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Recent advances in the development and application of power plate transducers in dense gas extraction and aerosol agglomeration processes

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Abstract

Power ultrasound (PU) is an emerging, innovative, energy saving and environmental friendly technology that is generating a great interest in sectors such as food and pharmaceutical industries, green chemistry, environmental pollution, and other processes, where sustainable and energy efficient methods are required to improve and/or produce specific effects. Two typical effects of PU are the enhancement of mass transfer in gases and liquids, and the induction of particle agglomeration in aerosols. These effects are activated by a variety of mechanisms associated to the nonlinear propagation of high amplitude ultrasonic waves such as diffusion, agitation, entrainment, turbulence, etc. During the last years a great effort has been jointly made by the Spanish National Research Council (CSIC) and the company Pusonics towards introducing novel processes into the market based on airborne ultrasonic plate transducers. This technology was specifically developed for the treatment of gas and multiphasic media characterized by low specific acoustic impedance and high acoustic absorption. Different strategies have been developed to mitigate the effects of the nonlinear dynamic behavior of such ultrasonic piezoelectric transducers in order to enhance and stabilize their response at operational power conditions. This work deals with the latter advances in the mitigation of nonlinear problems found in power transducers; besides it describes two applications assisted by ultrasound developed at semi-industrial and laboratory scales and consisting in extraction via dense gases and particle agglomeration. Dense Gas Extraction (DGE) assisted by PU is a new process with a potential to enhance the extraction kinetics with supercritical CO_2. Acoustic agglomeration of fine aerosol particles has a great potential for the treatment of air pollution problems generated by particulate materials. Experimental and numerical results in both processes will be shown and discussed.

Keywords: Ultrasonic processes; Power ultrasound; Mass transport; Dense Gas Extraction; Carbon Dioxide; Acoustic Agglomeration; Nuclear Safety; Severe Accident; Source Term Mitigation

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1. Introduction

In order to obtain an efficient transmission of energy in gas media, it is necessary to achieve a good impedance matching between the radiator and the gas medium, large amplitude of vibration and high-directional beams for energy concentration. Power transducers driving extensive radiators may achieve all these requirements in one device opening up new industrial opportunities. During last years, the Research Group of Systems and Ultrasonic Technologies (GSUT-CSIC) and the company Pusonics SL have been involved in the study, development and fabrication of innovative power ultrasonic systems for the propagation of high intensity acoustic waves in gases, and in the investigation of the applicability of these novel devices to food and environmental processes. The structure of this type of power transducers basically consists of a longitudinally tuned ultrasonic piezoelectric converter attached to a mechanical transformer acting as a vibration amplifier, coupled to an extensive plate radiator resonating in a flexural mode. To scale-up this technology at industrial stage there are important problems to overcome such as controlling the undesired effects due to the nonlinear behaviour of tuned devices driven at high power (Gallego-Juárez et al.,; 2008, Cardoni et al., 2009). For this purpose different strategies have been developed in order to enhance and stabilize the dynamic characteristics of ultrasonic assemblies at nominal power conditions.

This work deals with the last advances in the nonlinear control of piezoelectric power transducers. Also two new processes assisted by PU developed at semi-industrial and laboratory scales are presented. These are extraction with dense gases and fine particle agglomeration. DGE processes assisted by PU have the potential to enhance the extraction kinetics with supercritical CO_2 preserving the quality of the extracted product (Riera et al., 2004, 2010a, 2012). Acoustic agglomeration (AA) of aerosol particles by PU has a great potential for mitigating the impact of air pollution by fine particulate matter generated by industrial plants in daily operations or in the occurrence of severe accidents (Albiol et al., 2013).

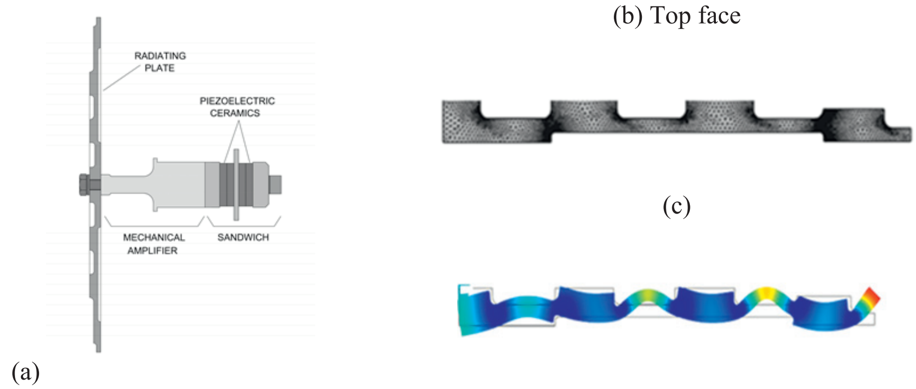

Figure 1. (a) Schematics of an ultrasonic plate-transducer; (b) 2D axi-symmetric FEM of the plate; (c) Predicted tuned plate mode

2. Recent advances in the characterization of power plate transducers

Circular stepped-plate transducers used for either coherent or focused radiation are made up of a circular radiator tuned in a specific axisymmetric flexural mode driven at its centre by a length expander piezoelectric vibrator, as shown in Figure 1(a). The design of this type of assemblies is typically carried out by Finite Element Methods (FEM). Figure 1(b) shows a 2D model of the directional stepped profile (top face) and the focused grooved profile (back face) of a circular stepped-plate radiator. In Figure 1(c) the modal shape of the tuned mode of the plate radiator calculated at 25.7 kHz is illustrated. The measurement of the plate vibration velocities was conducted by using a laser vibrometer (Polytec CFV055) in order to validate the numerical predictions for the plate-transducer dynamics.

It is well known that the vibration behaviour of ultrasonic devices driven at high power is often characterized by surprising phenomena which cannot be predicted by FEM or detected at low power by impedance analysers. Nonlinear effects of transducers such as saturation of the operational mode and tuned frequency shifts are largely