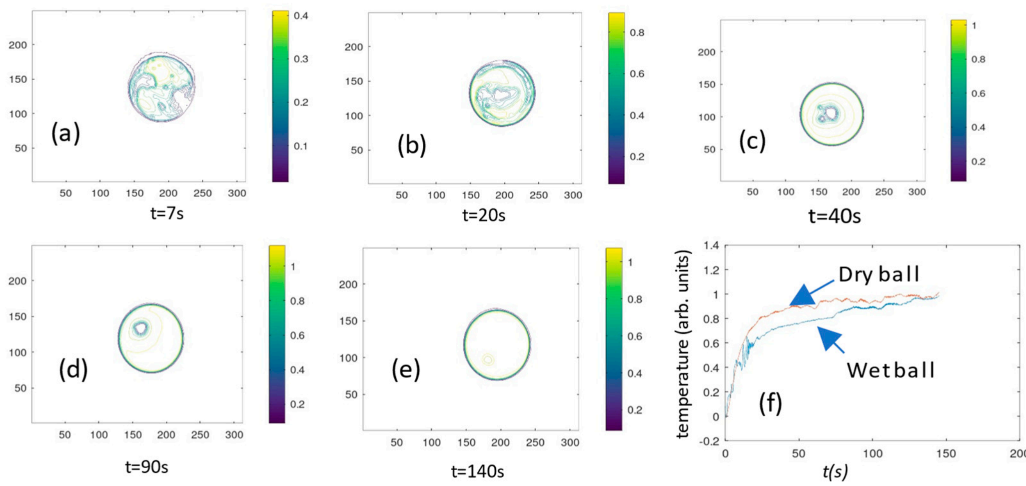

Figure 2. (**a**–**e**): Contour-plot of the IR image during convective drying experiment of the ball; (**f**) averaged temperature evolution comparison between wet and dry ball experiment.

3. Acoustic Levitation Method

A particle put into an ultrasonic standing wave tends to move towards an equilibrium position, where the acoustic pressure-induced force on its surface compensates the particle weight (First Experiments in 19th century, Kundt, 1866 [11]). This acoustic system is now simple to develop and is the subject of do-it-yourself demonstrations [12]. Therefore, the Spheric shape required for the ultrasonic levitation experiment is not easy (faceted particles, droplets. . .). The study of the stability and the particle size effects in such an acoustic field is modelized and recently studied in [13].

The acoustic levitation methods here make it possible to study particles with a mass of about 1 mg and about 1 mm in diameter. The assembly of Figure 3 shows that one can simultaneously study the average temperature responses of four particles on four different acoustic pressure nodes (1.2: 2 polystyrene particles of the same mass and 3.4: 2 Bio-Based Phase Change particles of the same mass from Croda Europe Ltd., Goole, UK). A uniform radiative heating is provided with a halogen lamp. It can be seen in Figure 4 (enlargement of the previous temperature contour plot) that these particles are not perfectly spherical in shape. Figure 5 shows that the temperature responses of particles 1 and 2 (polystyrene) and particles 3 and 4 (materials from Croda Ltd, Goole, UK.) are the same when they are of the same material and mass. The heating device here comes from a halogen lamp with a power of 1 kw, which amounts to an illumination of the particles of approximately 0.1 w per particle.

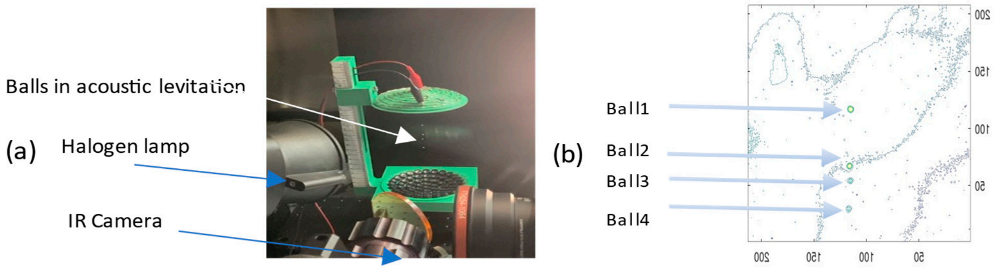

Figure 3. (**a**) Installation allowing simultaneous acoustic levitation and thermal excitation. (**b**) Identification of suspended particles using the infrared image traced in contour mode.

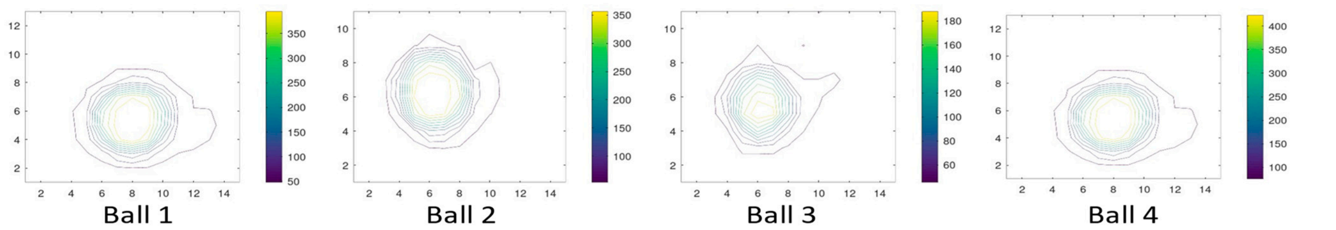

Figure 4. Enlargement of the previous image (Figure 3b) located on each of the 4 particles at t = 8 s.

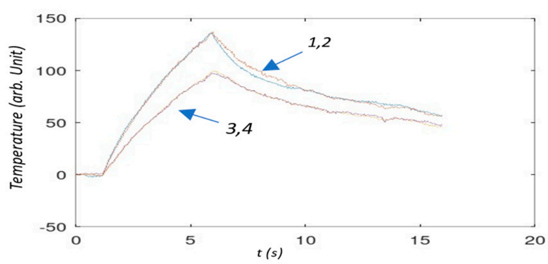

Figure 5. Transient behavior of the averaged temperature of the 4 particles.

4. Conclusions

This work shows preliminary results about the possibilities of comparative experiments, with reference situations in fields where the measurement of thermophysical properties of particles in levitation can be complex (changes of phase and surface state of the particles), even if they are isothermal. A complete study of these results must be supplemented by data on the specific heats the masses, the exchange surfaces and emissivity of the particles.

Author Contributions: J.-C.B. and F.A. conceptualization and writing original, A.A. and A.S. experiments and validation. All authors have read and agreed to the published version of the manuscript.

Funding: Internal funding of the I2M institute.

Data Availability Statement: Data available by contacting the authors.

Acknowledgments: Diego Baresh and the Acoustic team of I2M are greatly acknowledged for the help in the development of acoustic levitation methods.

Conflicts of Interest: The authors declare no conflicts of interest.

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