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Peak Sound Pressure Levels and Associated Auditory Risk from an H_2−Air "Egg-Splosion"

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S Supporting Information

ABSTRACT: The noise level from exploding chemical demonstrations and the effect they could have on audiences, especially young children, needs attention. Auditory risk from H_2−O_2 balloon explosions have been studied, but no studies have been done on H_2−air "egg-splosions". The peak sound pressure level (SPL) was measured for the first time and compared to the recommended SPL limits and some recently published work. All peak SPL results ended above 125 dB, some greater than 150 dB. The SPL results exceeded the World Health Organization (WHO) safe limits of 120 dB for children and 140 dB for adults.

KEYWORDS: *General Public, High School/Introductory Chemistry, Upper-Division Undergraduate, Demonstrations, Inorganic Chemistry, Public Understanding/Outreach, Safety/Hazards, Hands-On Learning/Manipulatives, Laboratory Equipment/Apparatus, Gases*

INTRODUCTION

The term "egg-splosion" refers to collecting hydrogen (H_2) gas in a hollowed out egg, and combusting the collected gas. For the production of H_2 gas, this demonstration relies on the oxidation of mossy zinc (Zn) by hydrochloric acid (HCl). The reaction forms zinc chloride ($ZnCl_2$) and releases hydrogen (H_2).

This paper presents the peak sound pressure level (SPL) results for exploding hydrogen−air (H_2−air) eggs. Studies on the auditory risk on exploding H_2−O_2 balloons and on other chemical demonstrations have been published.[1−5] Until now, no documented studies exist on the peak SPL levels for the "egg-splosion", although the demonstration is widely published and performed.[6−8]

EXPERIMENTAL PROCEDURES AND METHODS

Classroom

Sound pressure measurements were recorded in a tiered classroom approximately 34 ft × 38 ft designed to seat about 125 students. The demonstration was set up at the front center of the room (0 m) to minimize interference from surface reflections. The acoustic walls are Snap Tex with 1 in. insulation: The fabricated wall panels were assembled on site with an acoustic attenuation noise reduction coefficient (NRC) of 0.80 or higher. The acoustic ceiling is made of sound absorbing Armstrong Ultima tile. The acoustical flooring is a resinous stonetec UTF (urethane with quartz broadcast). The auditorium seating is KI Concerto. Independent background sound measurements were conducted in the classroom in 2014 and, with the HVAC on, received a national construction code (NCC) rating of 24 at 500 Hz which is considered very quiet (33 dB).

Safety Shield

The safety shield 36 in. × 24 in. was made of thick $^{3}/_{16}$ in. polycarbonate plastic attached to a heavy steel base (photo included in demonstrator notes in Supporting Information). The shield came from Flinn Scientific.

Microphone Positioning

Distance in meters (m) was measured from the reaction site on the demonstration table, with microphone attached to the sound meter at 1, 2, 4, and 8 m on each tier, respectively. When a safety shield was used, the peak SPL at 0 m was recorded on the demonstrator side of the shield. The sound meter with attached microphone and preamplifier was clamped vertically to a ring stand, with the sensing surface oriented upward at 90°, placing the microphone 1.5 m directly above the floor and 25 cm to the left of the detonating site. This microphone position was approximately in the proximity of the standing demonstrator's ear at 0 m.

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Sound Meter

Peak SPLs were recorded for each "egg-splosion" with a Larson Davis LXT1-QPR sound track class 1 high precision integrating sound level meter with peak detector. The LXT was equipped with a PCB Piezotronics $^1/_4$ in. pressure prepolarized precision condenser microphone model 377C10, calibrated during the experiment with a model CAL200 class 1 acoustic calibrator. This calibration was done before each "egg-splosion" in addition to the updated factory calibration with NIST traceable certification for the LXT1, CAL 200, preamplifier PRMLXT1, and $^1/_4$ in. microphone certifications. The frequency weighting scale A/C/Z was set to "A" weighting, the sound level that is closest to the range of human hearing.[9] This frequency weighting scale is most often recommended and referred to by Occupational Safety and Health Administration (OSHA) and Department of Environmental Quality (DEQ) regulatory requirements. The peak detector frequency weighting A/C/Z was set to "C", since the firearm industry has adopted "A" or "C" as the standard options in MIL-STD-1474E.[10] The LXT1-QPR had a response time of less than 30 μs using the "C" weighted digital peak detector. The model LXT1-QPR used in this experiment was designed for firearm testing making it an ideal choice for measuring chemical explosions.[11]

Egg Volume Determination

The volume of the eggs used in this study was calculated from the density of water at room temperature. The average volume of six extra-large (XL) eggs was determined and reported with the standard deviation (58 ± 2 mL).

Egg Preparation and Handling

These details are presented in demonstrator notes available as Supporting Information.

RESULTS

Results from the peak SPL for each "egg-splosion" are presented in Table 1 and Figure 1. Each result was repeated three times with the average value shown. Figure 1 includes error bars representing standard deviations of the average peak SPL determined for each three trials.

Table 1. Average Peak Sound Pressure Recordings as a Function of Distance from Reaction Site and Presence or Absence of any Safety Shield

Distance from Reaction Site (m)	With Shield on Demonstration Table (dB)	Without Shield on Demonstration Table (dB)
0	154.6	145.4
1	134.6	141.9
2	131.2	135.7
4	128.4	131.3
8	126.8	127.3

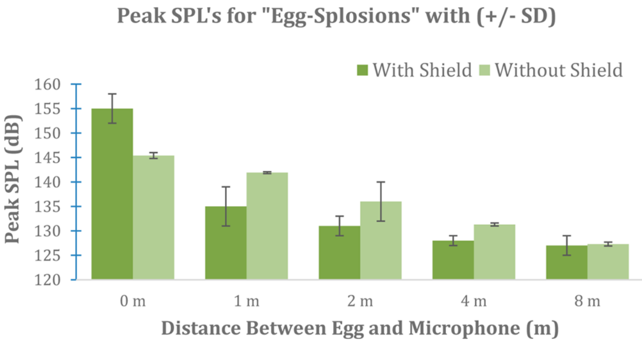

Figure 1. Height of each bar = average peak SPL (dB) for each three "egg-splosions" with/without safety shield with sound meter microphone at 0, 1, 2, 4, and 8 m. The vertical error bars attached are standard deviations representing the average variation in peak SPL for each of three determinations.

DISCUSSION

In the "egg-splosion" results, the XL eggs with a fixed volume of 58 ± 2 mL, and a H_2−air mixture, recorded an SPL with shield of 154.6 dB at 0 m (Table 1). Since the H_2−air ratio inside the XL eggs cannot be controlled, it was impossible to reduce the reactants in order to lower the peak SPL below the OSHA maximum limit of 140 dB as mentioned by Macedone and colleagues for other explosive demonstrations.[5] Since the XL-egg results exceeded the exposure standards, SPL was examined as a function of egg size. Testing medium (M) size eggs with an average volume of 45 ± 1 mL resulted in approximately a 22% reduction in reactants. This decrease in egg volume only resulted in about a 2 dB loss which fell well within the standard deviations reported for the XL eggs studied in Figure 1.

Macedone and colleagues found that a blast shield is not always effective for all demonstrations.[5] From the "egg-splosion" experiment results (Table 1) with safety shield, the sound energy was reduced on the audience side to 134.6 dB at 1 m versus the demonstrator side 154.6 dB. Without the shield, the average peak SPL recorded was reduced on the demonstrator side to 145.4 dB, but was much higher on the audience side at 1 m (141.9 dB vs 134.6 dB). The safety shield in the "egg-splosion" demonstration clearly attenuated the impulse noise reducing SPL levels on the audience side and deflecting the broken egg shells away from the audience. The broken egg shells became projectiles that fell in a radius approximately 3 m surrounding the demonstration table.

With the assumption that the sound propagates uniformly in all directions with no reflections or reverberations, the sound level will decrease with the square of the distance as the audience moves away from the source of the sound waves. Each doubling of the distance in an unobstructed field should theoretically reduce the sound level by 6 dB. We tested this out in a newly constructed lecture hall (see description of classroom in the Experimental Section). From the results (Table 1), sound diminished in intensity with distance but was not ideal in its propagation in the room. With the shield, the results (Table 1) show it acted as a barrier between the explosion site and each point of the measurement from 1 to 8 m, resulting in sound measurements less than what would be predicted by the inverse square law. Without the shield, the results (Table 1) at 8 m were about 2 dB higher than expected compared at 4 m. Because 8 m was the last row of the classroom, the microphone being positioned 1.2 m away from the rear wall could account for the raised intensity by 2 dB due to sound reflection. Similarly, the results at 4 m were 1.6 dB higher compared with 2 m. The ideal correlation was from 1 to 2 m where the sound level decreased about 6 dB as predicted. Every attempt was made to minimize auditory risks such as the time scale of the explosion, which included a delayed ignition after the hydrogen flame was lit.

The OSHA standard states exposure to impulsive or impact noise should not exceed 140 dB peak sound pressure level.[12] From the results of the "egg-splosions" (Table 1), this limit is

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clearly exceeded for the demonstrator. Dual protection with noise blocking headphones and commercial earplugs must be used as a part of the personal protection equipment (PPE) to achieve a noise reduction below 140 dB. The dual protection isolates the demonstrator from the immediate environment by preventing them from hearing normal sounds heard without ear protection. In this "egg-splosion" demonstration, the double ear protection caused difficulty to even hear the initial pop indicating the hydrogen flame above the egg was lit. However, the demonstrator must balance this communication deficit against protecting against the harmful effects of impulsive noise.

CONCLUSION

The results from this "egg-splosion" demonstration suggest that the magnitude of the peak SPL generated affords risk to both performer and audience. The World Health Organization (WHO) recommends no exposure to any peak SPL exceeding 120 dB for children and 140 dB for adults.[13] From the results (Table 1 and Figure 1), all of the peak sound pressures recorded were above 125 dB and sometimes greater than 150 dB. Since the auditory risk cannot be safely reduced to an acceptable level for all attendees, the following list of guidelines may help each demonstrator make their own decision.

- General lab safety procedures should be followed throughout this demonstration including mandatory eye protection (goggles), skin protection (gloves), clothing protection (flame resistant lab coats), fire extinguisher on site, and proper disposal guidelines for all chemicals.
- This experiment warrants ear protection for the entire audience. Young children must be properly protected. Ear plugs are inadequate.[14,15] Inserting an ear plug could cause injury to a child with small ear canals. Furthermore, ear plugs may not fit a child's ear properly, which could result in the reduction of the ear plugs' attenuation rating. Ear plugs also represent a choking hazard for small children. A safer alternative is to provide children with ear muffs. Most of these are padded and offer a comfortable snug fit with an NRR rating around 21 dB.
- A safety shield is mandatory for this "egg-splosion" demonstration.
- Audience should be warned ahead that the explosion will be loud. Some may want to step out.
- For the "egg-splosion" demonstration we recommend carrying a colored roll of tape at least 2 in. wide to tape off the front row of seats which puts the audience back at least 2 m from the demonstration table.
- NOISE HAZARD signs should be posted. The signs should conform to appropriate standards and provisions outlined in MIL-STD-1474E.[10]
- Protection of bystanders must be considered when selecting a demonstration location. The ears of non-attendees could be accidently injured by just walking by an open door during a chemical explosion. Entry doors to the event should be closed with signs affixed stating that a LOUD EXPLOSION IS IN PROGRESS.
- It is recommended that the demonstrator wear double ear protection.

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available on the ACS Publications website at DOI: 10.1021/acs.jchemed.6b00520.

Notes for the demonstrator, safety and hazard information for all chemicals used, and list of all materials needed (PDF)

■ AUTHOR INFORMATION

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Notes

The author declares no competing financial interest.

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