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OPTIMIZATION CONTROL OF CAVITATION SPATIAL DISTRIBUTION IN A DUAL SOURCE SONOREACTOR

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In this paper, the optimization control of cavitation spatial distribution by using of dual sound sources in liquid is investigated experimentally. An experimental system for cavitation spatial distribution control is set up and the “point” cavitation measuring method is proposed, which is a necessity in the optimization control of acoustic cavitations. Three point-measuring methods are adopted. Among them, the iodine releasing method and the aluminum foil erosion method have been improved by us. The trials focus on how facing dual sources promote the spatial distribution optiminum of acoustic cavitations, based on an approach proposed by Moholkar and his co-workers. More intense cavitations have been successfully produced experimentally in areas far away from acoustic sources and less and negligible cavitations produced in the vicinity of the acoustic sources. Improvements have been made to overcome the actual drawbacks in wider space and a simple example is given to show its feasibility. According to the experiments, the optimization of cavitaion spatial distribution can be achieved in industry scale.

1. Introduction

In the past couple of decades, ultrasonics has obtained wildespread applications in industry, such as in non-destructive test, medical diagnosis, high intensity focused ultrasound, nanotechnologies, waste water treatment, and so on [1,2]. Back in the 1920’s, the processing applications of ultrasound were found. Nowadays, such applications have extended to the branches called sonics, sonochemistry, sonoluminescence [1, 3, 4] et al. Those applications are attributed to the acoustic cavitaton, a “magic” phenomenon which induces extreme conditions such as high temperature and high pressure, high density and highly intense shock waves resulting from the collapse of the transient cavitaion bubbles [5].

But, up to now, the aforementioned successful processing applications of ultrasound based on cavitation mechanism are mainly confined to the laboratories. The major shortcoming of ultrasound reactors that has contributed mostly to their poor performance on an industrial scale operation is that cavitation occurs only in the close vicinity of the surface of the sonicator and consequently, severely limits the volume of the active part of the reactor [6,7]. Pandit et al. reported that the introduction of a second sound wave emitted by an ultrasonic horn in a sonoreactor results in better distribution of cavitational activity resulting in uniform yields, minimizing the formation of standing waves and more effective utilization of the reactant volume and dissipated sound energy, and therefore obtain maximum cavitational effects and higher chemical yields[8,9].

In this paper, first the theory of Moholkar et al.[6] are investigated with three “point”(actually, it’s “small area”) cavitation measuring methods are adopted and among them the iodine releasing method and the aluminum foil erosion method have been improved by us, which are prerequisites for spatial optimization control of cavitation. Secondly, the idea of using two or more crossing transducers to carry out the optimization control of cavitation spatial distribution is put forward to carry out the spatial distribution optimization control of cavitation.

2. Experimental setup

As a first step, we observe the oxidation of potassium iodide (releasing iodine method, RIM) [10, 11] and the weight loss of aluminium foil(aluminium foil method, AFM)[12,13] which both were improved by us as the quantitative indicator of cavitation intensity, the acoustic pressure measured by hydrophone method(HM) as qualitative indicator[14-20]. The power input is measured by the electrical power. The experimental setup is shown in Figure1. The transducers are driven by an ultrasonic generator designed by us. The power input and the phase difference between the two transducers can be individually adjusted accordingly.

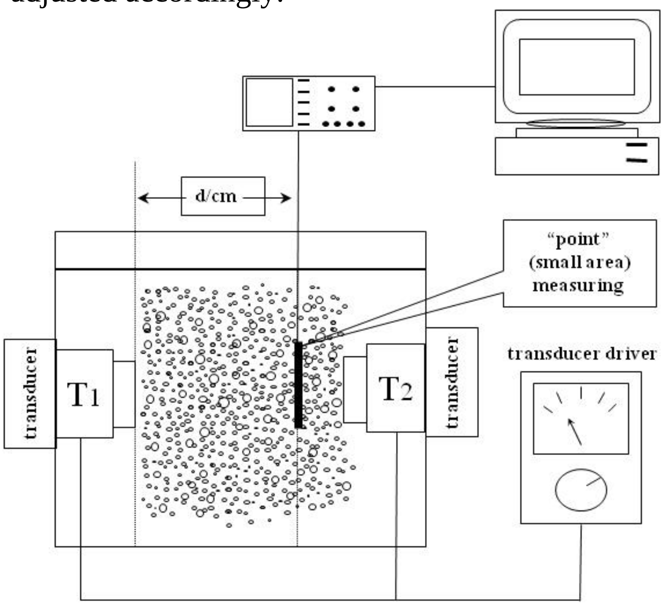
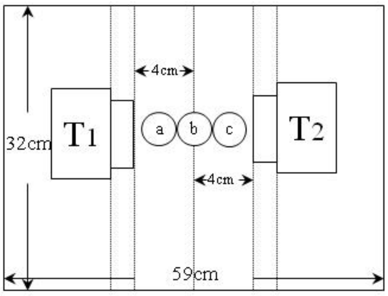


Figure 1. Schematic of experimental setup.

The liquid used is the tap water saturated with air(20oC and atmospheric pressure) in the reactor(59cm×32cm×35cm), the height of the tap water is 25cm. The transducers are driven at 18.5kHz, and the phase difference between them can be adjusted from 0 to 2π . The electrical power input can be adjusted from 0 to 200w respectively.

The acoustic cavitation intensity is measured by the solution of potassium iodide (0.2mol/L, prepared with the deionized water), ultraviolet and visible spectrophotometer (T6 New Century, Purkinje General, Beijing), aluminium foil with the thickness of 10~20 μm , analytical balance (GR202, A&D Company Ltd.), Hydrophone (8103, Bruel &Kjaer), digital storage oscilloscope (Waverunner LT372, Lecroy).

As is said before, the RIM and AFM are improved by us [21]. For RIM, the solution of potassium iodide is filled in the room temperature vulcanized silicone rubber (RTVSR, 1.0cm ID, 2.0cm OD, and 7.5cm height) whose acoustic impedance approaches that of water. In the experiments, the KI solution in the RTVSR is placed in position a, b and c in the reactor as shown in Figure2. For AFM, aluminiun foil (AF) of different shapes and dimensions has been tested. At last, the circular shapes of AF with a diameter of 1.3cm, 2.5cm and 5.0cm have been chosen and investigated respectively and because they perform similarly in cavitation field, for convenience, only the results of 5.0cm AF is given (see Figure3)[21].



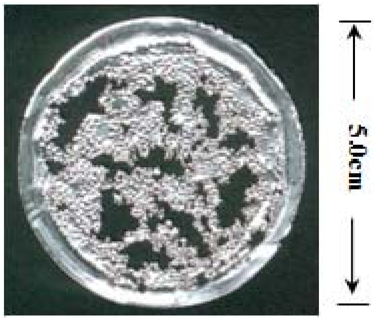
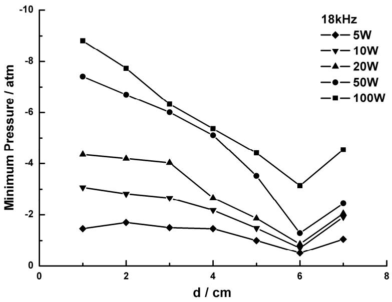


Figure 2. KI solution position in the reactor **Figure 3.** 5.0cm diameter AF eroded by cavitation

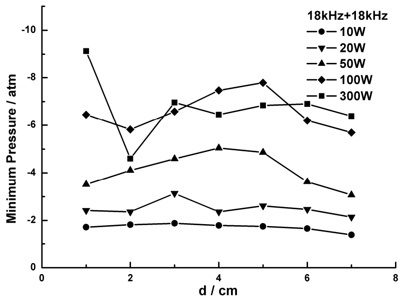
3. Results and discussions

3.1 Hydrophone method

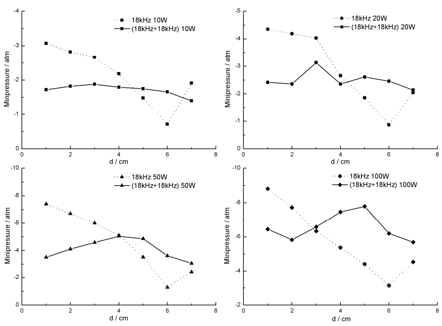
The hydrophone 8103 is placed in the center axis of T1 and T2 and moves away from T1. The distance between T1 and the hydrophone is d as shown in Figure1. The minimum pressure measured by hydrophone is shown in Figure 4. The total power input is the same when the single transducer operates and the dual transducers operate. In Figure 5, the pressure (absolute value) drops drastically for single transducers when the hydrophone moves away from T1 and it becomes worse for higher power input. On the contrary, for the dual transducers, the pressure not only drops little but also rises obviously until the hydrophone approaches T2. For the same power, compared with results of the single transducer, the distribution of the acoustic pressure produced by the dual transducers is more uniform and the absolute value of minimum pressure is lower which can reduce the occurring of "cavitation shield" and cone-like bubble formation [7]. Because the cavitation is produced by acoustic field, therefore the uniform distribution of acoustic pressure is the prerequisite of that of cavitation.



(a)Single transducer operates



(b) Dual transducers operate

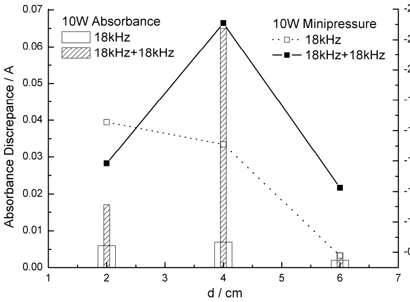


(c) Comparison of single and dual transducers

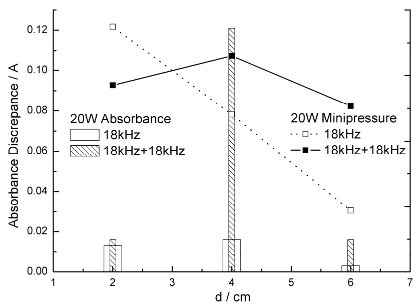
Figure 4. Relationship between minimum pressure and distance d measured by 8103

3.2 RIM

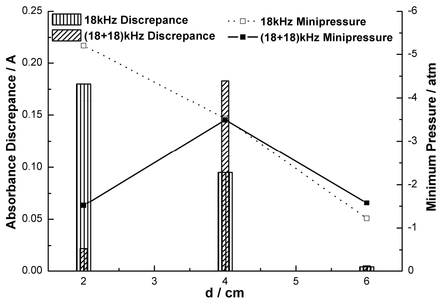
For RIM, the schematic is shown in Figure 2 and the results are shown in Figure5.



(a)10W



(b)20W

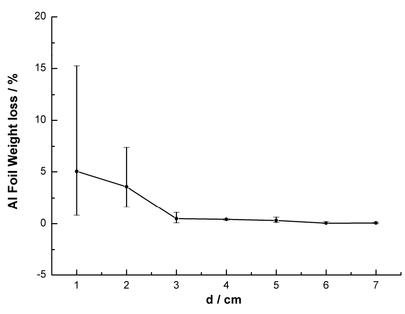


(c)50W

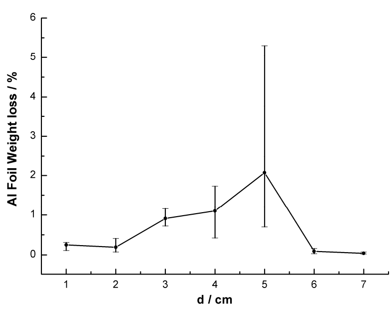
Figure 5. Comparison of RIM and hydrophone method for different power input

The RIM and HM were measured simultaneously. When the solution of KI was subject to the acoustics field in the RTVSR, the hydrophone 8103 was placed in the RTVSR too. The mini-pressure in Figure5 is the average of five measuring result. As shown in Figure5(c), RIM and HM coincide with each other very well. For single transducer, RI is higher when solution of KI is nearer to it and RI drops sharply when away from it. For dual transducer, RI is higher in the middle of the two transducers and negligible in the vicinity of transducers. In Figure5 (a) and (b), when the power input is 10W and 20W, RI is little for single transducer. But in the same power, the RI increases obviously, especially in the middle of transducers. What's more, in these two cases, the agreement of RIM and HM is not as good as that of 50Wcase. This phenomenon may show that besides the effect of the power input, the dual transducers do have the active effect on the RI. The reasons may be that the threshold of RI, i.e. of cavitation and the standing wave is eliminated when dual transducers operate. Tatake el al. explained it's because R_m^3 / t_c is increased [8]. It seems that the mechanism of the phenomenon needs further research.

3.3 AFM

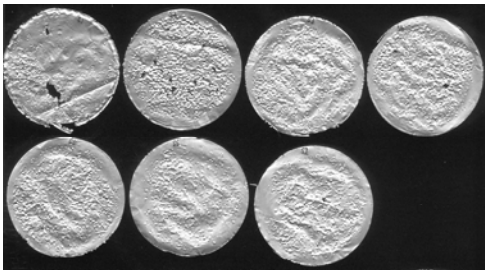


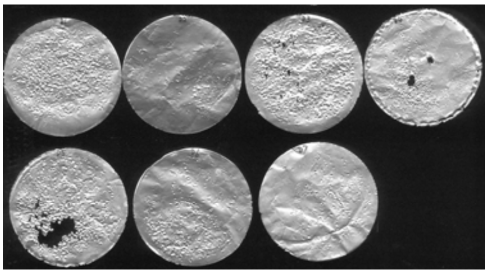
(a) Single transducer



(b) Dual transducers

Figure 6. The AF weight loss with the distance d





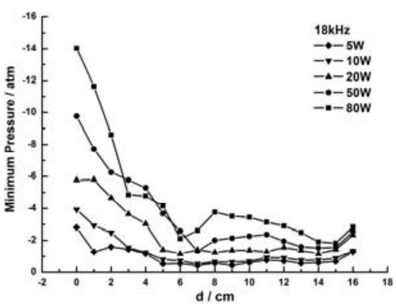
(a) Single transducer (b) Dual transducers

Figure 7. The photos of AF subject to cavitation

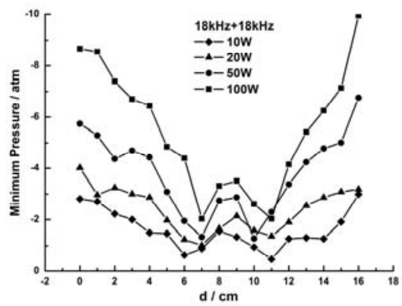
It shows in Figure 6 that for AFM, the experimental result is similar to the RIM and HM: for single transducer, the nearer to the transducer, the higher the AF weight loss. When AF moves away from it a few centimeters, weight loss is negligible. For dual transducers, weight loss is higher in the middle area, and negligible in the vicinity of transducers. From the photos of AF subject to cavitation, besides the weight loss, there are pits on the surface of AF even if its weight loss is negligible. Therefore, to evaluate quantitatively the cavitation better, the pits must be taken into account later.

4. Improments

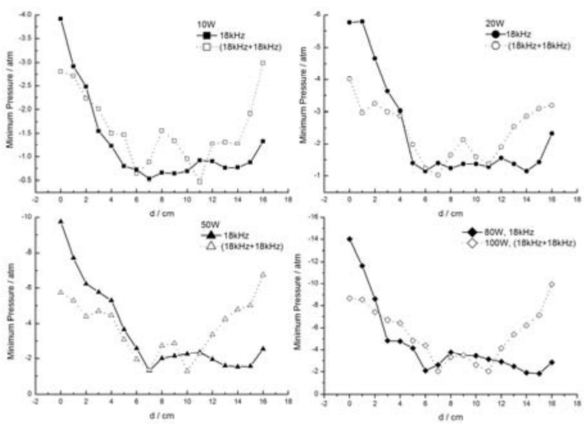
To enlarge the scale-up of cavitation, the distance between the transducer is moved further-16cm. The result of HM is shown in Figure 8. As can be shown, the spatial distribution uniform of the acoustic pressure is worse than that of the above mentioned.



(a) Single transducer operates



(b) Dual transducers operate



(c) Comparison of single and dual transducers

Figure 8. Relationship between minimum pressure and distance d measured by 8103

The phenomenon is slightly surprising because the theory of Moholkar, et al. [6] was based on the well established idea of emitting ultrasonic waves by using of ultrasonic transducers, far into the deep liquid region, increasing the pressure amplitude sufficiently to incept cavitation bubbles. Therefore, we shifted to search for the cavitation field to observe the transducer itself which usually is supposed to be an emitter of the acoustic wave [3]. Then we made some improvement of Moholkar et al[21], see Figure 9. In Figure 9, the distance d_1 is 4cm, and d changes from 4cm to 12cm. T1 and T2 are in phase or out of phase. The AF is placed in position “o”. The total power input is 50W. The result of AFM is shown in Figure 10.

When the two transducers are in phase (phase difference is 0), effective cavitation can be produced only when d is 4cm or 5cm. When they are out of phase, cavitation can be produced in wider space. Due to space limitation, only a simple example about our improvement is given. More work needs to been done and will be introduced in detail later.

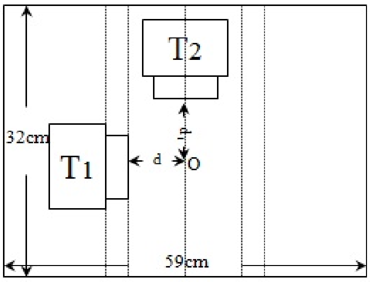


Figure 9. Schematic of orthogonal transducers

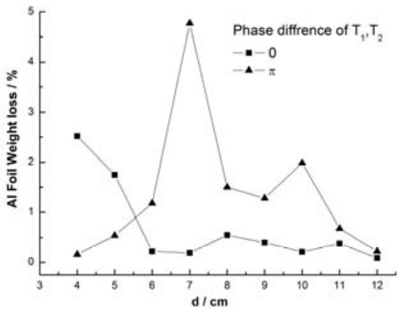


Figure 10. AFM of orthogonal transducers

5. Conclusions

It is well known that cavitation is the major mechanism of sonochemistry and sonoprocessing. The abundant instances of successful applications in laboratory are restricted in industry for the lack of batch equipments. In recent years, more efforts have been made to scale up the cavitation and optimize it. But up to now, the problem has not been solved yet.

In this paper, experiments have been done to improve the situation mentioned above. The idea is proposed by Moholkar et al [6]. During the test, the “point” (small area) cavitation measuring methods are proposed, adopted and improved by us. The reason why the “point” method is emphasized is that it is the prerequisite of spatial distribution control and optimization of cavitation. To use cavitation better, the cavitation must be produced accurately in the position that it is needed.

Generally speaking, more cavitations are easily produced in the vicinity of the transducers that emit the acoustic wave[3,7]. But in our trial, more cavitations have been successfully produced in the middle space of the two transducers, whereas, in the vicinity of the transducer, its occurrence is lesser and negligible. This is very important because it makes it possible for us to produce cavitations in wider area and increase the total power input. Certainly, the drawback of the theory of Moholkar et al. is discovered in practice. Our improvements will make the optimization of cavitation spatial control more feasible in industry scale.

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