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SONOPROCESSING OF FLUIDS FOR ENVIRONMENTAL AND INDUSTRIAL APPLICATIONS

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+ABSTRACT

Ultrasonics processing is becoming an increasily attractive field due to the sustainable character of the use of ultrasonic waves: low energy consumption and no contaminating processes. However the applications of ultrasonic energy in fluids, and more specifically in gases, have been limited for the difficulty to generate efficiently such energy in large scale processes. To overcome this problem a new family of ultrasonic generators with extensive radiators were developed during the last years. Such new generators opened possibilities to study and implement new processes in fluids at industrial level. This paper deals with the characteristics and performance of some new sonoprocesses in gases and multiphase media developed at industrial and/or semi-industrial level for environmental and industrial applications.

INTRODUCTION

Ultrasonic processing is based on the adequate exploitation of the nonlinear effects associated to the high -intensity ultrasonic waves. The most relevant nonlinear effects related to high-amplitude waves are: wave distortion, radiation pressure, acoustic streaming, cavitation in liquids and the formation and motion of dislocation loops in solids. As a consequence of these effects, a series of mechanisms may be activated by the ultrasonic energy such as heat, agitation, diffusion, interface instabilities, friction, mechanical rupture, chemical effects, etc,. Such mechanisms can be employed to produce or to enhance a wide range of processes that very much depend on the irradiated medium.

There are a large number of ultrasonic processes which have been already developed at laboratory stage, but only a few of them, have already been introduced in industry. Such situation is specifically relevant in the case of the applications in gases where the great majority of the potential sonoprocesses remain at laboratory level. This situation can be mainly attributed to the problems related with scaling up the ultrasonic processing systems which requires efficient and powerful ultrasonic transducers and a proper distribution of the acoustic field in the processed medium.

During many years the Power Ultrasonics Group of the Spanish Research Council (PUG/CSIC) has been involved in the study and development of a new technology of high-power sonic and ultrasonic generators for use in gases and in its application to some specific environmental and industrial problems.

This presentation deals with the characteristics and performance of some sonoprocesses developed by applying the new ultrasonic generators.

POWER ULTRASONIC TECHNOLOGIES FOR SONOPROCESSES IN FLUIDS AND MULTIPHASE MEDIA

Sonoprocessing in fluid and in multiphase media (i.e. fluids with suspended particles, drops or bubbles or porous solids with fluids inside) is a field of application with a very wide potential.

For the generation and application of high-intensity ultrasound to fluid or multiphase media special high power transducers are needed covering adequate requirements. The fluid media (specially the gases) present a low specific acoustic impedance and a high acoustic absorption. Therefore, in order to obtain an efficient transmission of energy, it is necessary to achieve a good impedance matching between the transducer and the medium, large amplitude of vibration and high-directional or focused beams for energy concentration. In addition, for large-scale industrial applications, high power capacity and extensive radiating area would be required in the transducers.

To cover such specific requirements a new ultrasonic generation technology was developed where the main points achieved are the increase of the power capacity and efficiency of the transducers and the enlargement of the working area and the radiator design to reach, as much as possible, a uniform distribution of the acoustic field. Such technology is incorporated in a family of power ultrasonic generators with extensive radiators which is mainly based on the stepped-grooved plate transducer but also includes transducers with cylindrical radiators and with flat plate radiators with reflectors.

The basic structure of such transducers (Figure 1) consists essentially of a piezoelectrically activated vibrator which drives an extensive radiator. The vibrator itself is constituted by a piezoelectric element of transduction in a sandwich configuration and a solid horn which acts as a vibration amplifier. The extensional vibration generated by the transducer element and amplified by the mechanical amplifier, drives the radiator which vibrates flexurally in one of its axisymmetric modes. The extensive surface area of the radiator increases the radiation resistance and offers the vibrating system good impedance matching with the medium. The radiator is generally a vibrating plate of stepped, grooved or stepped-grooved profile. The special shape and profile of the radiator permits the control of the vibration distribution and the radiation pattern in such a way that high directional or focusing radiation can be obtained in order to produce high-intensity acoustic levels [1].

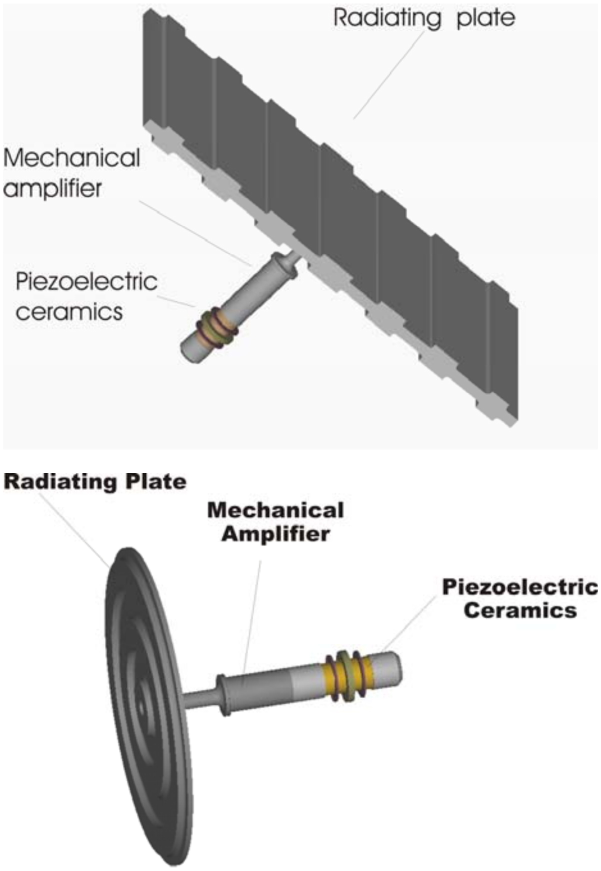

Figure 1. Circular and rectangular stepped-plate transducers

Different prototypes of circular and rectangular stepped-grooved-plate directional and focusing transducers were developed for the frequency range 10-40 kHz and power capacities up to about 1 kW. The main characteristics of such transducers can be summarized in the following table:

Table 1.

Electroacoustic efficiency	75-80%
Directivity (3dB beam width)	<2º
Power capacity	1 kW
Frequency range experimented	10-40 kHz
Maximum intensity levels	170 dB

The implementation of such different types of transducers and the corresponding electronics has been essential for the advancement in the establishment of new sonoprocesses for environmental and industrial applications [2]. We will refer in this paper to some of them, such as air cleaning, dewatering of sludge in sewage treatment and defoaming.

AIR CLEANING: FINE PARTICLE REMOVAL FROM INDUSTRIAL FUMES

Removal of fine particles (smaller than 1-2 microns) from industrial flue gas emissions is one of the most important problems in air pollution control. In fact, these tiny particles constitute a major health hazard because of their ability to penetrate deeply into the respiratory tissues and their generally toxic character. In addition such particles make up a significant proportion of the particulate emissions and the conventional filtration systems, such as the electrostatic filters, are inefficient for these sizes.

Therefore, an improved technology is needed, especially at the present moment in which new more stringent controls have been introduced to protect the environment and the climate following the recommendations of Kyoto and Copenhagen Conferences.

As is well known, the application of high-intensity acoustic fields to an aerosol may induce collision and agglomeration of the suspended particles, giving rise to larger particles. Therefore, acoustic agglomeration represents a promising procedure to precondition fine particles in order to be efficiently removed by conventional filters. Acoustic agglomeration has been long time studied but the development into industrial application has been slow, probably because of the lack of adequate full scale macrosonic agglomerators.

For efficient acoustic agglomeration the main requirements to be covered are: high-intensity acoustic fields (usually more than 150 dB), homogeneity of the acoustic field over the volume to be treated and operating frequency adapted to the particle size for maximum efficiency.

At pilot plant stage, a multifrequency agglomeration chamber of 3.5 m long and 0.5x0.7m in section, with four circular stepped-plate transducers of 10 and 20 kHz was developed and tested. The chamber was designed for flow rates up to 2000 m^3/h and was tested as a fine particle preconditioner with an electrostatic filter for the treatment of fumes produced by a fluidised bed coal combustor.

The results of such tests (Figure 2) showed that the introduction of the acoustic system improved the precipitation efficiency of the electrostatic filter, obtaining additional reductions of the fine particle of the order of 40% (in certain cases this value arrived up to 70%) [3].

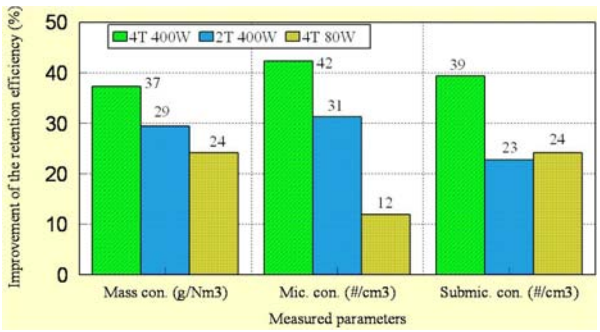

Figure 2. Reduction of particle emission

This can be considered a significant effect particularly bearing in mind the very small size of the particles, the narrow gain margin let by the electrostatic filter, the low level of energy applied and the very short treatment time.

This system was tested at industrial scale and can be applied to any industrial process where agglomeration and precipitation of airborne particles is required.

SLUDGE FILTRATION

One of the present requirements in sewage treatment is the dewatering of sludge [4]. To that purpose, conventional filtration techniques are not satisfactory because the phenomenon of fouling or blocking the pores is frequently produced resulting in slow processing rates or in flux decline. As a consequence the residual moisture in the filter cake always remains high, and it is very difficult to remove.

High-power ultrasonic processing may be effective in the release of the residual moisture. Ultrasonic energy directly coupled to the sludge causes the alternating stresses an effective deliquoring by creating channels for moisture migration.

Filtration of finely dispersed sludge is generally made by using a porous filtration medium and applying a driving force to achieve flow through it. The solid particles are retained on the surface or within the filtration medium while the liquid passes through it. Vacuum, pressure or centrifugation can be used to force the fluid flowing.

To improve conventional rotary vacuum filtration, power ultrasonics is applied directly coupled to the cake formed into the filter surface during the process.

The alternating stresses generated by the ultrasonic vibration improve the effect of the vacuum pressure. In fact, while the static pressure alone may block pores and channels, the alternating compressions and depressions produced by the acoustic wave into the cake may open them and facilitate migration of the liquid. Different effects seem to play a role in the mechanism of ultrasonic dewatering. First of all, the acoustic stresses produce a kind of “sponge effect” which facilitates the migration of moisture through natural channels created between solid particles. In addition, air bubbles trapped in micropores can grow by rectified diffusion producing displacement of the liquid. Cavitation may be another important effect to separate colloidal attached moisture.

By applying the ultrasonic technique reduction of the interstitial moisture of about 25% (Figure 3) is achieved with less than 10 seconds of treatment and acoustic intensities in the range of 0.1-1 W/cm^2

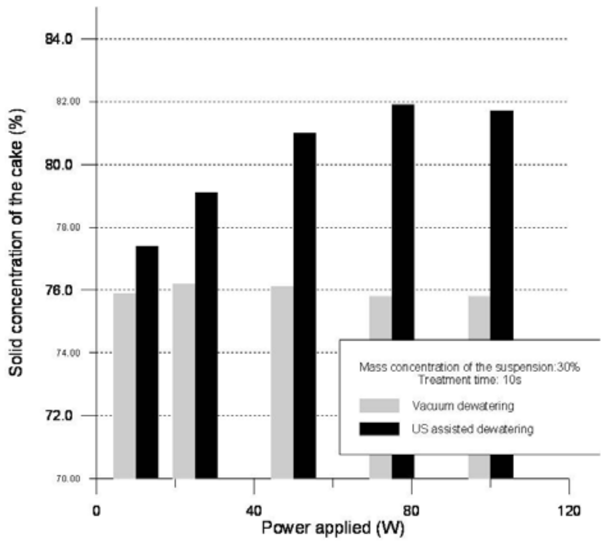

Figure 3. Reduction in moisture content

Therefore the application of ultrasonic energy allows to obtain whole sludge dewatering higher than 80%. Such result represents a substantial improvement on the conventional dewatering techniques [5].

Figure 4. Ultrasonic Defoaming System

ULTRASONIC DEFOAMING

Foam is generally an unwanted by-product in industrial processes because it causes difficulties in process control and in equipment operation. A typical example is in the fermentation industry where foam represents one of the biggest problems**.** There are several methods to control foams, the most efficient is the use of chemical anti-foaming agents but they contaminate the product. Other methods involving mechanical, thermal or electrical devices are not very effective [6].

The application of high-intensity ultrasonic waves represents a clean and efficient procedure to break foam bubbles. The potential use of ultrasound for foam breaking was first introduced by using acoustic defoamers based on aerodynamic acoustic sources. However such devices have many disadvantages as the need for high air generation capacity, control and sterilization of the air-flow and they often involve high energy consumption.

A new ultrasonic defoamer is based on the use of the stepped-grooved-plate high-power transducer for air-borne focusing ultrasound. Such system has been successfully tested for the control of excess foam produced in fermenting vessels and in other reactors of great dimensions as well as on high-speed canning and bottling lines during the filling operation. Ultrasonic defoaming systems for frequencies of 21, 26 and 40 kHz to be used statically or dynamically by means of rotational or scanning devices are presently manufactured by the specialised Spanish company PUSONICS and worldwide commercialized [7].

CONCLUSIONS

The sonoprocesses reviewed in this paper clearly demonstrate that the potential of the use of high-intensity ultrasonic waves is linked to the development of the proper specific technology for the medium to be treated. In addition such technology has to be scalable for industrial application.

Sonoprocessing in gases is an unexploited field that starts to be opened with the new technology of the stepped-grooved plate transducers.

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