Effect of Particle Size and Composition of Oxidisers on Sound Level Analysis of Firecrackers

A. Jeya Rajendran[a] and T. L. Thanulingam[b]

[a] Department of Chemistry, Loyola College, Nungambakkam, Chennai-600034, India.
Email: jeyarajendran@yahoo.com

[b] Fireworks Research and Development Centre, Petroleum and Explosives Safety Organisation, Sivakasi 626124, India. Email: tlthanulingam@yahoo.co.in

Abstract: *Two types of oxidizers, potassium nitrate (KNO_3) and potassium perchlorate ($KClO_4$), were used and the particle size of the oxidizers was varied by using a ball mill. The particle size was determined by a particle size analyser. Pyrotechnic mixtures of compositions using the two different oxidizers potassium nitrate and potassium perchlorate, in different particle sizes, mixed with sulphur (S), aluminium (Al) and boric acid (H_3BO_3) were used to make sound-producing bullet-bomb firecrackers for analysis. The bulk density of the pyrotechnic mixture was found to vary from 0.372 to 0.622 g cm^{-3} depending on the variation of composition and particle size of the mixture. Increasing the percentage of oxidizer in the pyrotechnic mixture from 50 to 57% increased the sound level but above 57% of oxidizer decreased the sound level produced from newly formulated bullet-bomb firecrackers. A linear relationship exists between the weight of the mixture taken and the sound level produced. Decreasing the particle size of the oxidizers increased the sound level of the firecrackers.*

Keywords: *Sound level, pyrotechnic mixture, bullet-bomb, firecrackers, ball mill, particle size analyser.*

1. Introduction

Firework manufacturing is fully labor-intensive in India, where hardly any standardization or mechanization of the processes is employed and hence no definite relationship could be established between a particular variety of fireworks and their chemical composition, weight of chemicals used and the resulting sound levels. The choice of fuel and oxidizer can significantly affect the activation energy, heat of reaction and the efficiency of energy feedback.[1] The selection of fuel and oxidizer has the potential to have a major influence on the efficiency of a pyrotechnic mixture.[2] Thermal stability and heat of decomposition of the oxidizer are the important factors in fixing the chemical compositions of the pyrotechnic mixtures used for making firecrackers. The activation energy, the amount of energy required for an oxidizer to make its oxygen available to react with the fuel, depends on the nature of the oxidizers. Some oxidizers require input of a large amount of energy, while others actually produce energy in the process of releasing their oxygen. There is always an optimum fuel to oxidizer ratio, which produces the fastest burning rate.[3] Pyrotechnic mixtures are homogenized to a particular particle size to improve the efficiency of the firecrackers. Particle size is an important factor affecting the efficiency of the firecrackers.[4] As per the Government of India notification 'Sound emitting fire crackers with sound level exceeding 125 dB(A) or 145 dB(C) peak at 4 m distance from the point of bursting are prohibited (Notification *vide* GSR 682 (E) dated 5.10.1999)'.[5] Most of the small companies in Sivakasi, South India, started giving priority to the manufacture of only light or colour-producing firecrackers and neglected to manufacture sound-producing firecrackers. The mechanism as well as different possible ways of controlling sound in some types of sound-producing firecrackers, cake-bombs, hydrogen-bombs and atom-bombs have been reported in detail.[6,7] It was found that even though the sound

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level produced from the firecrackers which are available on the market exceeds 130 dB(AI) it could be very well controlled within the allowed level.[6] In order to prove the validity of the sound level analysis, a similar type of firecracker, the bullet-bomb, was taken for analysis. The present study assesses the sound level produced from the fireworks by changing the oxidizers, their particle size and composition of fuel to oxidizer ratio.

2. Experimental

2.1 Chemicals and materials

The chemicals used for the preparations of the firecrackers were obtained from a firework manufacturing company. The purity and assay of the chemicals were potassium nitrate (KNO_3), potassium chlorate ($KClO_4$): 97.6%, S: 99.9%, Al: 99.8% and H_3BO_3: 99%. It was reported that Al of grades 333 (60 mesh/250 micron size) and 666 (100 mesh/150 micron size) produce flash instead of producing sound while Al of 999 grade (200 mesh/63 micron size) alone produces effective sound.[6] The chemicals used in making fireworks are aluminium powders of grade 999 (200 mesh/63 micron size), KNO_3 and $KClO_4$, of 150, 200 and 240 mesh (105, 75 and 63 microns), sulphur (S) of 200 mesh (63 microns) and boric acid (H_3BO_3) of 200 mesh (63 micron) sizes. All these chemicals were sieved using a 150 mesh brass sieve. The samples were stored away from light and moisture till they were packed within the paper shell of the firecracker unit (Figure 1).

2.2 Preparation of pyrotechnic mixture

The Fritsch, GmbH, "pulverisette 6" planetary ball mill was used for preparing different particle sizes of oxidizers based on a well established procedure.[7] 20 g of the material (oxidizer) was placed in a bowl with 100 ml of ethanol, and then 50 tungsten balls were placed in the bowl. The lid was closed and locked. Milling was carried over for 15 minutes at a speed of 300 rpm. After cooling the bowl for 5 minutes, milling was again done for 15 minutes. If the ethanol level became low, some more ethanol was added in order to keep the powder in the colloidal state. This state was easy to grind with no hazards. After grinding for 2 hours, the colloidal state powder was transferred to an air-tight container and it was kept safe. The container was kept in the open atmosphere to separate the powders from ethanol. The powder was collected after evaporating the ethanol.

2.3 Measurement of particle size

The particle size was measured[7] using a 'Zetasizer Nano ZS particle size analyzer'. Hydrodynamic or aerodynamic particle size is equal to the diameter of the sphere that has the same drag coefficient as a given particle. There is often a need for a certain average particle size for the ensemble of particles. The particle size is measured, by taking 0.01 g of the powder in a glass plate and drying it. It is mixed with 50 ml of ethanol and it is sonicated for 2 minutes. The sonicator works in the frequency range 20 kHz to 50 kHz and the amplitude is set at 31%. After sonication, the solution is poured into the cuvette of the particle size analyzer which is made of polymer to measure the particle size.

2.4 Measurement of bulk density

The bulk density of the pyrotechnic mixture was measured by placing pyrotechnic mixture of known mass in a measuring device to measure the volume occupied.

2.5 Firecrackers

Firecrackers from a bullet-bomb (Figure 1) were manufactured manually by experienced

Figure 1. *Firecracker, bullet-bomb.*

technicians of the fireworks manufacturing company for analysis. A flow chart for preparing bullet-bombs is given in Figure 2. The chemical mixtures of $KNO_3/Al/S/H_3BO_3$, and $KClO_4/Al/S/H_3BO_3$, in three different ratios were taken by changing the fuel to oxidizer ratio as 50–65/29.5–14.5/22/0.05%. The chemicals used in the mixture were sieved separately and mixed thoroughly on non-conducting surfaces like newspaper, rubber mats etc., by sieving with a mesh No. 40 (425 microns), 4 to 5 times to get a homogeneous mixture. The chemicals were finely powdered to the required size by using ball mill techniques. This chemical mixture was used to fill a paper case with an inner diameter of 13 mm, outer diameter of 16 mm, with a tube thickness of 1.5 mm and tube height of 27 mm. The paper shell is made up of using 220 gsm paper with a bursting factor of 3.96 kgf cm^{-2}. The bottom of the tube is sealed with mud that is obtained by mixing 20 g of alluvial soil, 5 g of red soil and 3 g of gum powder and made into a paste by adding small quantity of water. The tube filled with mud is dried in sunlight for two days and filled with the pyrotechnic mixture in different ratios and the tube is again sealed at the top with mud obtained by mixing 20 g of alluvial soil and 4 g of gum powder and allowed to dry. The fuse wire (40 mm, quick match) was inserted using a brass needle and kept in its place by charcoal powder. Coloured fancy papers were used to cover for appearance and dried for about 24 hours in the sun to make the firecrackers ready for testing (Figure 1). In order to check for the reproducibility of the parameters measured, five bullet-bomb firecrackers with the same chemical composition and with the same amount of pyrotechnic mixture as given in Table 2 were prepared.

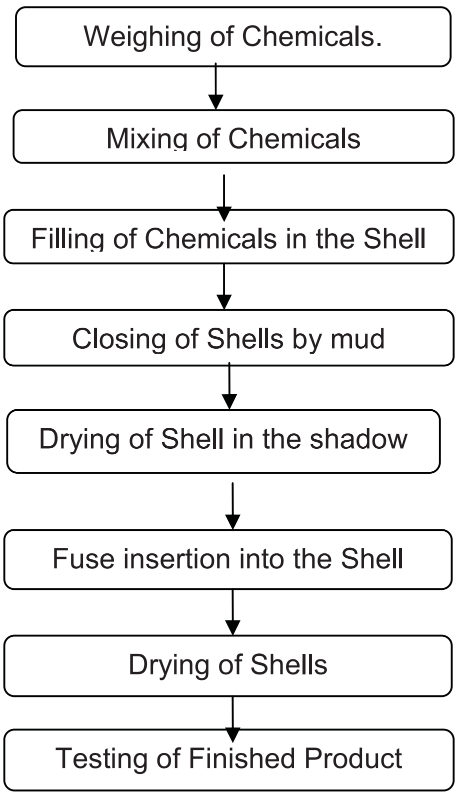

Figure 2. *Flow chart for manufacturing of the bullet-bomb.*

2.5 Instruments

Sound level tester

The sound level test is carried out as per the rules of notification of PESO (Petroleum and Explosives Safety Organisation), formerly known as 'Dept. of Explosives', Govt. of India.[8] The noise level was measured by four sound level monitors using Model No.824L obtained from Larson & Davis, USA and the average values of the four readings were taken as sound level data. These meters are capable of measuring the noise level in dB(A) and dB(C), by flat weightings with slow, fast, impulse detectors. The measurements were taken at 1.2 m elevation from the level of bursting at 4 m distance.[6] The meters were placed at four points and the angle between them was 90 °C. A 5 m diameter hard concrete surface was used as the site for carrying out the sound level test. A microphone converts sound into electrical power and a decibel meter reads out sound power in watts or dB.

3. Results and discussion

Sound level analysis

Factors affecting sound level

The sound level produced from firecrackers with two types of oxidizers, KNO_3 and $KClO_4$, was studied. The effects of different particle sizes (105, 75, 63 micron) and three different percentages of chemical composition of oxidizers (50, 57.5 and 65% with fuels of Al and sulphur) on the sound levels are given in Table 1 and 2. The pyrotechnic

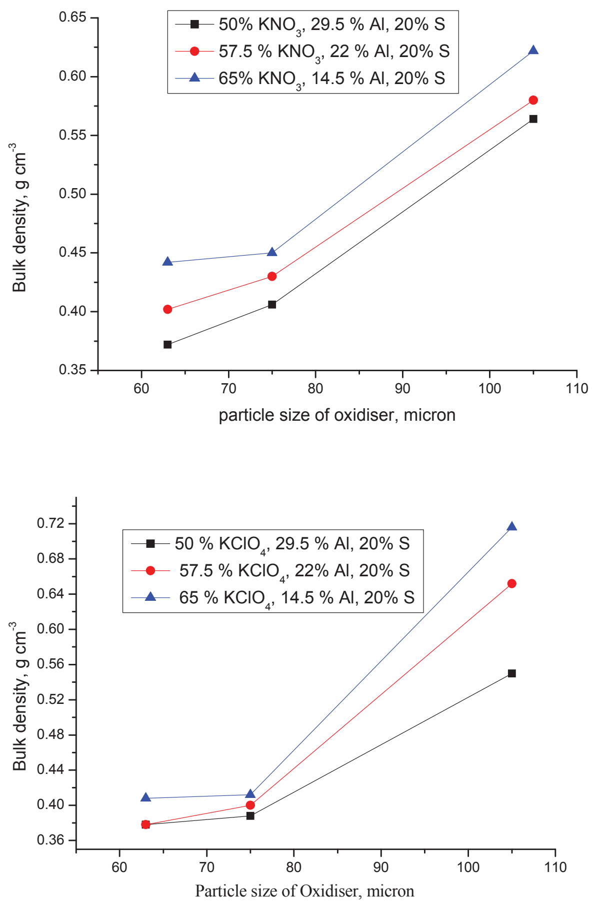

Figure 3. *a (upper) bulk density versus particle size of pyrotechnic mixture (KNO_3, Al, S and H_3BO_3); b (lower) bulk density versus particle size of pyrotechnic mixture ($KClO_4$, Al, S and H_3BO_3).*

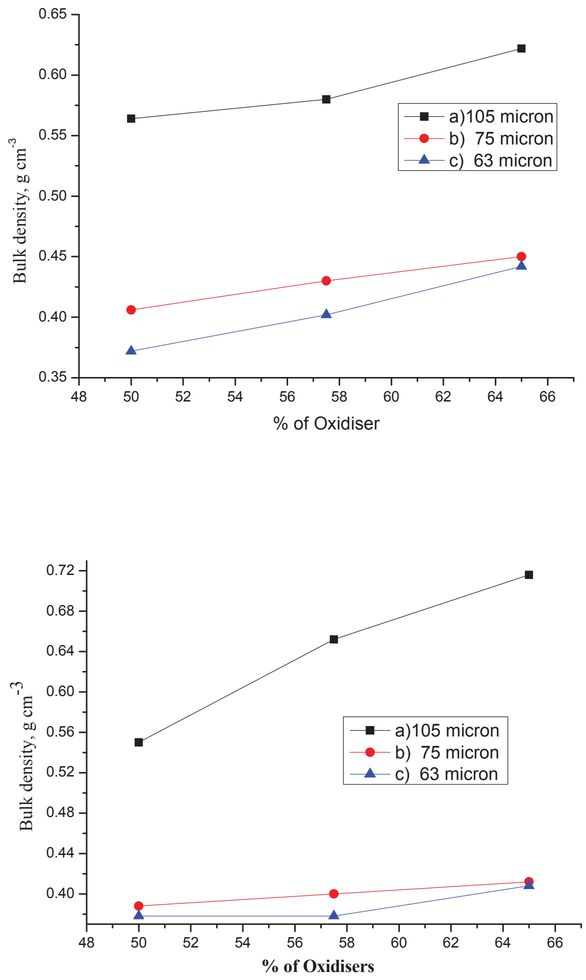

Figure 4. *a (upper) bulk density versus % of KNO_3 in pyrotechnic mixture (KNO_3/Al/S/H_3BO_3 as 50–65/29.5–14.5/20/0.5%): particle size of KNO_3 is a) 105 micron b) 75 micron c) 63 micron; b (lower) bulk density versus % of $KClO_4$ in pyrotechnic mixture ($KClO_4$/Al/S/H_3BO_3 as 50–65/29.5–4.5/20/0.5%): particle size of $KClO_4$ is a) 105 micron b) 75 micron c) 63 micron.*

mixture was homogenized to particles of different sizes using ball mill techniques and by using sieves of particular mesh size. The bulk density of the pyrotechnic mixture was measured and it was found that bulk density was increased on increasing the particle size for both the types of oxidizers, KNO_3 (Figure 3a) and $KClO_4$ (Figure 3b) and it increased with the increase in the % compositions of the oxidizers in the pyrotechnic mixture from 50% to 65% at particular particle sizes (Figure 4a and 4b).

Different parameters like the amount of pyrotechnic mixture, compositions, different types of oxidizers and particle sizes were varied and the corresponding sound levels were measured. As the amount of pyrotechnic mixture is increased, the sound level also increases for both types of oxidizers KNO_3 and $KClO_4$ (Figure 5a and 5b). Figure 6 shows the comparative study of the oxidizers KNO_3 and $KClO_4$ in producing sound with respect to the variation of the amount of pyrotechnic mixture.

In the case of oxidizer (KNO_3), three different proportions of mixtures were analysed. In the

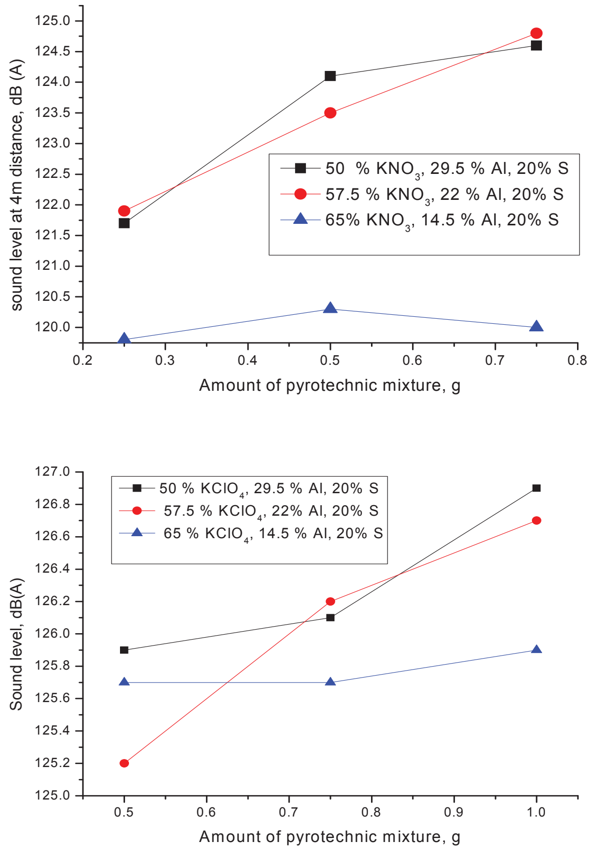

Figure 5. *a (upper) sound level versus amount of pyrotechnic mixture (KNO_3, Al, S and H_3BO_3); b (lower) sound level versus amount of pyrotechnic mixture ($KClO_4$,/Al/ S /H_3BO_3).*

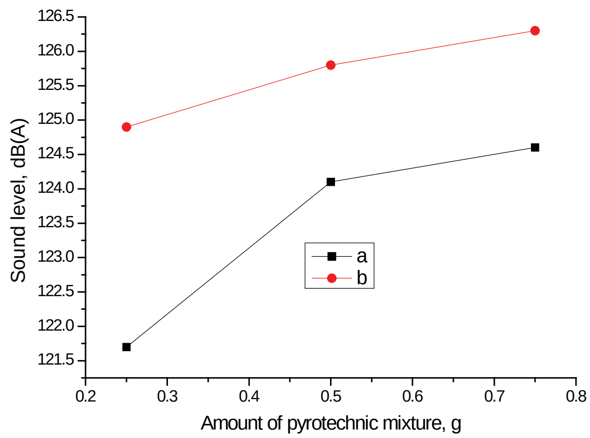

Figure 6. *Sound level versus amount of pyrotechnic mixture: a: 50% KNO_3/29.5% Al/ 20% S /0.5% H_3BO_3. b: 50% $KClO_4$ /29.5% Al/ 20%S /0.5% H_3BO_3 and particle size of KNO_3 and $KClO_4$ is 75 micron.*

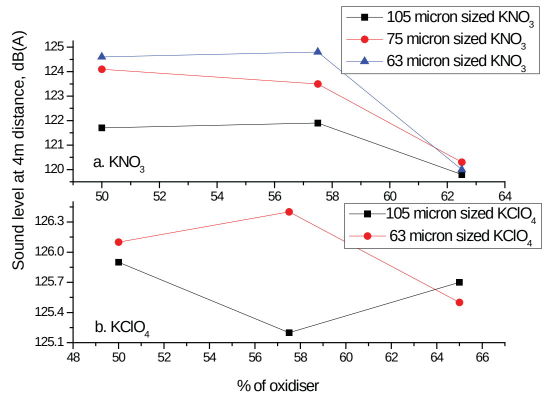

Figure 7. *Sound level versus % of oxidizer of pyrotechnic mixture. a: KNO_3, Al, S and H_3BO_3 and b: $KClO_4$/ Al, S and H_3BO_3.*

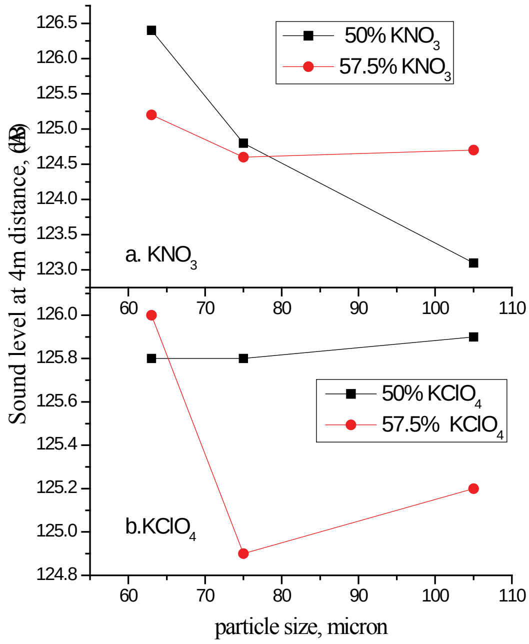

Figure 8. *Sound level versus particle size of a: KNO_3/Al/S/H_3BO_3 and b: $KClO_4$/Al/S/H_3BO_3.*

cases of 50% and 57.5% of oxidizer, as the % of oxidizer is increased the sound level also increases (Figure 7). But for 65% of oxidizer, the same trend is not observed for both types of oxidizers, KNO_3 and $KClO_4$ (Figure 7) which is more pronounced

Table 1. *Sound levels produced from the bullet-bomb firecrackers using the oxidiser KNO_3.*

Sieves used	Sample name	Oxidizer KNO_3 (%)	Fuel		H_3BO_3 (%)	Bulk density/ g cm^{-3}	Wt. of chemicals/g	Sound level[a]	
			Al	S				dB(AI)	dB(C)
150	A	50.0	29.5	20.0	0.05	0.564	0.5	122.5	
							0.75	124.7	
							1.00	124.7	
	B	57.5	22.0	20.0	0.05	0.580	0.50	120.2	
							0.75	123.1	
							1.00	124	
	C	65.0	14.5	20.0	0.05	0.622	0.50	Flash	
							0.75	122	
							1.00	Flash	
200	D	50.0	29.5	20.0	0.05	0.406	0.25	121.7	142.8
							0.50	124.1	143.7
							0.75	124.6	143.7
	E	57.5	22.0	20.0	0.05	0.430	0.25	121.9	142.5
							0.50	123.5	143.5
							0.75	124.8	143.8
	F	65.0	14.5	20.0	0.05	0.450	0.25	119.8	142.2
							0.50	120.3	141.9
							0.75	Flash	Flash
240	G	50.0	29.5	20.0	0.05	0.372	0.20	Flash	Flash
							0.40	123.7	143.7
							0.60	124.3	143.8
	H	57.5	22.0	20.0	0.05	0.402	0.20	120.2	141.5
							0.40	122.8	142.9
							0.60	124.2	143.8
	I	65.0	14.5	20.0	0.05	0.442	0.20	Flash	Flash
							0.40	Flash	Flash
							0.60	120	141.9

[a] Sound level data given are the average values of five trials recorded simultaneously by four sound level meters.

for 63 micron sized pyrotechnic mixture with the oxidizer $KClO_4$. As the amount of oxidizer is increased above 59%, less sound is produced. The variations of particle size with the sound level are given in Figure 8 which clearly indicates that as the particle size increases the sound level decreases.

The optimum fuel to oxidizer ratio is very much essential in producing sound in firecrackers.

4. Conclusion

In sound producing bullet-bomb firecrackers, the pyrotechnic mixtures containing two different oxidizers, KNO_3 and $KClO_4$, with Al, S and H_3BO_3 were used. $KClO_4$ is a powerful oxidizer in producing sound effectively in firecrackers. The composition consisting of 50–57.5% of oxidizer KNO_3/$KClO_4$, 20% S, 29.5–22% Al and 0.5% H_3BO_3 appears to be an ideal composition

Table 2. *Sound levels produced from the bullet-bomb firecrackers using the oxidiser $KClO_4$.*

Sieves used	Sample name	Oxidizer $KClO_4$ (%)	Fuel		H_3BO_3 (%)	Bulk density/ gc m^{-3}	Wt. of chemicals/g	Sound level[a]	
			Al	S				dB(AI)	dB(C)
150	J	50.0	29.5	20.0	0.05	0.550	0.5	125.9	
							0.75	126.1	
							1.00	126.9	
	K	57.5	22.0	20.0	0.05	0.652	0.50	125.2	
							0.75	126.2	
							1.00	126.7	
	L	65.0	14.5	20.0	0.05	0.716	0.50	125.7	
							0.75	125.7	
							1.00	125.9	
200	M	50.0	29.5	20.0	0.05	0.388	0.25	124.9	143.8
							0.50	125.8	143.8
							0.75	126.3	143.8
	N	57.5	22.0	20.0	0.05	0.400	0.25	124.1	143.4
							0.50	124.9	143.6
							0.75	122.6	143.4
	O	65.0	14.5	20.0	0.05	0.412	0.25	Flash	Flash
							0.50	Flash	Flash
							0.75	Flash	Flash
240	P	50.0	29.5	20.0	0.05	0.378	0.20	124.4	143.7
							0.40	125.5	143.8
							0.60	126.1	143.8
	Q	57.5	22.0	20.0	0.05	0.396	0.20	124.6	143.7
							0.40	125.5	143.8
							0.60	126.4	143.8
	R	65.0	14.5	20.0	0.05	0.408	0.20	124.1	143.6
							0.40	125	143.8
							0.60	125.5	143.8

[a] Sound level data given are the average values of five trials recorded simultaneously by four sound level meters.

in producing the allowed sound pressure level. Decreasing the particle size of the pyrotechnic mixture increased the sound level produced from the firecrackers which indirectly supports the idea of using a smaller amount of pyrotechnic mixture in the firecrackers. In India, $KClO_4$ is a banned chemical due to its high impact and friction sensitiveness and it could be easily replaced with the oxidizer KNO_3, especially in sound producing firecrackers.

Acknowledgements

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