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Bubble Power and Ultrasound

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Abstract: If anyone begins to think about the term ultrasound, the first thing that comes to the mind is the fact that it is used in animal communications (e.g., bat navigation and dog whistles). Also, one may start to think that this term is familiar in daily life and has been used many times in medicine applications for foetal imaging, (SONAR). However, many questions come to the mind, such as, what is happening when ultrasound is transmitted through the body? If it is sound, he asks himself why I cannot hear any sound? The interaction between bubbles and sound waves in liquids leads to the phenomenon of acoustic cavitation. The meaning of the word cavitation is not known or understandable for many people. This paper is to contribute the knowledge ofbubble power under the action of ultrasound and to give a more comprehensive description of this phenomenon.

Keywords: Bubble power, Cavitation, Ultrasound.

Introduction

To explain what the sound means, a brief introduction to the principles of sound and acoustics is required. Sound is a sequence of waves transmitted as pressure wave, compression and rarefaction, which propagates through a medium and must cause some excitation in that medium.Sound can be classified in different categories, depends on the characteristic frequency. The human ear can hear sound of a frequency from 20 Hz to 20 kHz. Inaudible sound can be divided into infrasound and ultrasound.

Infrasound is sound with a frequency too low to be detected by the human ear, i.e., $f < 20$ Hz down to 0.001 Hz. It is characterized by the ability to cover long distances and get around obstacles with little dissipation.
This frequency range is utilized for different applications, e.g., monitoring earthquakes and petroleum formations below the ground.

Ultrasound is sound with a frequency higher than the upper limit of human hearing, i.e., $f > 20$ kHz. Some animals, such as dogs, dolphins and bats, have an upper limit higher than the human ear limit and therefore, they can use ultrasound for communication and navigation.

Also, the ultrasound can be subdivided into two classes, based on its application. The first one is non-destructive ultrasound, characterized by a frequency range between 2 and 10 MHz. Non-destructive ultrasound has low intensity and it is used for a variety of relaxation phenomena. The second class is a destructive one, characterized by a frequency range between 20 and 900 kHz, and of high intensity. Destructive ultrasound is used for different medical and industry applications [1, 2].

Bubble, Ultrasound, and Cavitation

The story started in the last years of the eighteenth century,when the complications with design and development of ship propellers happened: The plans at that time were to control and achieve higher ship speeds.
In 1894 the British torpedo-boat destroyer “Daring” sailed less than a fast speed design, the actual speed was 24kn, while it was expected to be 27 kn. The engineers thought the reduced speed was due to the formation of water vapour bubbles on the blades, and in that way the propeller performance and consequently the speed was reduced. At the same time, another ship met similar problem and it was realized that, when the propeller starts to work, high pressure gradients occurred, and liquid around the propeller was torn apart and bubbles were formed.

A large part from the engine power was consumed in the formation of these bubbles instead of moving the ship forward. The second problem appearing was that the implosion of these bubbles was accompanied by high pressure and temperature and as a consequence, erosion and pitting of the propeller blades occurred. Following that a proposal by R.E . Froude (1895) to explain and define this phenomenon of thisharmful propeller behavior was called “Cavitation” derived from the Latin word “cavus” which means “hollow” in English.

Nowadays the term “Cavitation” is a widely accepted phenomenon in different branches of science and technology and it is used for many different purposes [2].

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Depending on the principles of the cavitation phenomenon, there are different types and the most important ones are illustrated in Fig. 1.

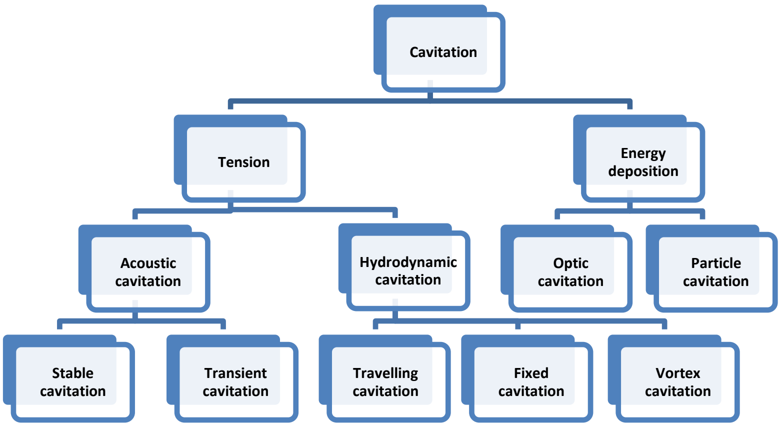

Fig. 1: Classification scheme for different types of cavitation

Acoustic Cavitation

The bubble motion during the acoustic cavitation phenomenon can be divided into stable and transient cavitation. Stable cavitation is defined by the creation and oscillation of gas bubbles in a liquid. While transient cavitation comes up when bubbles collapse and release a large amount of energy [3].

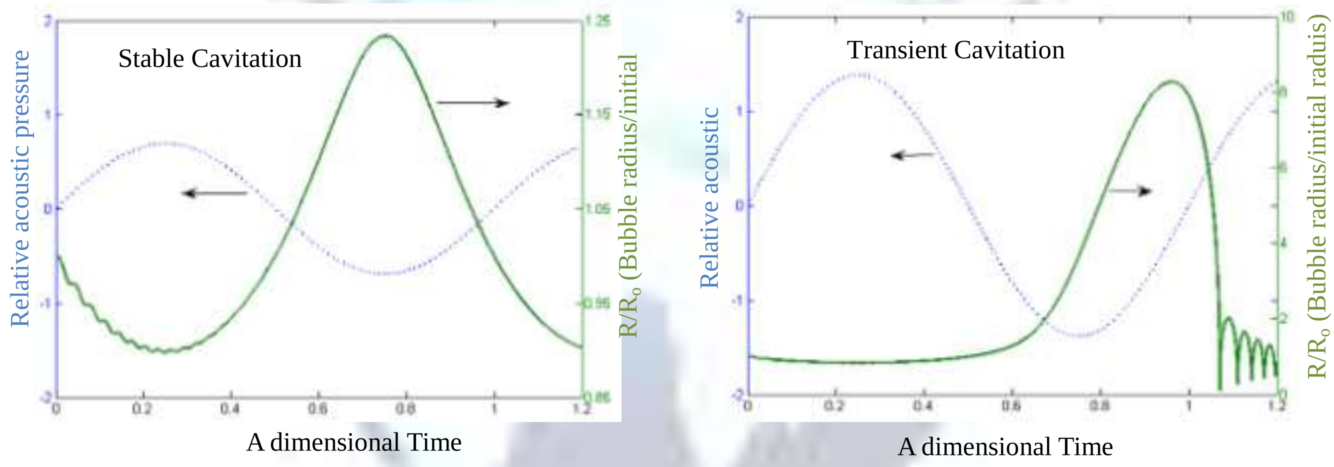

Fig. 2: Acoustic pressure and bubble radius versus time for the two types of cavitation. Adapted from Ref. [4]

How Does Acoustic Cavitation Work

The ultrasound is a type of sound wave and it is propagated in a way of a series of compression and rarefaction waves induced in the molecules of the medium through which it passes. At sufficiently high power the rarefaction cycle may exceed the attractive forces of the molecules of the liquid and cavitation bubbles will form.

During the acoustic cavitation, bubbles produce high power and this phenomenon has caught the attention of scientists and researchers and is still the focus of many research works.

After the formation of the bubbles in the liquid, the sound pressure field (Ultrasound) forces these bubbles into nonlinear oscillation.During this process, the bubble is compressed which leads to generation of short flashes of light periodically and production of very high pressure and temperature at the end of the collapse event. These parameters with high values can be harnessed in different medical and industrial applications.

Ultrasound Applications and Background

The first commercial and practical use of an ultrasonic device appeared around 1917 and was the first "echo-sounder" invented and developed by Paul Langévin (1872-1946). He was born in Paris and was a contemporary to Marie Curie and Albert Einstein. The original "echo-sounder" eventually became underwater SONAR for submarine detection during the Second World War.

The early "echo sounder" simply sent a pulse of ultrasound from the keel of a boat to the bottom of the sea from which it was reflected back to a detector also on the keel. The distance to the bottom could be measured from the time taken for the signal to return to the boat. If a foreign object (e.g., submarine) was between the boat and the bottom of the seabed an echo signal would have receivedat a time different from the calculated time. Arapid development of use a soundtechnology in various fields has occurred since then.

Modern Ultrasound Applications

Ultrasound in Medical Applications

1. For diagnostic use, ultrasound provides a technique for human body scanning especially in foetal imaging. Basically all imaging from the SONAR device used in medical applications isconsidering the same pulse-echo type as developedfor electronic devices. The refinements enable the equipment not only to detect reflections of the sound wave but also much more subtle changes in the media through which sound passes (e.g., those between different tissue structures in the body).

This type of ultrasound wave which is used primarily in this type of application with high frequency (in the range 2 to 10 MHz) and is called Non-destructive ultrasound.

2. It is found that non-destructive ultrasound can be used in wide rangesofrelaxation phenomena and it is considered as an alternative to massage.The induced ultrasound waves make the tissues to moveand it has been found that improves muscle physiology and is more effective than the rubbing of a masseur.

Then, the enormous development which happenedin the modern life has led to more interest of using sound technologies and discovers more applications and phenomena. The acoustic cavitation is considered as one of the more recentphenomenaused in the present time and basically the second class of ultrasound(Destructive ultrasound) and bubble power are used in applications.

3. Latest technologies in fat loss. This is a specific mechanical effect called “Acoustic Cavitation” which affects the medium through the generation and subsequent destruction of cavitation bubblesacting specifically on the fat cells.

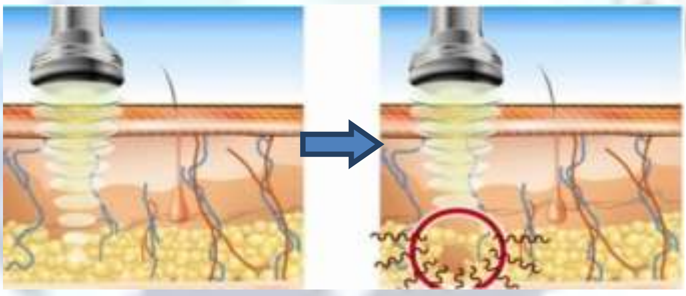

Fig. 3: Fat loss using acoustic cavitation

4. In modern days, using destructive ultrasound has been found very successful in the removal of kidney stones. This technology uses the mechanical effect of the ultrasound, so that the stone can be completely destroyed and excreted via the patient’s urine, without the need for surgery.

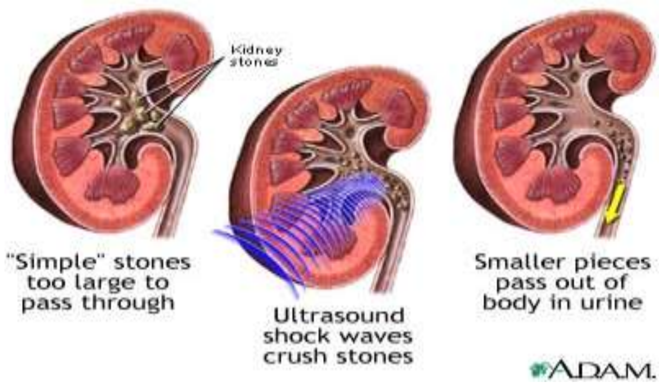

Fig. 4: Removal of kidney stonesby acoustic cavitation mechanism [5]

Ultrasound in Industry Applications

1. Ultrasonic Cleaning

In industry, ultrasound has been used forcleaning of surfaces,in different areas such as electronics, optics and medicines. Usually theefficiency of ultrasound cleaning depends on the nature of thematerial to be cleaned.
For example, no perfect cleaning will be achieved for materials like rubber which partially absorb the sound.On the other hand the method is highly effective for sound-refracting itemsmade of glass and metal.
Ultrasonic cleaning isachievedby effects of cavitation bubbles i.e., acoustic cavitation whichslowly destroy the small particles on thesurface.

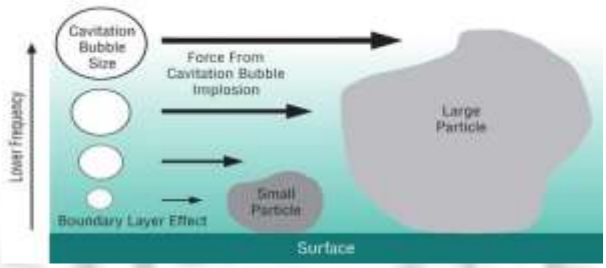

Fig. 5: Ultrasonic cleaning [6]

In industrial applications, cleaning of nanoparticles with dimensions smaller than 50 nm is becoming a major challenge in semiconductor manufacturing. The goal of each cleaning step is to maximize the particle removal efficiency, while minimizing the damage of the device. Acoustic cavitation induced cleaning has shown great promise in meeting these requirements [7].

2. Ultrasonic Welding

Ultrasonic welding technique is a major application of ultrasound at low frequency in industry today. It has the advantages of not involving long heating and cooling cycles compared to more traditional methods. Welding of plastics in this manner also provides a weld with a high joint strength that is equivalent to between 90-98% of the normal material strength.Application of such technology is not just limited to plastics, it has also been used to paint tins and weld aluminium, which is extremely difficult by more conventional means due to the hard oxide layer [8].

3. Sonoluminescence phenomenon

Sonoluminescence (SL) is the phenomenon of light emission associated with the collapse of bubbles oscillating under an ultrasonic pressure field. Sonoluminescence phenomenon can be divided as follows: Single Bubble SonoLuminescence (SBSL) and Multiple Bubble SonoLuminescence (MBSL) [9]. The first one characterizes the emission of light from a single acoustically driven bubble in a liquid. On the other hand, the second type refers to the light emitted by multiple bubbles at higher acoustic pressures. Single bubble and multibubblesonoluminescence in water, means that a bubble at specific conditions (depending on the initial bubble radius, bubble contents, liquid properties and acoustic field properties) can be emitted during collapse by flashes of light in picoseconds interval of time. These flashes of light have intensive ultraviolet light, which activate the catalysts to decompose the organic compounds in water. Thus, the researchers and scientists continue to study this phenomenon experimentally to find out reach the conditions that give the highest flashes in water to apply this phenomenon in the water-treatment techniques.

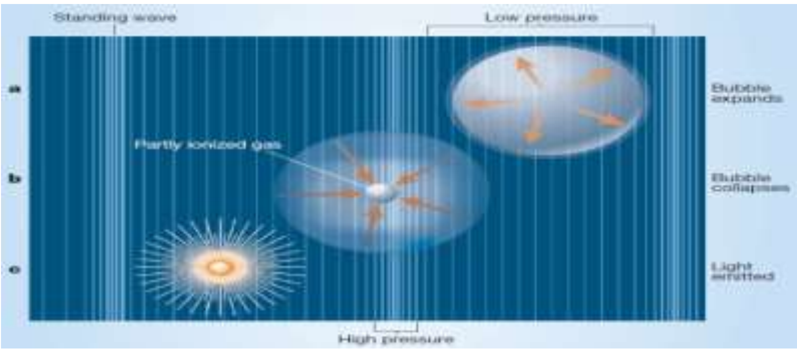

Fig. 6: Single bubble sonoluminescence SBSL. Adapted from Ref. [10]

4. Sonochemistry

Sonochemistry is a chemical reaction starts by action of an oscillating cavitation bubble [11]. The study of sonochemistry is the application of ultrasound waves on chemical processes. The acoustic cavitation phenomenon is the principle of sonochemical effects in the chemical systems. Recently, Sonochemistry has reached powerful growth in different fields such as chemistry and environmental Protection.

Conclusion

The principle of using ultrasonic waves in producing bubbles in liquids (Acoustic cavitation phenomenon) is essentialin many areas of science and technology.The study ofthis phenomenonis an open problem of criticaleffectsin the development of different applications of high power ultrasound in industry and medical applications. The bubble in acoustic cavitation produces very high pressure and temperature during collapse. As a result of the intensive compression of the bubble content during the collapse in liquids under ultrasound, temperatures can approach thousands of degrees celsius, thusreaching the conditions on the surface of the sun. Also, the pressures can increase up to hundreds of atmospheres, approaching condition which issimilar to the pressure at the bottom of the ocean. This article gives anexplanation of the principle of acoustic cavitation phenomenon and provides basic comprehensive information to the researchers who like to simulate and study this field.

Acknowledgments

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