LETTERS TO THE EDITOR

COMMENTS ON "STATISTICAL CHARACTERISTICS OF INCIPIENT TWO-PHASE NOISE FOR REACTOR DIAGNOSIS"

In a paper[1] that appears on p. 94, De analyzed acoustic pulses from discrete bubbles created in the throat of a venturi. The basis of his analysis is that "The detection of one pulse can be assumed to indicate the collapse of one bubble." On the basis of this assumption and the observation that pulses are registered in clusters of three to five where the intracluster spacing of pulses appears to be at a nearly constant Δt and the clusters appear to arrive according to a Poisson distribution, he concludes, "Such noise results from bubble clusters incepting periodically in a train (3-5 appearances) and trains appearing at random."

The purpose of this Letter is to suggest an alternative interpretation of the experimental results based on observations made in related work performed in 1973-1975 but never adequately published. The alternative interpretation is that bubbles are incepted randomly and that each bubble produces between one and five pressure pulses when it collapses. If this is the case, then the basic theoretical understanding of De's experiment is much more straightforward than the mysterious "back action of bubble nucleation on flow turbulence."

An experiment was performed in 1974 to study the details of steam bubble collapse in water.[2] High-speed films were synchronized with pressure pulses from bubble collapse. Typical bubble lifetimes were 60 ms, and dead time between bubbles was ~90 ms. Thus, the repetition frequency of these bubbles was near 7 Hz. Figure 1 shows the bubble volume calculated by rotating the observed area from films along with the observed pressure pulses. Note that these cases exhibit two pulses per bubble. Other cases were observed to produce several pulses per bubble. The cause of this was that the initial bubble would become distorted, part of it would separate, condense, and collapse. This would be followed by a distortion, separation, and collapse of the remaining bubble until all of the initial bubble had finally collapsed.

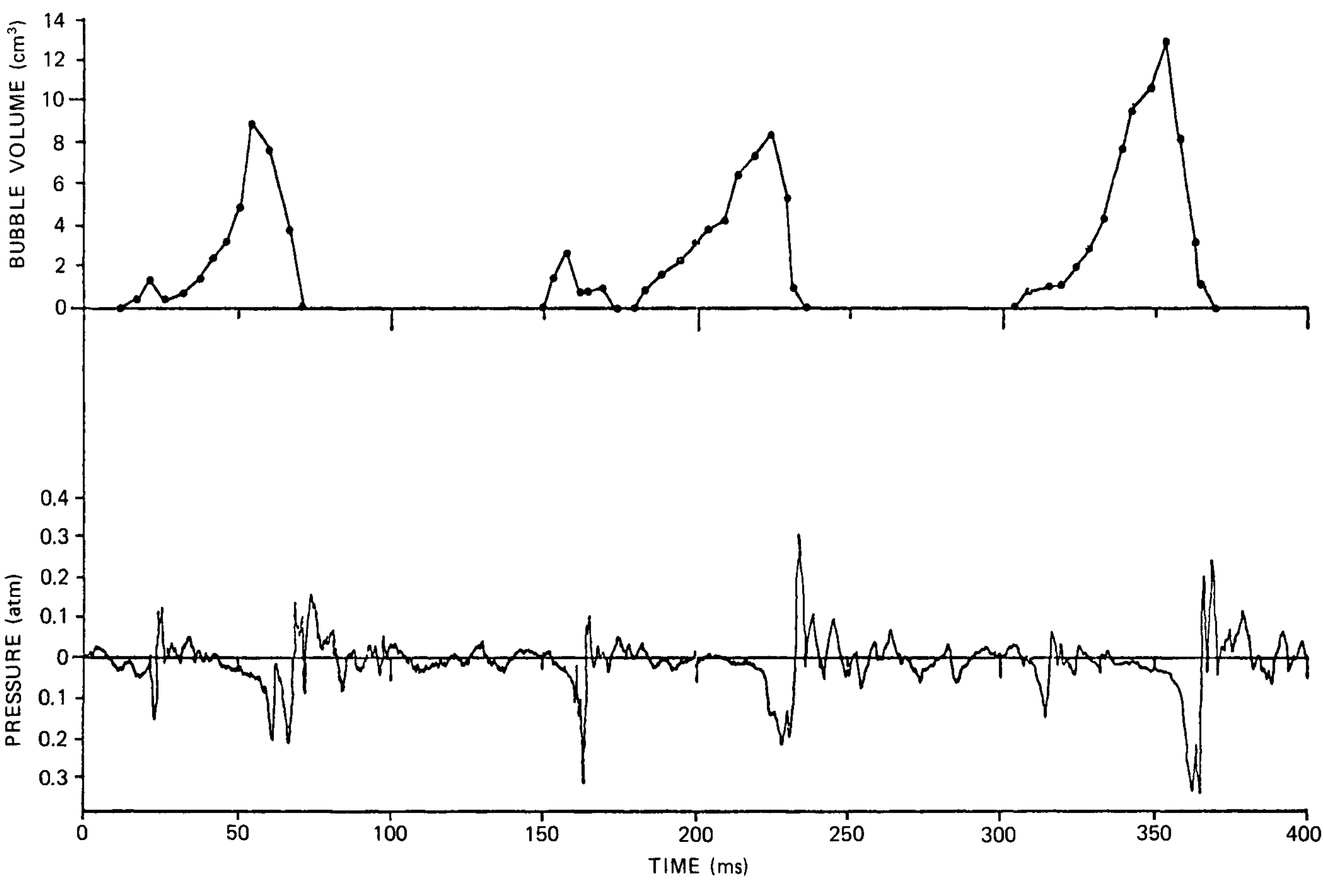

Fig. 1. Bubble volume and pressure from simulated local boiling.

The rapid changes in observed volume shown in Fig. 1 that correlate with pressure pulses are actually collapses of a part of the main bubble for the early pulses followed by collapses of the remainder of the main bubble.

To determine if the measured pulses were related to the variation in bubble volume, a simple relationship was derived for a spherical bubble in an infinite medium:

$$P(t) = \frac{\rho_d}{4\pi r} \frac{d^2 V_B(t)}{dt^2} \ . \qquad (1)$$

In Eq. (1)

ρ_d = liquid density

r = distance between bubble and pressure detector

$V_B(t)$ = time-dependent bubble volume.

To test the adequacy of this relation, the observed bubble volume was differentiated twice and compared to the measured signal. The result is shown in Fig. 2. Note that both measured pressure peaks are closely matched by the differentiation. The additional apparent peak at ~65 ms is most likely induced by the high noise contamination to be expected when measured data are doubly differentiated.

De's bubbles have volumes of order 0.04 cm^3 and existence times of order ~7 ms; whereas, Wright's[1] bubbles had radii about six times larger than De's and existence times about nine times longer. Therefore, observation of the details of the collapse mode of these larger, longer lasting bubbles was easier to achieve by photographic means in Wright's case than in De's experiments.

Of course, the analogy between these two results does not prove that De's assumption of one pulse per incepted bubble is incorrect. However, De offered no conclusive evidence that multiple collapse pulses per incepted bubble cannot occur. Since a somewhat similar experiment has conclusively demonstrated that multiple collapse modes are observed, it is possible that such modes are also operative in De's case.

In terms of theoretical understanding, it seems much easier to envision and analyze a situation in which bubbles are incepted randomly at a mean rate and undergo multiple collapse than to conceive of the physics associated with clustered inception. A mechanism that turns clusters of incepted bubbles "on" and "off" according to a Poisson law is not at all understood. A mechanism of bubble collapse where pieces break away from the main bubble and collapse sequentially has been observed and could be understood in principle by analyzing condensation rates at the surface of distorted bubbles.

It is suggested that in future experiments of this type a careful investigation be made to determine if the interpretation is more properly clustered inception or multiple collapse.

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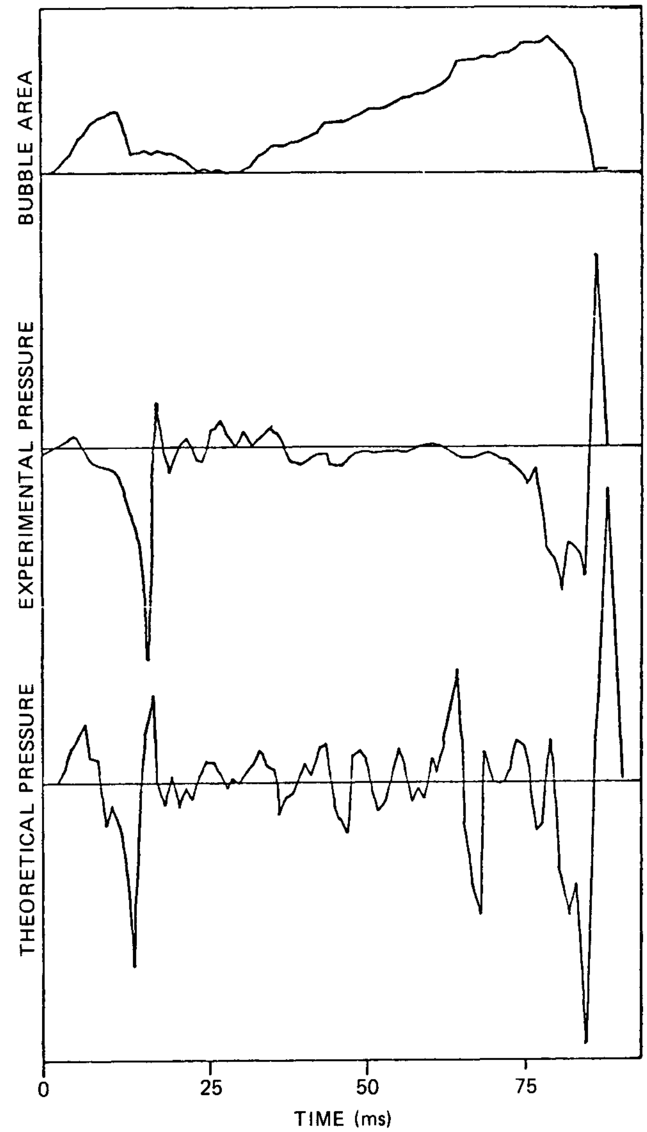

Fig. 2. Measured and predicted pressure.

REFERENCES

1. M. K. DE, "Statistical Characteristics of Incipient Two-Phase Noise for Reactor Diagnosis," *Nucl. Technol.*, **62**, 94 (1983).

2. S. A. WRIGHT, "Sodium Boiling Detection in LMFBRs by Acoustic-Neutronic Cross Correlations," PhD Dissertation, University of Washington (1975).

REPLY TO "COMMENTS ON 'STATISTICAL CHARACTERISTICS OF INCIPIENT TWO-PHASE NOISE FOR REACTOR DIAGNOSIS' "

The author thanks Albrecht and Wright for their interesting discussion and alternative interpretation[1] of the experimental results. The experiment they conducted showing multiple collapses of a bubble yielding multiple acoustic pulses is very interesting. High-speed photographic observations here[2] in a similar venturi have also shown that bubbles oscillate, and sometimes the oscillation results in the fragmentation and collapse of a portion of the bubble as was observed by Albrecht and Wright. However, the present statistical observations of bubble inception in the venturi cannot be explained by multiple collapse as suggested by Albrecht and Wright. The bubble oscillation frequencies (5.0 to 20.0 kHz) observed photographically[2] and acoustically[3] in the venturi are much too high to cause the large peaks in the time interval distribution (~5 ms). The bubbles in the present study range in diameter (size at full growth) from 0.254 to 1.27 mm, have high natural frequencies (5.0 to 20.0 kHz), and collapse much more rapidly (~100 μs from maximum size) than the steam bubbles observed by Albrecht and Wright. Also note that the distance between the venturi throat entrance (point of inception) and the mean axial location (Fig. 1) of bubble collapse is 10 cm. The bubbles traveling at ~40 m/s (venturi throat velocity) would take ~$2\frac{1}{2}$ ms to travel this distance. The time intervals (~5 ms) at the peaks of the distribution are longer than the total lifetime of the bubble.

The time interval between pressure pulses due to bubble oscillations and multiple collapse were not recorded in the present experiments because a 500-μs dead time was used during data acquisition. The intent of the experiments was to analyze the intermittent nature of cavitation inception shown in Fig. 2 and which is evident by an unaided audiovisual observation of the bubbles in the venturi.

One can conclude from the above discussion that

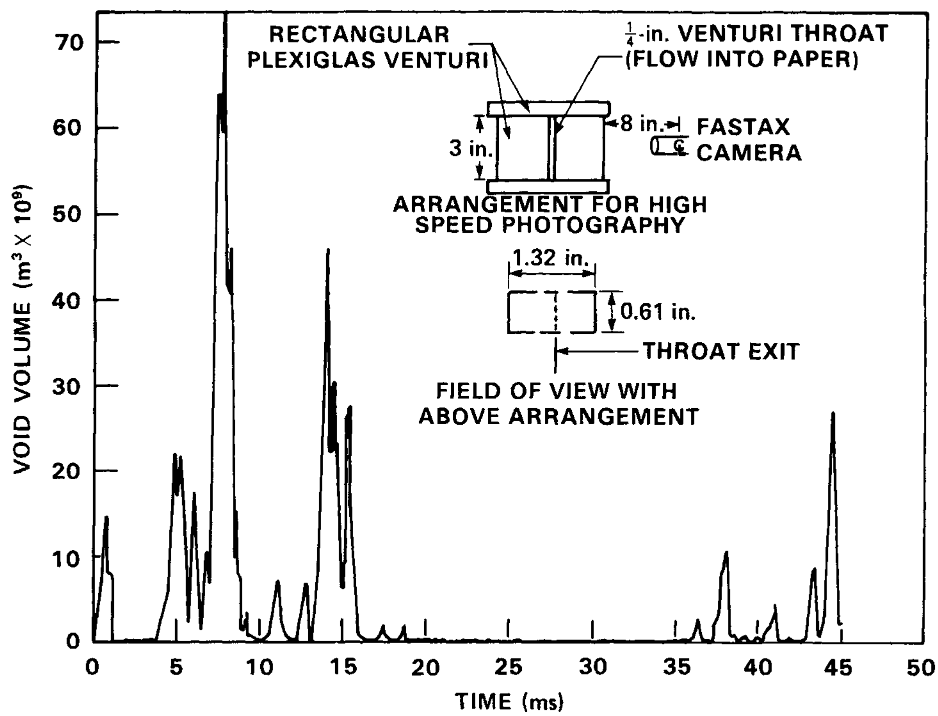

Fig. 1. Plexiglas venturi flow path.

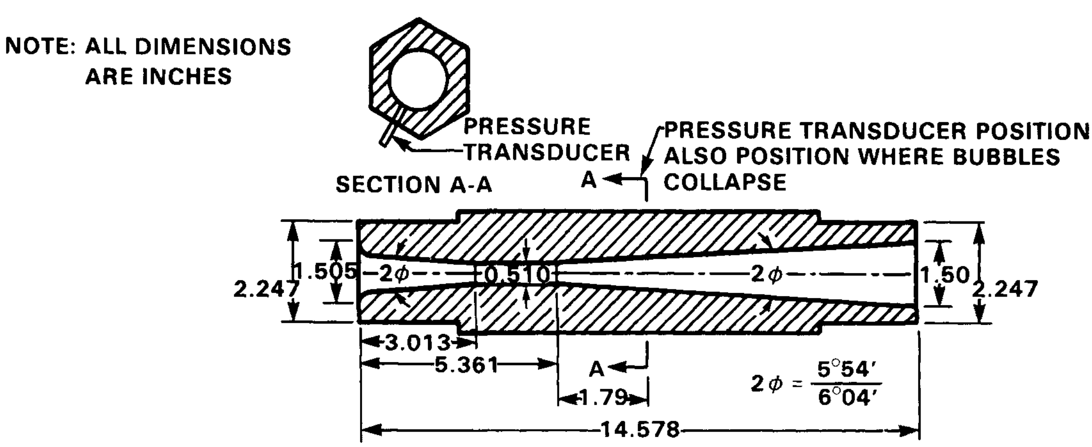

Fig. 2. Total void content in the field of view versus time (see Ref. 4).

oscillations and multiple collapse of a bubble does occur for cavitation bubbles in a venturi, but this phenomenon cannot explain the statistical observations presented in the paper. However, multiple collapse of large steam (or sodium vapor) bubbles in reactor channels can result in another unique feature in the acoustic signature that can be used in a boiling detection scheme.

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REFERENCES

1. R. W. ALBRECHT and S. A. WRIGHT, "Comments on 'Statistical Characteristics of Incipient Two-Phase Noise for Reactor Diagnosis,' " *Nucl. Technol.*, **62**, 116 (1983).

2. R. D. IVANY, "Collapse of a Cavitation Bubble in Viscous, Compressible Liquid–Numerical and Experimental Analyses," PhD Thesis, University of Michigan (1965); see also R. D. IVANY and F. G. HAMMITT, "Cavitation Bubble Collapse in Viscous, Compressible Liquids–Numerical Analyses," *Trans. ASME J. Basic Eng.*, *D*, **87**, *4*, 977 (1965).

3. M. K. DE, "Acoustic Waves from Hydrodynamic Cavitation," PhD Thesis, University of Michigan (1980).

4. Yu. L. LEVKOVSKII, "Modeling of Cavitation Noise," *Sov. Phys. Acous.*, 13, *3* (Jan.-Mar. 1968).