Experimental Studies on Role of Scattering Centers on Wave Energy Attenuation

by

S. H. Kim, C.L. Knaff, R. P. Taleyarkhan
Oak Ridge National Laboratory
Oak Ridge, TN 37831-8045

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SUMMARY

In accelerator-driven neutron sources such as the Spallation Neutron Source (SNS)[1] with powers in the 2 MW range (time-averaged), the interaction of the energetic proton beam with the mercury target can lead to very high heating rates in the target. Although the resulting temperature rise is relatively small (a few °C), the rate of temperature rise is enormous (~10^7 °C/s) during the very brief beam pulse (~0.58 μs). The resulting thermal-shock induced compression of the mercury leads to the production of large amplitude pressure waves in the mercury that interact with the walls of the mercury target and the bulk flow field. Understanding and predicting propagation of pressure pulses in the target are considered critical for establishing the feasibility of constructing and safely operating such devices. Safety-related operational concerns exist in two main areas, viz., (1) possible target enclosure failure from impact of thermal shocks on the wall due to its direct heating from the proton beam and the loads transferred from the mercury compression waves, and (2) impact of the compression-cum-rarefaction wave-induced effects such as cavitation bubble emanation and fluid surging. Preliminary stress evaluations indicate stress levels approaching yielding conditions and beyond in selected regions of the target. Also, the induction of cavitation (that could assist in attenuation) can also release gases that may accumulate at undesirable locations and impair heat transfer.

A companion paper[2] introduces the concept of scattering centers (SCs) in the fluid to mitigate thermal shock issues. The general approach is based on wave energy attenuation via use of appropriately-configured SCs (such as gas-filled low impedance cylinders/spheres, or gas injection) in the bulk or at liquid-structure interface regions. Benefits of using such approaches are briefly described in the companion paper[2]. The same companion paper also describes a numerical simulation demonstrating attenuation in thermal shock-induced pressure waves that one may expect with introduction of SCs in mercury fluid. This paper documents results of scoping experiments conducted to assess the relative role and extent of SCs on wave energy attenuation. This scoping study had the goal to assess and confirm the relative roles of: (1) low impedance SCs distributed in mercury and water, and (2) large impedance SCs distributed in a relatively low impedance liquid.

The experiment was designed to provide quick-turnaround data for demonstrating the impact and power of the use of SCs on wave energy attenuation. This was motivated by the need to assure that reasonable confidence could be derived for motivating the implementation of such devices in the SNS target design and for integral studies with direct proton beam energy deposition. As such, a simple experimental setup was required. The setup consists of a plastic dish (with a 9cm x 13cm cross-section) filled with a chosen working fluid. At one end is an ultrasonic driver tip (12.5 mm diameter) which can deliver acoustic energy (up to several hundred watts in steps) at a drive frequency of 20 kHz. At the other end of the reservoir a pressure transducer is affixed with its measuring face submerged in the working fluid. The ultrasonic driver tip and the pressure transducer are located mid-way between the bottom and free surface of the working fluid.

Figure 1(a) shows SCs affixed to a plastic cover. The SC materials were chosen to be either plastic or stainless steel. The SC tube dimensions (capped at either end to provide for an air-

filled space throughout the length) were nominally, 6.35mm outer diameter (OD), and 3.5mm inner diameter (ID). These relative dimensions introduce an air void fraction of ~ 1v/o (based on the tube ID), and a total mercury or water displacement void fraction of ~ 4v/o (based on the tube OD).

After filling the reservoir with the chosen working fluid to a given depth, the experiments were conducted by gradually increasing acoustic power and noting the wave forms of pressure variations from the pressure transducer. At each power level experiments were conducted first without any SCs, followed by introduction of plastic SCs and then with stainless steel (SS) SCs.

It is clearly seen from Figure 1(b) (with mercury as working fluid) that the introduction of SCs have a very significant influence on attenuating the pressure wave energy introduced by the ultrasonic driver. Reductions of 90% and greater were observed. A similar reduction was obtained with water as working fluid; however, SS SCs give rise to relatively modest reductions in wave energy attenuation compared with plastic SCs, where the wave energy attenuation is smaller.

The above-mentioned results reveal the following important physics-related characteristics:

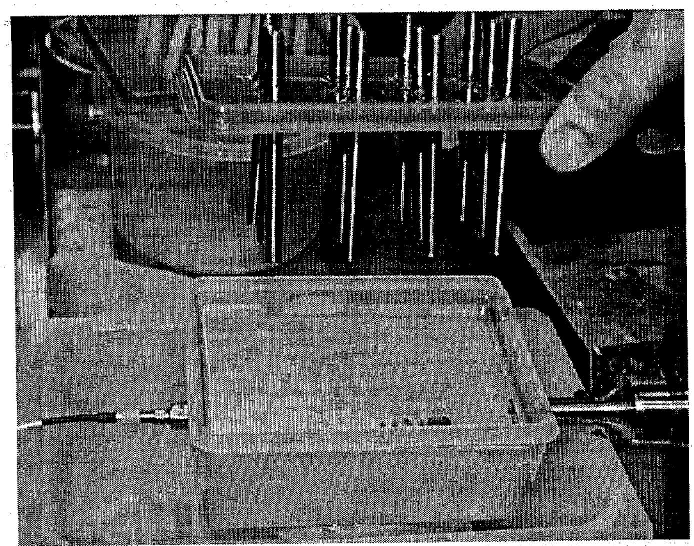
1) Using SCs of the geometry used in this study where the material is of lower (or comparable) impedance than the working fluid can give rise to very significant rarefaction-type scattering-induced attenuation. This is clearly evident from results of attenuation with plastic or SS SCs in mercury, and use of plastic SCs in water.

2) Using SCs of the geometry used in this study where the material is of significantly higher impedance than that of the working fluid can give rise to only modest, or little wave energy attenuation which is governed by compression-wave scattering. This was clearly evident from results of attenuation with SS SCs in water. The lesson here pertains to the possible suggestion of using materials such as hollow tungsten cylinders in the SNS target.

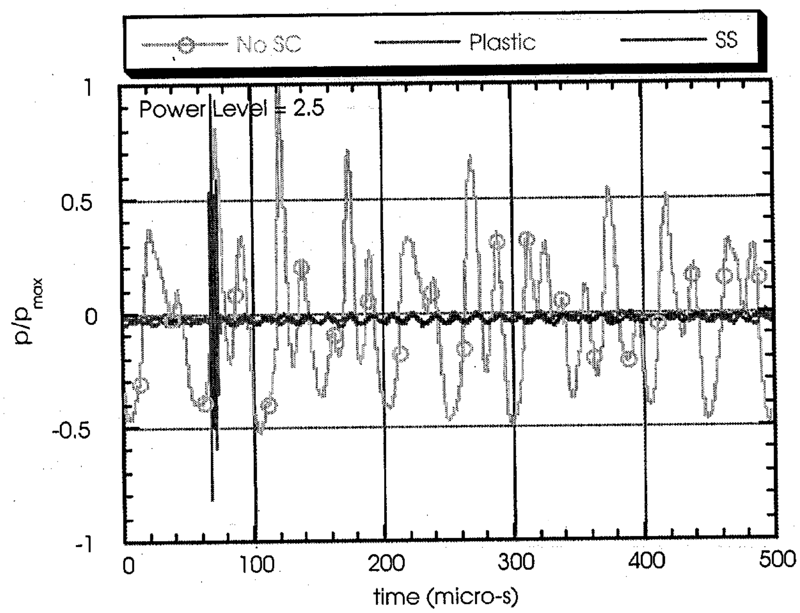
The above-mentioned results confirm results of recent hydrocode simulations[2], and provide encouragement that the suitable use of SCs in mercury targets may become a possible means for reducing or eliminating deleterious thermal-shock effects. Clearly, there are several aspects that have yet to be studied (e.g., wave energy attenuation with distance from radiating source, effect of various sized SCs, effect of the relative positioning of SCs, etc.). Systematic studies are planned and will be reported later.

<u>References</u>

1) T.A. Gabriel, et.al., "Overview of the NSNS Target Station," *Proc. of International Topical Meeting on Advanced Reactor Safety*, ARS'97, Orlando, Florida (1997).
2) R. P. Taleyarkhan, and S. H. Kim, "Overcoming Thermal Shock Problems in Liquid Targets," Transactions of the Annual Conference of American Nuclear Society, San Diego, CA, June 2000.



(a)



(b)

Figure 1 (a) Test section geometry (with stainless steel tube SCs about to be placed into mercury as the working fluid), and (b) Wave forms with and without SCs in mercury