Self Sustained Reaction of Nuclear Synthesis under the Action of Ultrasonic Cavitation in Deuterated Liquids

B.F. Kostenko[α1], **I.A. Lomachenkov**[β,γ], **M.B. Miller**[δ], **J. Pribiš** [ε], **A.V. Sermyagin**[δ]

[α] *Laboratory of Information Technologies, JINR*
[β] *University Centre, JINR*
[γ] *Dubna International University*
[δ] *Institute in Physical-Technical Problems, Dubna*
[ε] *Technical University, Košice, Slovakia*

Abstract

At present, in the field of the development of ways of controlled reactions of nuclear synthesis, a nonconventional direction contiguous to inertial confinement of hot plasma — cavitational or bubble nuclear synthesis, is issued. This direction originates from researches of the single bubble sonoluminescence phenomenon, SBSL [1]. Taleyarkhan [2] reported about the observation of products of thermonuclear synthesis, i. e. fast neutrons and tritium activity, using deuterated acetone C_3D_6O as a working liquid, and a foreign source of energetic nuclear particles for cavitation seeding. Though the experimental data are not confirmed yet by independent researches, theoretical investigations remove all doubts about validity of the basic idea [2], [5]. In this paper, an improved self sustaining lay-out of bubble fusion, when the products of nuclear fusion are used as cavitations exciters, is reported. Two alternative ways of the approach realization, are considered. The clue to the new approach lies in the basic features of the two bubble sonoluminescence, TBSL.

1 Introduction

Cavitational, or bubble, nuclear synthesis came from researches of the single bubble sono-luminance phenomenon at which small steam-to-gas bubble retained dynamically in a pressure antinode of acoustic resonator filled with a specially prepared liquid, see Fig. 1. The resonator is pumped up on a ultrasonic frequency (which is usually about 26 kHz in the case of water). The collapsing bubble emits with a clock periodicity extremely short bluish light flashs (see Fig. 2).

If the working liquid is degassing water, the input acoustic energy density must be concentrated by twelve orders of magnitude to produce light. Varying parameters of the resonator and acoustic field, selecting type of a working liquid, one could figure on the achievement of super high temperatures, sufficient for processing thermonuclear reactions. In 2002, Taleyarkhan reported [2] about the observation of products of thermonuclear synthesis, that were neutrons with the energy 2.45 MeV and tritium activity, on application of deuterated acetone C_3D_6O as a working liquid.

In the original installation, Taleyarkhan applied careful acetone clearing from gaseous and solid impurities and its subsequent cooling up to 0° C. On the basic frequency about 20 kHz, the amplitude of excitation of the acoustic resonator was 15 atm, that was ten times higher than for observing SBSL in water. Using a technique of registration of fast

[1]Corresponding author – email: bkostenko@jinr.ru

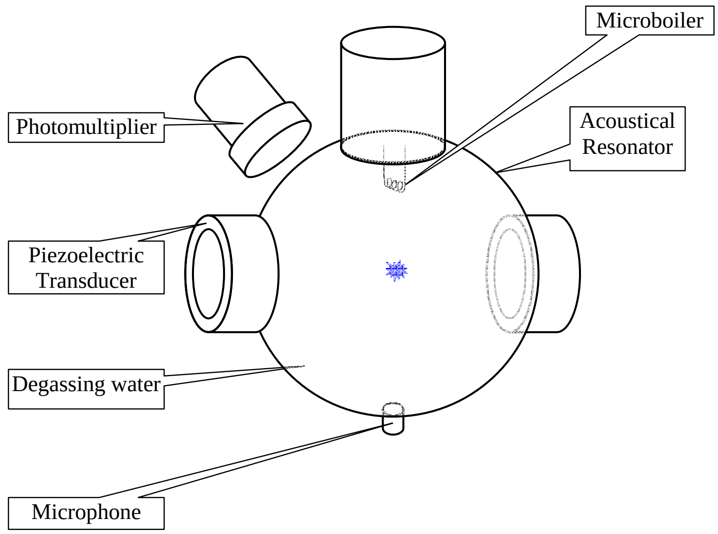

Fig. 1: Layout of resonator for observing of SBSL

neutrons in coincidences to flashes of sonoluminescence allowed one to reduce background substantially. This is important, as for seeding cavitations the fast neutrons with energy 14 MeV from the pulse neutron generator, phased-in with the acoustic pumping, were used.

Fig. 2: Sonoluminescent bubble in the center of acoustic resonator, diameter ≈ 7.5 cm, filled with degassing water (Institute in Physical-Technical Problems, Dubna)

The use of fast neutrons for seeding cavitations allowed one to obtain extraordinary relative change of bubble volume, about $10^{12} - 10^{15}$, which resulted in unprecedented compression parameters at collapse. Subsequently, Taleyarkhan carried out the experiments using other equipment, varying the ways of cavitations excitation, with the help of fast neutrons from radioisotope Pu-Be-source [3], and with the help of alpha-particles arising at decay of natural uranium, which was entered into the working liquid as very concentrated solution of uranyl nitrate [4].

2 Theory

Numerical simulation shows that, in a half-cycle of lowering of the acoustic field up to high negative values, bubbles with the initial size 10 – 100 nm experienced fast growth and achieved the maximum size of about 1 mm. At a phase of compression, catastrophic collapse took place, at which the speed of a bubble wall achieved supersonic speed, of order 100 km/s, with shock waves formation. As a result, at the final stage of collapse, during 0.1 – 1 ps, the super high temperatures, $T \sim 10^8$ K, and pressure, $p \sim 10^{10}$ atm, sufficient for realization of thermonuclear reactions developed on a scale about 30 nm. The choice of acetone as a working liquid was motivated by its high value of breaking strength. Besides, its vapor has high condensation factor and that resulted in a low value of steam pressure on the bubble collapse stage; vapor would, otherwise, hamper the bubble jam.

Mathematical description of the process is based on a numerical solution of the conservation equations for mass, momentum, and energy, which have the form (assuming the spherical symmetry of the bubble is retained):

$$\begin{cases} \frac{\partial \rho}{\partial t} + \frac{1}{r^2}\frac{\partial}{\partial r}\left(\rho u r^2\right) = 0, \\ \frac{\partial}{\partial t}\left(\rho u\right) + \frac{1}{r^2}\frac{\partial}{\partial r}\left(\rho u^2 r^2\right) + \frac{\partial p}{\partial r} = 0, \\ \frac{\partial e}{\partial t} + \frac{1}{r^2}\frac{\partial}{\partial r}\left(u r^2\left(e+p\right) - \lambda r^2 \frac{\partial T}{\partial r}\right) = 0. \end{cases}$$

Here ρ, u, p, T, e, and λ are mass density of compressed fluid, its local velocity, pressure, temperature, density of energy, and thermal conductivity, correspondingly.

Besides, the equations of state and the Hertz-Knudsen-Langmur model for interphase boundary, embracing the condensation factor treatment, were included in the solving system of equations. In particular, for highly compressed fluid, the Mie-Gruneisen equation of state and the Born-Mayer potential function for "cold" component of pressure as well as modern experimental data on shock adiabat for C_3D_6O were used. The processes of dissociation and ionization and corresponding energy loss, an influence of molecular, electron, and ion thermal conductivity were taken into account too. Numerical solution of the system was found using Godunov's method which is characterized by a high stability, what is essential for the shock wave description.

The D-D fusion neutron production rate may be calculated as

$$n = \int dt \int dV \, \frac{n_D^2}{2} < v\sigma(v) >,$$

where n_D is the concentration of the deutrons per volume unit and $< v\sigma(v) >$ is the weighted cross section for the fusion reaction. The neutron production rate turns out to be in a good agreement with the Taleyarkhan experiment.

3 Hypotheses

Actually, the theoretical description of the cavitational thermonuclear fusion is based on some unproved physical hypotheses suggested by R.I. Nigmatulin. According to the first of them, *1) the equations of state for the dissociated phase may be taken the same as for the nondissociated one*, since a noticeable realignment of molecular fragments is not expected to occur during $t < 1$ ps (the so-called frozen shock adiabat is used). Furthermore, it is assumed that *2) electrons in plasma have no time to become as warm as ions* at the picosecond stage of the bubble collapse, and that *3) an additional positive impulse of pressure of order of several tens of atmospheres is formed* in the multi-bubble system.

Estimations of nuclei cooling time by electrons in superdense nonequilibrium plasma formed at cavitation bubble collapse in deuterated acetone were carried out in papers [6], [7]. They completely confirmed the second Nigmatulin's suggestion.

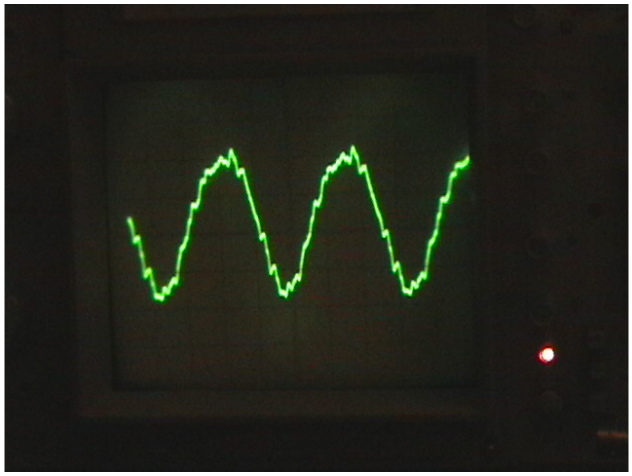

Fig. 3: Signal from microphone attached to resonator. Beside basic harmonic, the higher frequencies exiting during bubble collapse (i.e., ripples), are presented

The third Nigmatulin's hypothesis is still not proved. Earlier was recognized [8], that at SBSL in the resonator, the acoustic field possesses rather complex spatio-temporal structure influencing sufficiently on observable parameters SBSL and its stability. Besides the basic harmonic, which usually is used to pump the acoustic resonator, the acoustic field consists of high-frequency harmonics (see Fig. 3), up to the fiftieth harmonic and above, that are excited in process of bubble collapse. The latter circumstance may be an evidence of complexity of the task to reproduce the results of Taleyarkhan. One of the essential features of his experiments is the creation under the action of fast neutrons, in the central area of the resonator, a primary bubble cluster containing about 1000 bubbles. The structure of this cluster (which can be named as coherent bubble cluster [9]) and its dynamics, as Nigmatulin proposed, are the factors of resonant amplification/suppression of individual bubble collapses and the keys to the problem of bubble fusion.

4 Self sustained nuclear synthesis

It is worthwhile to consider a new principle of realization of self-sustained reaction of bubble fusion, based on the optimistic scenario of development of this area of study. Till now, no offers were put forward to improve the Taleyarkhan approach, with the exception of [9, 10], with the purpose to make the process of bubble fusion be self-sustained. The direct approach to the task solution consists of using two or more identical resonators (Fig. 4). The pumping of resonators should be synchronized so that the pressure minimum in one resonator coincides with the pressure maximum of neighbor resonator. Then the fast neutrons that arise in the first resonator, arrive in the second resonator just during the phase of stretching, and create in its volume a cavitation embryo. An accessory neutrons source (pulsed neutron generator, or radioisotope source) is required only to

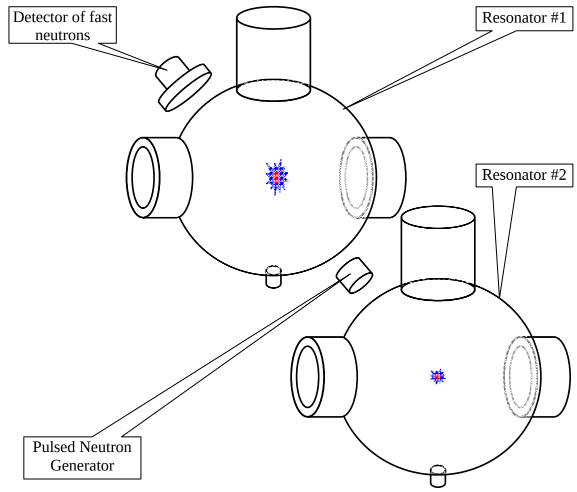

Fig. 4: First modification of Taleyarkhan's layout

initiate cavitations in one of the resonators. Then, if the tuning of parameters is correct, bubble fusion will function in an autonomous regime.

The approach that is more graceful consists in use of one resonator working on the second or higher harmonic (Fig. 5). The clue to this approach lays in peculiarities of

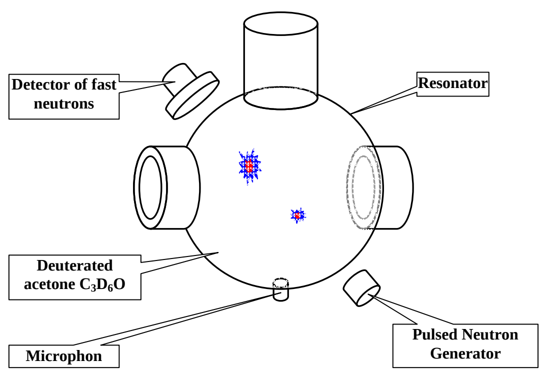

Fig. 5: Second modification of Taleyarkhan's layout

few bubble sonoluminescence. Namely, the excitation of the resonator with the second harmonic leads to creation of double centered acoustic field of standing vibrations; the relative phase difference of vibrations in these centers is close to π. Therefore, the instant of collapse in one of the centers coincides with the nucleation interval in another center, and vice versa. In this lay-out, the output of nucleosynthesis products is expected to be $2 \cdot 10^2 \div 10^3$ times more, than in the initial canonical approach of Taleyarkhan with the external neutron generator.

5 Conclusion

It is significant that the basic idea about an opportunity of achievement conditions for nuclear fusion at bubble collapse is steal not disproved even by the most furious opponents of Taleyarkhan. In particular, though crucial, points concerning the choice of working liquid and the ways of cavitation excitation are subjects of criticism [11].

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