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TEMPERATURE DEPENDENCE OF SINGLE-BUBBLE SONOLUMINENCES (SBSL)

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Abstract

This paper presents an experimental documentation of production of Single-bubble Sonoluminescence (SBSL) and its temperature dependence. The sonoluminescent bubble experiences continuous rapid contractions and expansions with precise regularity. The intensity of light emitted by bubble is depending on the bubble size. The main purposes of this research are to investigate the luminescence intensity and the maximum bubble size with variation of water temperature. In this study it has been observed that the luminescence intensity and the bubble size are inversely proportional to the water temperature. The size of the bubble was measured by Mie-scattering and light intensity measured by Photo-Multiplier Tube (PMT).

Key words: Sonoluminescence, Single-bubble Sonoluminescence (SBSL) and Temperature dependence.

1.INTRODUCTION

Sonoluminescence (SL) is the production of visible light by a gas bubble that is suspended in fluid (normally water) by an acoustic standing-wave field. Presently understanding if the phenomena suggested that Sonoluminescence may result in temperatures of over 10^5 K (which approaches the temperature found in the solar corona), such a high temperatures makes the study of Sonoluminescence especially interesting for the possibility that it might be a means to achieve thermonuclear fusion. If the bubble is hot enough, and the pressures in it high enough, fusion reactions like those that occur in the Sun could be produced within these tiny bubbles. Pressure of over 10^{12} Pa (close to the pressure at the center of the planet Jupiter), the wavelength of the emitted light is short – the spectrum extends well into the ultraviolet i.e. light emission of less than 10^9 s duration and the concentration of mechanical energy of up to 10^{12}, The mystery of how a low –energy-density sound wave can concentrate enough energy in a small volume to cause the emission of light is still unsolved. In Sonoluminescence, a 10μm diameter of bubble (i.e. a bubble with a diameter of about 1/10 the width of a human hair) oscillating in an audio frequency, ultrasonic field synchronously emits on the order of a million photons in a short pulse each acoustic period. The mechanism for the light emission is still not completely understood and is being investigated by research groups around the world. There is general agreement that the violent collapse of a micron size bubble to its hard core limit is at the heart of the light emission process.

There are two types of Sonoluminescence that have been discovered to date. There are: (1) Multiple- bubble Sonoluminescence (MBSL), and (2) Single-bubble Sonoluminescence (SBSL). First, Multiple-bubble Sonolumiensecece involved the emission of light from not one, but many bubbles of air trapped in water. Typically, the light obtained from multiple-bubble Sonoluminescence was much weaker that single –bubble Sonoluminescence, which meant that it was not possible to observe the glow in daylight. The complexity of a system which involved many bubbles caused many problems in the formulation of theoretical models of Sonoluminescence, and it is probably this which leads to the lack of interest in futher research. Another one is single-bubble Sonoluminescence (SBSL), a single bubble of air is acoustically levitated in water which is bombarded with sound waves. The bubble is seen to emit light which is visible in a lit room. The bubble varies in size with the pressure of the applied sound field, and the light is emitted as flashes which occur so rapidly that it appears as if the bubble is emitting light continuously.

In 1896 Henri Becquerel discovered that a uranium Salt could darken a photographic plate, and from this effect he went on to discover radioactivity. In 1934 H. Frenzel and H. Schultes expose a photographic plate to acoustic waves generated in a water bath and also observed a darkening of the plate. They attributed that result to luminescence from the sound field-an effect that has come to be known as Sonoluminescence. The luminescence they observed did not result from the sound field directly but arose through a process called cavitation, in which voids filled with gas and vapor are generated within the liquid during the tensile portion of the pressure variation. Single-bubble sonoluminescence was discovered in 1989 by Felipe Gaitan, then a gradute student at the University of Mississippi working with Larry Crum. Crum had seen hints of light emission from a single bubble in 1985, and Gaitan’s objective for his thesis was to search systematically for it. Gaitan was carrying out a set of experiments on the oscillation and collapse of bubbles, using a flask of liquid lined with transducers tuned to set up an acoustic standing wave at the resonant frequency at the jar. When the pressure amplitude of the sound waves is larger than the ambient pressure, the pressure in the flask becomes negative, putting the liquid under tension. At large enough tension, the liquid breaks apart (cavitation),creating unstable bubble clouds collapse with enormous force, powerful enough to do serious damage to the surfaces of solid bodies in their vicinity.

2. SONOLUMINESCENCE PROCESS

Sonoluminecence is the conversion of sound into light. Ultrasonic waves are aimed at an air bubble in a small water cylinder. In this process the bubble is trapped at a pressure node which is located at an antinode of sound. Once this bubble is trapped, it is driven at a great enough amplitude to cause the bubble to swell and shirk at regular cycles corresponding to the cycle of the sound wave. During this cycles, 50 ps light flashes are emitted about every 30 μs. The bubble swells without the addition of any molecules so at the point of greatest radii the pressure inside the bubble to violently collapse. It has been measured that at the point of greatest size, the bubble is approximately 50 microns and the collapses to only about 0.5 microns. Putterman states that this is the smallest size the bubble can become because at this point the repulsion forces between the gas atoms is great enough to prevent further collapse. Putterman further explains that the minimum size of the bubble is determined by the van der waals forces of the atoms at the core of the bubble. It is during this collapse that the light is emitted. This is due to the adiabatic compression of the gas trapped inside of the bubble.

A simple Schamatic diagram is shown in Fig. 1 to understand the Sonoluminescence process.

(a) The bubble starts out at a size around 5 microns (millionths of meter);
(b) Then it expands to a maximum size (not to scale) of about 50 microns. At this larger size there is a near-vacuum inside the bubble because of the relatively few air molecules present. This low-pressure near-vacuum region is surrounded outside the bubble by a much higher-pressure region, which causes.
(c) A catastrophic collapse of the bubble to between 0.1 and 1 micron. During this compression phase a flash of light.
(d) Emerges from the bubble.

Fig. 1. Schematic diagram of Sonoluminescence Process.

3. EXPERIMENTAL SET-UP AND PROCEDURE

The experiments were carried out in the Gas-dynamics Laboratory, Department of Aerospace Engineering, Nagoya University, Japan. The experimental set-up is shown in Fig. 2 (Schematic) and Fig.3 (Photograph).

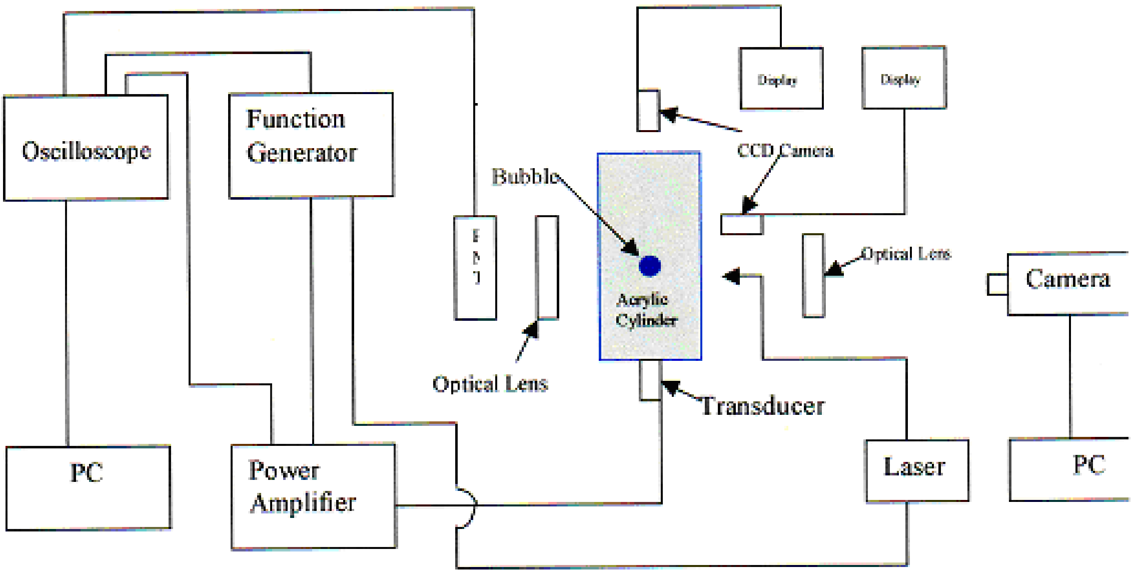

Fig. 2. Schematic diagram of experimental set-up.

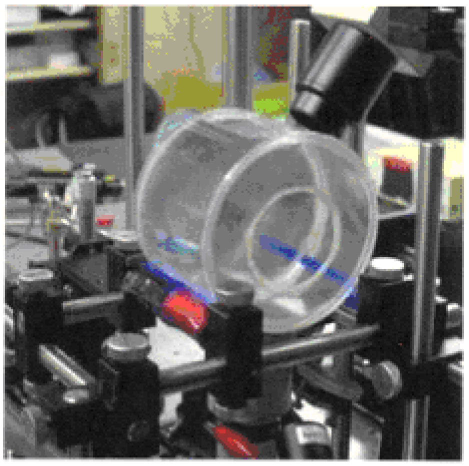

Fig.3. Photograph of Experimental set-Up

For conducting the experiment the following procedure were followed. De-gas the water: This process is commonly known as degassing. In this experiment the water was boiling for 20-30 minutes and sealing the container as soon as the boiling stopped. And pour the de-gassed water into the acrylic cylinder. And turn on the temperature controller, fix-up the working temperature and wait until the working temperature reach to the inside acrylic cylinder water. Then turn on all electronic device i.e. Function generator, Power amplifier, PC and Oscilloscope. Insert air into cylinder water by syringe and create bubble, trap it, adjusting frequency and amplitude and see it glow. When looking at the cylinder for the bubble, it is convenient to be in a dark place with a light source behind the flask. This makes the finding of the bubble easier. Once the bubble is found, it can easily be found at other times. Adjust the frequency and amplitude for bubble stability. When the bubble is stable and luminescence, make the experimental from room dark and turn on Photo-Multiplier tube, the

Oscilloscope will show the luminescence intensity in graphical from and transferring data from oscilloscope to PC and save it.

4. EXPERIMENTAL RESULTS

The initial goal of this study was to investigate the intensity of Single Bubble Sonoluminscence (SBSL) with variation of liquid (water) temperature and the final goal was to measure the maximum bubble size at different liquid (water) temperature, i.e. temperature dependence of Single Bubble Sonoluminescence (SBSL). The goals were achieved by measure the luminescence intensity as a function of voltage (Photograph of Bubble). Typical outputs of PMT and bubble photograph are shown in Fig. 4 and Fig. 5.

During the first experiment, it was found that the luminescence intensity depends on liquid (water) temperature and it is about inversely proportional to square root of liquid (water) temperature, i.e. as the liquid (water) temperature was increasing the intensity of light emission from bubble decreased which is shown in Figure 6 and it follows the following fitted curve.

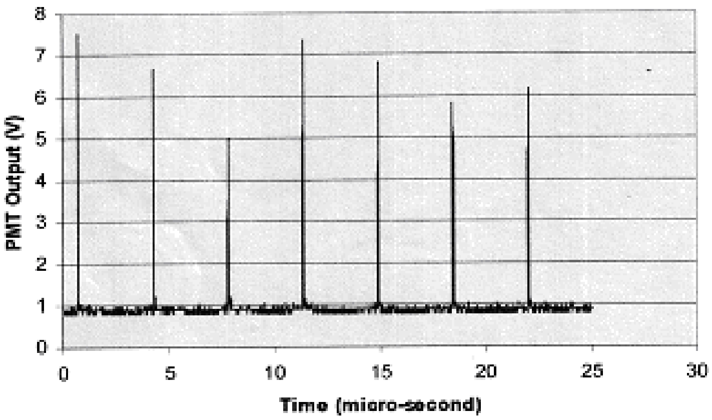

Fig. 4. Typical PMT Output in Oscilloscope at 8.2°C water temperature.

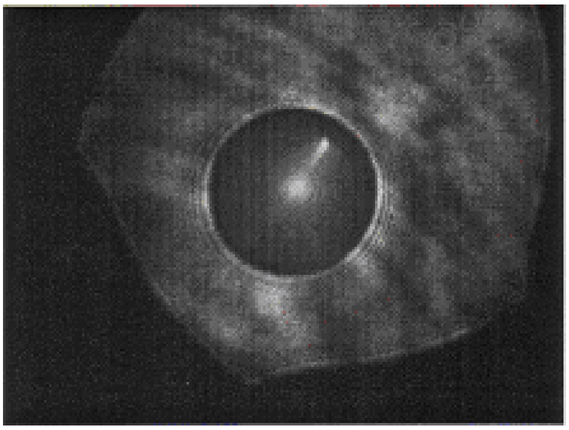

Fig. 5. Maximum Bubble Size Photograph at 7.5° water temperature.

During the second experiment, it was also found that the maximum bubble size depends on liquid (water) temperature and it is about inversely proportional to the cubic root square of liquid (water) temperature, i.e. as the liquid (water) temperature was increasing the maximum bubble size decreased which is shown in Figure 7 and it follows the following fitted curve.

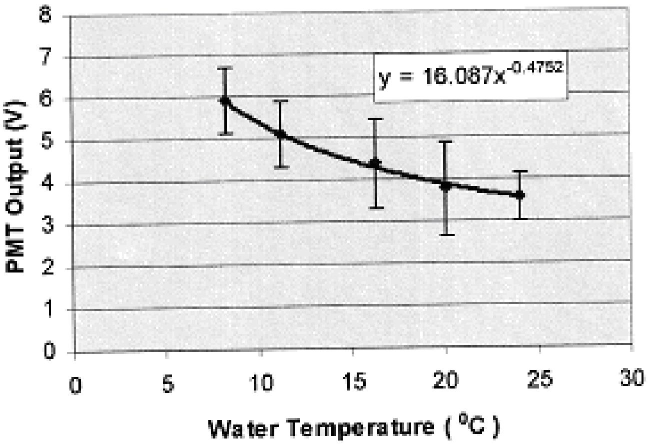

Fig. 6. Water Temperature Vs Luminescence Intensity Curve.

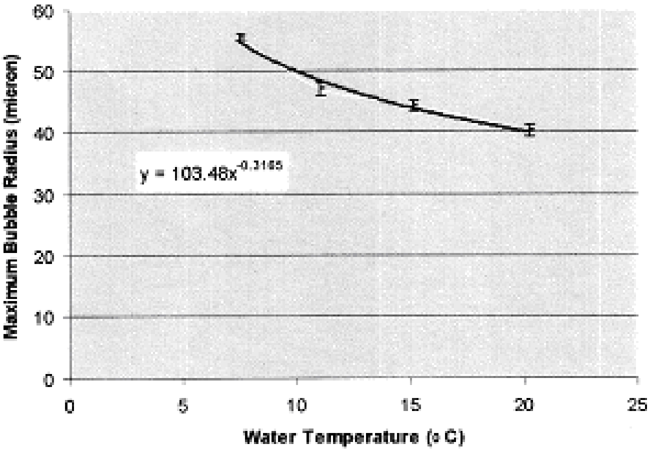

Fig. 7. Water Temperature Vs Maximum Bubble Radius Curve.

5. DISCUSSIONS

From this study it has been shown that the Sonoluminescence intensity decrease with increasing the liquid (water) temperature, i.e. the bubble is brighter at low water temperature than higher temperature. The luminescence intensity is the function of temperature of the bubble ($I_t=I_t(T_{bubble})$) and it is directly proportional to the inside bubble temperature. If the inside temperature of the bubble increases, the emission of light from bubble will be increased. At low water temperature the bubble contains less air gases, such as Nitrogen, Oxygen, Carbon dioxide etc., expect noble gas (Ar), compare tohigher water temperature. Because at low water temperature most of the air gases, such as Nitrogen, Oxygen, Carbon dioxide etc., are dissolved into water. So in the same bubble the ratio of noble gas (Ar) increases but decreases the ratio of the others air gases (such as Nitrogen, Oxygen, Carbon dioxide etc.). As the bubble compressions and expansions are adiabatic, the change in temperature of bubble is depends on the degree of freedom of presence air gases inside the bubble at the same internal energy. This change in temperature is inversely proportional to the degree of freedom, i.e. increase the degree of freedom decrease the bubble inside temperature. The degree of freedom of noble gas (Ar) is 3 and others air gases (such as Nitrogen, Oxygen, Carbon dioxide etc.) are 5. So, at the same internal energy the temperature of Ar. is higher than others. For this reason the bubble is brighter at low water temperature than higher water temperature. As the bubble collapses, the pressure does work on the decreasing volume, which energy goes to increasing the kinetic energy of moving fluid. The bubble is a spherical cavity and let its initial radius R_0 in an infinite reservoir of water at pressure P.

When the bubble collapsed to radius R its volume changed by amount

$$v = \frac{4\pi}{3}(R_0^3 - R^3) \qquad (1)$$

So the work done is

$$KE = W = Pv = \frac{4\pi}{3}(R_0^3 - R^3) \approx \frac{4\pi R_o^3 P}{3}$$

Where the approximation holds once $R \ll R_o$

Kinetic Energy of Bubble

$$KE = \frac{1}{2}kT^2 \qquad (2)$$

Where T is the inside temperature of bubble.

In the second experiment is has been found that the maximum bubble radius decreases with increases the water temperature because from equation 2 and 3 it is clear that the maximum bubble radius is proportional to the inside bubble temperature with some constants. Previously it has discussed that the inside bubble temperature is a function of water temperature, inversely proportional, i.e. if the water temperature increases then the inside bubble temperature will be decreased. So, it can say that the maximum bubble radius is also a function of water temperature and it’s inversely proportional. For this reason the maximum bubble radius decreases water temperature.

As the maximum bubble radius decrease with increasing water temperature, from equation 2, it is easy to understand that the kinetic energy must decrease with increasing water temperature. Suppose that all the kinetic energy of the collapsing bubble is converted to photons with the spectrum $dN \alpha \frac{dE}{E}$. (Bremsstrahlung-like spectrum), Where E is the kinetic energy. The emitted photons are proportional to kinetic energy and kinetic energy is inversely proportional to water temperature. So the emitted photons are inversely proportional to water temperature, i.e. if the water temperature increases, emitted photons will decrease that means the luminescence intensity decrease with increase water temperature as light is emitted in the from of photons. In whole of the experiments in this study, liquid (water) temperature considered ±0.1°C.

6. CONCLUSIONS

The following conclusions can be made after summarizing the present study:
(a) The luminescence intensity depends on the water temperature which is $y = 16.087x^{-0.4752}$.
(b) The maximum bubble radius also depend on the water temperature which is fitted by $y = 103.48x^{-0.316}$.

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