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Airblast TNT equivalence for a range of commercial blasting explosives

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Abstract

Results are reported from a programme of work undertaken by the UK Health and Safety Executive to investigate the airblast produced by commercial sector explosives having velocities of detonation (VoD) in the range 2000–8200 m s^{-1}. The data produced will be useful in evaluating the blast hazards of such explosives in industrial circumstances and also as a means of assessing post-accident damage. All of the solid explosive materials studied produced blast waves which ramped up into shock-wave form close to the point of initiation. The dependence of peak overpressure and positive phase impulse on scaled distance is presented and compared to that of TNT. The TNT equivalence (TNT_e) technique is shown to be applicable to solid phase explosives with a wide range of VoD, although the precise values of TNT_e vary with distance. Crown Copyright © 2000 Published by Elsevier Science B.V. All rights reserved.

Keywords: Explosive; Explosion; Airblast; TNT equivalence; Shock wave; Overpressure; Impulse; Damage; Airburst

1. Introduction

This paper describes a programme of work undertaken at the Health and Safety Laboratory (HSL) to investigate the blast waves produced by a range of commercially

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available explosive materials when initiated in free-air. The data presented in this paper complement previously reported results for similar materials detonated at ground level [1].

The strength of explosions is commonly related through the TNT equivalence (TNT_e) concept to the effect from an equivalent mass of TNT. This provides a useful but crude means of comparing the severity of blast effects and likely damage–distance relationships from a variety of explosion sources.

Blast effects from military high explosives such as TNT have been widely reported [2–4]. However, little information has been published regarding the blast from materials with lower velocities of detonation (VoDs) which release their energy more slowly.

The present study was undertaken to examine whether TNT_e can be applied to explosives with VoDs significantly lower than that of TNT. Direct experimental measurements of blast parameters were made in order to investigate whether the pressure profiles and distance dependence of blast waves generated by low order commercial explosives (mining explosives can have VoDs as low as 2000 m s^{-1}) were sufficiently similar to those from TNT for the technique to be valid.

2. Experimental

The explosives examined in this study, Table 1, were chosen to cover a range of ballistic mortar [5] strengths and detonation velocities.

In order to generate symmetrical blast waves, spherical charges of uniform density were required. Thin-walled frangible plastic shells were used to contain the explosives, as shown in Fig. 1. On reaching the test site, a Nobel no. 6 detonator was inserted into

Table 1
Details of the materials studied

Explosive	Description	Velocity of detonation (m s^{-1})	TNT_e by ballistic mortar (%)	Density (g cm^{-3})
PE4	RDX/lithium grease (88/12)	8200	130	1.6
Super Dopex	92–94% Nitro-glycerine (NG) gelatined with 6–8% nitro-cellulose	7700 (Blasting Gelatine)	98	1.6
TNT	Cast TNT spheres for reference purposes	6900	100	1.6
Nitroguanidine	Commonly used in propellant manufacture, Class 1.1D dry	2600	85	0.3
Powergel 700	Slurry explosive	3500–4500	71	1.1
Driftex	NG based gelatinous permitted mining explosive (P1)	2500–3500	57	1.6
Penobel	NG powder permitted mining explosive (P4/5)	2000	37	1.3

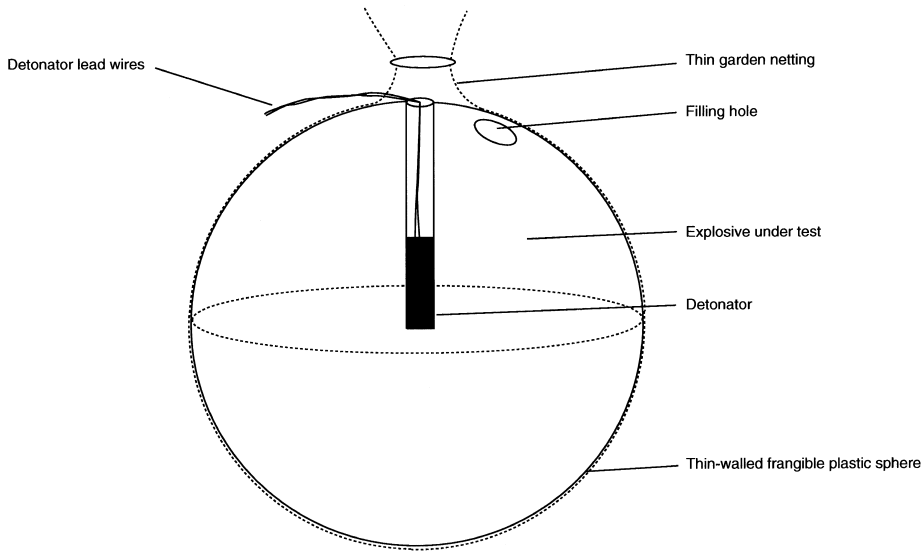

Fig. 1. Schematic of explosive charge.

the charge through a hollow plastic tube located in the top of the sphere. The charge was then suspended by thin netting and hoisted to 5 m above the ground before initiation. Experiments were conducted to compare the blast recorded from plastic cased and uncased charges, and it was found that, within experimental error, the thin plastic shell cases had no effect on the intensity of blast waves produced.

Initiation of materials which were not cap-sensitive (e.g., nitroguanidine, TNT) was achieved by means of a detonator–booster system. Small tetryl pellets were used to initiate the TNT spheres. Spherical boosters of Super Dopex were placed at the end of the detonator pocket to boost the charge of nitroguanidine.

The firing programme for the trials is detailed in Table 2.

Dynamic air pressure measurements were made with 12 Meclec FQ-11c piezo-electric gauges (resonant frequency 80 kHz) mounted in B12 baffles. Electrical signals from

Table 2
Programme of experiments

Material	Charge weight (kg)	No. of repeat tests	Initiation system
PE4	1	5	detonator
Super Dopex	0.05, 0.23, 0.9	5, 3, 4	detonator
TNT	0.22, 0.44, 3.4, 6.7	4, 4, 4, 4	detonator + small tetryl booster
Nitroguanidine	4.9	1	detonator + 0.22 kg Super Dopex
Powergel 700	3.5	5	detonator
Driftex	4.9	5	detonator
Penobel 2	3.7, 21	5, 5	detonator

these gauges were amplified using Kistler 5011 charge amplifiers (having 200 kHz frequency range), and recorded on a Nicolet 500 series datalogger. Twelve bit samples were taken at a sampling rate of 1 MHz. Gauges were positioned at a height of 5 m off the ground, at distances of 5, 10, 20, 30, 40, 50, 75 and 100 m from the firing position, as shown in Fig. 2. All of the equipment was calibrated and quoted results are traceable to national standards where appropriate.

The techniques used to scale and analyse the recorded blast were as reported previously [1].

The modified Friedlander equation was fitted to the upper portion of the backslope of the blast waves in order to compensate for the non-ideal response of the pressure gauges, caused by their finite response time and the presence of noise on the signal. This technique, which has been reported elsewhere [3,6], enabled peak overpressures to be obtained by extrapolation. The effect of variations in ambient pressure on the results was compensated for by Sachs scaling the data to 1 kg and standard atmospheric pressure [1].

Positive phase impulse per unit area was calculated by numerical integration of the recorded blast waves using Fast Analysis and Monitoring of Signals (FAMOS) software [7]. Impulse values derived by this method were again Sachs scaled.

In order to provide a direct comparison under the experimental conditions used for the trials, some tests were done to measure the airburst characteristics of TNT spheres.

In our previous analysis of blast pressure measurements [1,8], we compared the airblasts measured from commercial explosives with published TNT airblast data. The

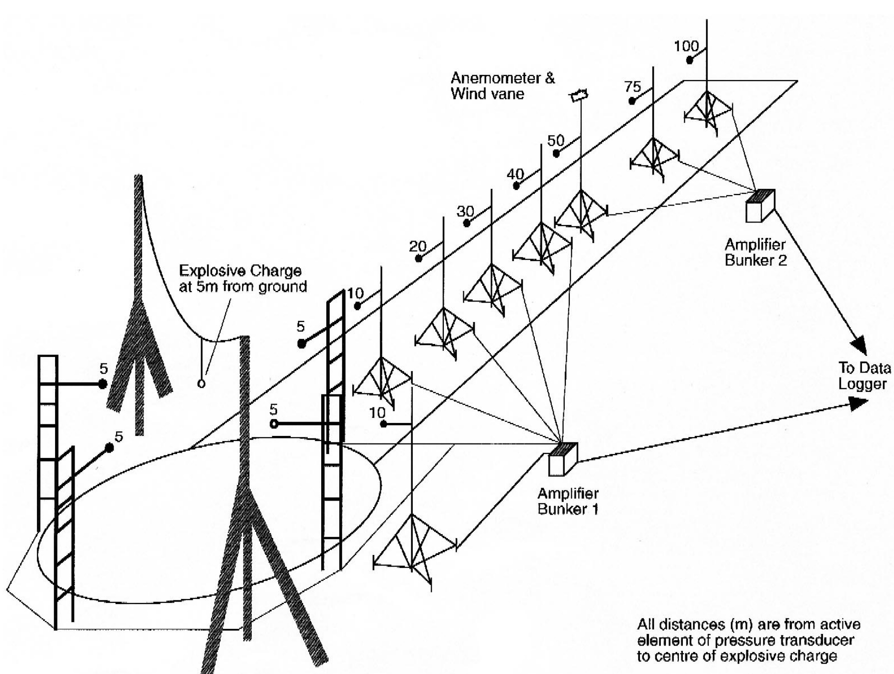

Fig. 2. Layout of blast measurement facility.

analysis presented here used the TNT blast parameters measured at HSL to calculate TNT_e values by overpressure and impulse.

Best straight lines were fitted to the data points obtained from these experiments and values of TNT_e by overpressure and impulse were subsequently calculated using the methods reported by Maserjian and Fisher [9] and later used by Esparza [10].

Extrapolation of the measured TNT data to scaled distances greater than those measured was necessary in order to evaluate the TNT_e for the low power explosives such as Penobel 2. A straight line was fitted to the low pressure TNT data points on a log–log graph against Z. This yielded a gradient of -1.25 which is in reasonable agreement with the value of -1.38 reported by Honma et al [11] for weak (< 200 Pa) shocks in air.

3. Results

It was found that the positive phase of pressure recordings from gauges at distances greater than 20 m from the initiation point was modified by the presence of a

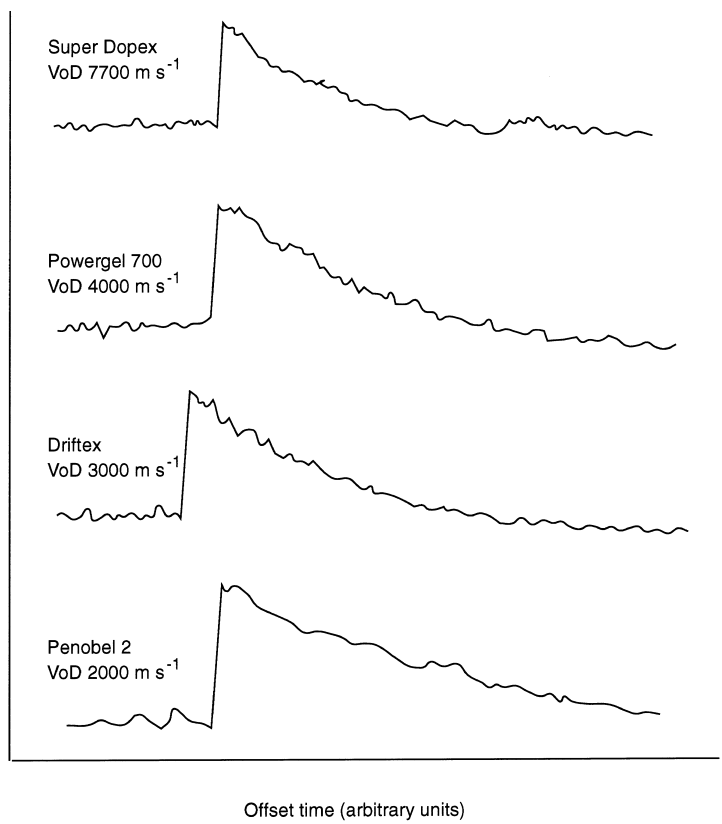

Fig. 3. Pressure profiles for a range of explosives, measured at 5 m from the initiation point.

Table 3
TNT_e of a range of commercial explosives

Explosive	TNT_e by ballistic mortar (%)	$[TNT_e]_{OPmax}$ (Average) (%)	$[TNT_e]_{I+}$ (Average) (%)
PE4	130	135	130
Super Dopex	98	105	98
Nitroguanidine	85	76	76
Powergel 700	71	56	53
Driftex	57	55	50
Penobel 2	37	17	16

ground-reflected wave. In order to provide a meaningful comparison between the measured blast waves from commercial sector materials and those for TNT, only pressure waves free from unwanted ground reflections were analysed to obtain values of peak overpressure and positive phase impulse.

Fig. 3 shows the blast wave profiles from four of the explosives studied, measured at 5 m from the initiation point. The profiles have been scaled horizontally and vertically for illustrative purposes. No smoothing of the data has been performed. It is clear that all of the blast waves had achieved shock wave form at a distance of 5 m from the initiation point (i.e., a maximum scaled distance of 6.9 m $kg^{-1/3}$).

The values of TNT_e by overpressure and impulse evaluated from the measured blast parameters are presented in Table 3. The use of experimentally determined rather than

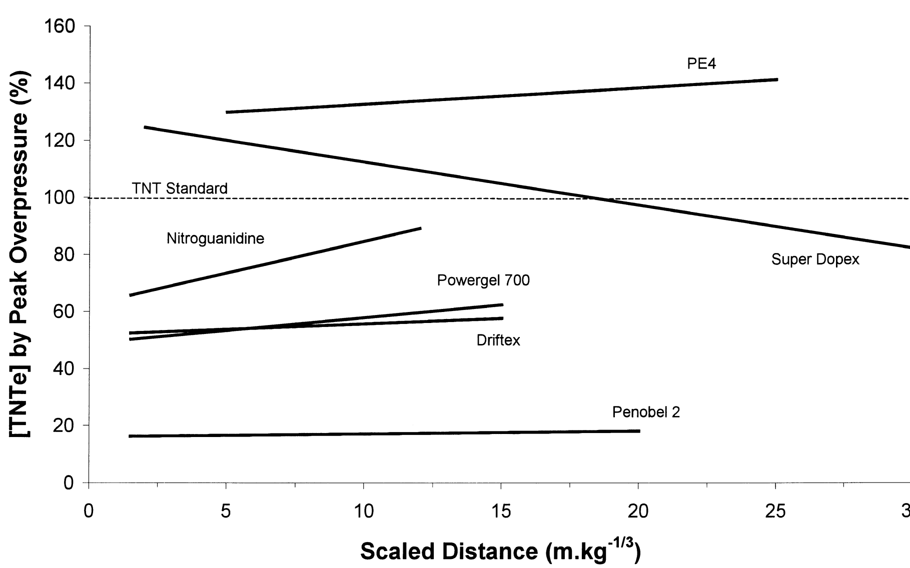

Fig. 4. The dependence of TNT_e by overpressure on scaled distance.

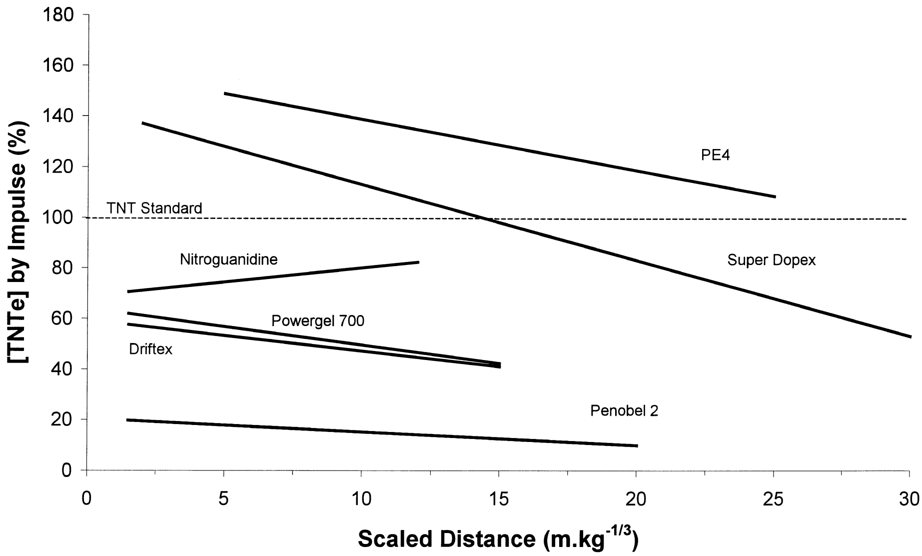

Fig. 5. The dependence of TNT_e by impulse on scaled distance.

literature values for the characteristics of TNT accounts for the differences between these results and previously published air blast data [8].

The dependence of blast wave TNT_e on scaled distance is illustrated in Figs. 4 and 5.

4. Discussion

The two different methods of calculating TNT_e give very similar values and rank the explosives in the same order. The average TNT_e values are also in reasonable agreement with those from ballistic mortar experiments, but there is an indication that the lower the energy of the explosive the greater the effect of the loss of confinement when the explosive is tested in the airburst configuration. For example, Penobel 2 is a permitted mining explosive which is designed to release its full energy only when confined.

The similarity of the two TNT_e values derived for each of the explosives from the airblast trials can be contrasted to a previous study of similar materials detonated at ground level [1] which indicated that TNT_e was dependent on whether it was derived from overpressure or impulse data. This observation may, however, be related to the fact that the earlier study used general literature values [12] as the TNT reference rather than, as in the present study, data derived from cast TNT spheres in the same experimental configuration as the other explosives investigated. In general, there is a spread in published TNT data, especially for positive phase impulse. Since TNT_e is calculated by cubing a ratio of scaled distances, any variation in the data are accentuated and consequently literature TNT_e values show considerable variation.

Figs. 4 and 5 indicate that the values of TNT_e by overpressure and impulse are distance dependent. The dependence is greater for TNT_e calculated by impulse than by overpressure for most of the explosives studied, although it does not appear to be correlated to the VoD of the explosive. The distance dependences of PE4 and Super Dopex, the explosives with most similar VoDs to TNT, are greater in magnitude than Penobel 2, which has a very low VoD. The faster decay of impulse with distance for all of the explosives examined except nitroguanidine may be linked with the oxygen balance of the explosives. TNT and nitroguanidine are both heavily oxygen deficient [13] (−73.9% for TNT and −30.7% for nitroguanidine) and consequently the detonation products contain hot fuel, which combines with oxygen from the air during after-burning. The energy liberated by this process may continue to drive the blast wave away from the charge for a longer period than for the explosives with good oxygen balance. The other commercial explosives studied are nearly oxygen balanced and therefore will have far less (if any) after-burning to prolong the blast wave generation.

5. Conclusion

Blast waves from a range of explosives having VoDs between 2000 and 8200 m s^{-1} have been examined in this study. Pressure recordings made during these experiments showed that the blast waves had achieved shock wave form within 6.9 m $kg^{-1/3}$ from the initiation point. At greater distances, structural loading from all of the explosives studied can therefore be expected to follow a shock-wave form, and hence, models based on TNT are applicable. The information presented in this paper should be useful for both the assessment of damage following an accidental explosion and for estimating the potential blast hazards from different quantities of commercial sector explosives.

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