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Airborne Power Ultrasonic Technologies for Intensification of Food and Environmental Processes

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Abstract

Airborne power ultrasound is a green technology with a great potential for food and environmental applications, among others. This technology aims at producing permanent changes in objects and substances by means of the propagation of high-intensity waves through air and multiphase media. Specifically, the nonlinear effects produced in such media are responsible for the beneficial repercussions of ultrasound in airborne applications. Processing enhancement is achieved through minimizing the impedance mismatch between the ultrasonic radiator source and the medium by the generation of large vibration displacements and the concentration of energy radiation thus overcoming the high acoustic absorption of fluids, and in particular of gases such as air. Within this work the enhancing effects of airborne power ultrasound in various solid/liquid/gas applications including drying of solid and semi-solid substances, and the agglomeration of tiny particles in air cleaning processes are presented. Moreover, the design of new ultrasonic devices capable of generating these effects are described along with practical methods aimed at maintaining a stable performance of the tuned systems at operational powers. Hence, design strategies based on finite element modelling (FEM) and experimental methods consolidated through the years for material and tuned assembly characterizations are highlighted.

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1. Introduction

Airborne power ultrasound consisting in the generation and transmission of high-intensity pressure waves in air at frequencies in the range 20 to 50 kHz is considered an attractive emerging technology with a great potential in food and environmental applications. The recent development of specific ultrasonic technologies based on power piezoelectric transducers driving extensive plate radiators, described by Gallego-Juárez et al. (2010), Riera et al. (2011) and Gallego-Juárez et al. (2015), lead to a renewed academic and industrial interests in the applicability and scalability of airborne power ultrasound technology in multiple operations. The reasons behind the interest in these novel transducers are their electro-acoustic efficiency (up to 80%), high energy concentration (high directivity and/or focalization), power capacity (up to 0.5-1 kW) and ability to generate large vibration displacements in air. The technology consists of an ultrasonic vibrator, constituted by a Langevin piezoelectric transducer and a mechanical amplifier that drives an extensive plate radiator in a flexural mode (Gallego-Juárez et al., 1978) generating high-intensity ultrasonic waves. These waves propagate through air, gases or aerosols producing a series of linear and nonlinear effects such as co-vibration, entrainment, radiation pressure, high amplitude compressions and rarefactions, diffusion enhancements, turbulence and acoustic streaming as described by Riera et al., (2015).

Since 2008 the CSIC and Pusonics SL have been working together to introduce airborne ultrasonic technology into laboratories and industries by designing customized ultrasonic devices with enhanced radiation characteristics. As a result of this joint effort, different tuned system designs and development strategies have been investigated and developed to control the dynamic behaviour of power ultrasonic piezoelectric systems, as highlighted by Cardoni et al., (2009) and Cardoni et al., (2012).

The work presented in this paper deals with: a) the latest advances in the development of airborne ultrasonic technologies for the intensification of lab scale freeze drying processes of interest for the food industry, and b) the first experimental results obtained in a pilot scale installation for the agglomeration of fine aerosol particles produced in severe accidents such as those involving nuclear power plants by high-intensity ultrasonic waves

2. Freeze drying processes assisted by power ultrasound

As shown by Gallego-Juárez et al., (1999), Mulet et al., (2003), and García-Pérez et al., (2012), by applying airborne power ultrasound the kinetics of drying processes may be intensified at moderate temperatures in comparison with conventional driers. To overcome the difficulty existing in the direct application of airborne ultrasound in conventional driers, CSIC and the Universitat Politécnica de Valencia (UPV) have designed and developed a new type of ultrasonic drying chamber (UDC). The system consists of three parts: a) a flat plate-transducer consisting of a rectangular radiating plate and a piezoelectric vibrator; b) a static structure incorporating reflecting surfaces for distribution of the acoustic field, and c) a drying chamber.

Table 1. Electrical response of the flat plate-transducer versus power

Power (W)	Phase V-I (º)	Impedance (Ω)	Current (mA)	Voltage (V)	Frequency (Hz)
10	1	804	110	89	21114
100	2	650	393	258	21081
200	4	640	527	366	21078
300	3	600	692	418	21075

As a result of FEM work performed using Comsol Multiphysics package following a design protocol presented by Riera et al., (2011), the geometry of a rectangular flat-plate transducer structure and positioning of reflectors for acoustic field optimization and drying chamber configuration were defined. The rectangular plate radiator was designed to resonate in a flexural mode with 12 Nodal Lines (NL) (Fig. 1). The radiator material was manufactured using 7075 aluminium alloy and the tuned system operated at a power up to 300 W. The resonance frequency of the