Acoustically Induced Cavitation Fusion

Lawrence A. Crum

Applied Physics Laboratory, University of Washington, 1013 NE 40th Street, Seattle, WA 98105, USA

Abstract: In 1982, Hugh Flynn was issued a patent (No. 4,333,796) for a "Method of generating energy by acoustically induced cavitation fusion and reactor therefor." Although it was largely ignored at the time, there have been several recent papers that treat the subject of acoustically induced fusion as quite plausible. Such prescience in the area of cavitation research was typical of Hugh's work. This patent shows an enormous grasp of detail, suggesting that Hugh must have given a great deal of thought and energy to its composition. The author will review some of the interesting aspects of this patent as well as describe some of the most recent activity on this topic.

INTRODUCTION

The patent issued to Hugh was first filed on May 19, 1978 and was not granted until June 8, 1982, a rather long period and probably indicated that obtaining a patent on cavitation induced fusion was not an easy thing to accomplish. The level of detail provided in this patent is quite unusual—it is 30 columns in length—and provides information that would seem more appropriate to a research paper. The author would like to describe some of the remarkable ingenuity that is in this patent and how Hugh's views of 20 years ago are applicable today.

CAVITATION REACTORS

Hugh envisioned two types of reactors, called Cavitation Fusion Reactor (CFR), Types I and Type II. In Type I, the fusion was principally generated within the fluid medium itself—an interesting concept in itself. Since he wanted to get as intense cavitation as possible, he decided that if he used molten metals at the host liquid, he could get very high temperatures and pressures within the cavitation bubble. For his Type I reactor, he favored lithium, or a lithium/beryllium mixture at a temperature of about 1000 K. At this temperature, lithium has just the right combination of physical parameters (viscosity, vapor pressure, surface tension, density, etc.) to be an ideal fluid in which to produce intense cavitation. An even more important property of lithium that makes its choice of a host fluid ideal is that it is an excellent moderator of fast neutrons, and has a high cross-section for neutron capture. The following nuclear reactions occur when a mixture of deuterium and tritium is used as the gas contained within the bubble: \( ^1\text{H}^2 + ^1\text{H}^1 = ^1\text{H}^3 + ^1\text{H}^1 + 4.03 \text{ MeV} \), \( ^1\text{H}^2 + ^1\text{H}^3 = ^1\text{H}^4 + n^1 + 17.6 \text{ MeV} \), \( n^1 + ^6\text{Li} = ^1\text{H}^7 + ^1\text{H}^4 + 4.8 \text{ MeV} \). Thus, one can start with plentiful and inexpensive deuterium, generate fusion and heat, and also "breed" additional tritium. Note that there is no radioactivity from this reactor, because the fast neutrons are rapidly thermalized and captured by the lithium, releasing more energy and creating additional tritium.

Of course, the most important requirement is to get the fusion in the first place. Again, the choice of lithium helps. Because there are few extraneous cavitation nuclei that can be stabilized in molten lithium, only those "seed" nuclei introduced into the system will be cavitated. Thus, very large acoustic pressure amplitudes can be achieved. An important part of Hugh's contribution to cavitation research was his development of numerical solutions to the Rayleigh-Plesset equation (1). When he first published this analysis, his calculations were the most accurate to date, and are still useful in certain regions of cavitation parameter space. Hugh calculated that if he started with a cavitation nucleus at an initial radius of 0.2 \( \mu \text{m} \) (filled with a mixture of deuterium and tritium), then an acoustic field with a negative pressure of 100 bars and a frequency of 2.0 kHz would expand this nucleus to a maximum size of 2680 \( \mu \text{m} \); the subsequent positive pressure of 100 bars would cause this bubble to implode to a minimum size of 0.012 \( \mu \text{m} \), for an expansion ratio in radius of 2.2 \( \times 10^4 \), and in volume of 1.1 \( \times 10^{15} \)!. With these expansion ratios, and assuming simple adiabatic compression, the final temperature and pressure in the bubble would be 4.22 \( \times 10^7 \) K and 1.67 \( \times 10^{12} \) bars, respectively.

These temperatures and pressures are large enough in themselves to produce fusion within the collapsed bubble, but in Hugh's Type I CFR, fusion occurs principally in the host liquid. As the bubble implodes, there is a shock wave created in the liquid due its rapid acceleration by the rebounding bubble. Hugh calculated that the temperature in a small shell of liquid surrounding the bubble would be 2.64 \( \times 10^7 \) K (only slightly lower than that in the bubble) and the density of the liquid in this shell would be 1.69 \( \times 10^3 \) gm/cm\(^3\) (a remarkably high number—Hugh doesn't say...
what equation of state he uses for the liquid). In this version of the reactor, "...thermonuclear fusion of tritium and deuterium [occurs] in the fusion shell enclosed by the shock".

In a Type II CFR, "...fusion is brought about by the high temperatures and pressures caused by adiabatic compression of the bubbles' contents in the terminal phase of collapse". Thus, in this case, the fusion occurs within the bubble. In order for this to occur, Hugh recommends that the host liquid be molten tin, or a similar metal; the temperature should be raised to between 1400-1500 K; and the acoustic pressure amplitudes need to be in the range of 100-200 bars. In order to obtain a sufficient flux of neutrons, he also wanted to use relatively large cavitation nuclei--on the order of 10 μm, which would expand to the relatively enormous size of 1.82 cm! With these large sizes, he starts to worry about maintaining the stability of the interface during collapse--a very important criterion. He recognizes that gravitation will induce distortions in the shape and lead to spherical instabilities and notes that this problem could be solved by simply putting the reactor in zero-g. Always the pragmatist, however, he also recognizes that the zero-g environment is difficult to access so he developed an ingenious trick--he will superimpose a nonuniform magnetic field on the cavitation field at the center of his reactor and by magnetic levitation, remove the effect of gravity. This magnetic levitation of the bubbles in the cavitation field can be done because the host liquid is metallic. Hugh describes his magnetic field levitation system in some detail and even calculates the fields required to "cancel the gravitational force in the host liquid in the presence of a bubble". These fields vary in magnitude from 76-466 kilogauss (depending upon the host liquid, the size of the bubble, etc.). These are very large magnetic fields. (For example, the fields generated by superconducting magnets in a Magnetic Resonance Imaging system are on the order of a few tens of kilogauss).

PRESENT POSSIBILITIES FOR CAVITATION FUSION

This patent by Hugh would probably have gone unnoticed if it were not for some recent studies that suggest that cavitation induced fusion is not altogether impossible. The recent discovery of Single Bubble Sonoluminescence [SBSL] by Felipe Gaitan (2) has reawakened interest in this topic. In SBSL, it is possible to obtain a single, stable, cavitation bubble that collapses with such violence that it radiates strong electromagnetic emissions each acoustic cycle. These emissions tend to increase with decreasing wavelength into the UV, where the absorption of the host liquid prevents a determination of the full spectrum. Consequently, a number of theoretical models have been conceived to explain the source of these emissions and to predict the temperatures achieved within a collapsing bubble. Some of these models suggest that a shock wave is created in the gas contained within the collapsed bubble and this shock wave can induce extremely high temperature and pressures at the very center of the implosion. Calculated values of these temperatures and pressures predict that a few neutrons per collapse could be generated by an imploding cavitation bubble (3). Active searches are now underway to find these neutrons; indeed, a second patent has been issued to Seth Putterman and his colleagues that treats this topic from a more modern perspective (4).

HUGH'S INSIGHT

In revisiting this patent, the author was intrigued by the prescience of Hugh's thoughts on cavitation induced fusion. For example, it is likely that molten metals will be required if any appreciable level of fusion is to be obtained--indeed, Hugh crude analysis of the important problems in bubble dynamics are still applicable. Moreover, the problem of interface instabilities needs to be solved, and the suggestion to remove the effect of gravity is being examined today through studies of the intensity of SBSL in zero-g.

ACKNOWLEDGMENTS

A portion of the work on SBSL described in this paper was supported by the NSF and the DoE.

REFERENCES