

New small scale gaseous detonation data compared with Tang and Baker's blast curves : a discussion on the energy to be considered as producing the blast wave after a gaseous detonation

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1 Introduction

This paper is related to the study of the effects of an explosion and particularly the pressure due to the blast wave induced by a detonation. We report some experimental data obtained previously with the detonation of small gaseous charges [1] and bring a comparison between these data and the theoretical models proposed by Tang, Baker and Baker [2][3][4][5].

The major goal of the experiments reported in [1] was to predict the effects of high energy explosives in real scale situations with using measurements made at the laboratory scale involving small gaseous charge. This experimental set-up offers the possibility to perform an important number of experiments with varied geometries as targets and is feasible with relatively limited resources (see [6][7]). Meanwhile, if the approach of predicting the gaseous detonation effects by the use of a TNT equivalency has been widely examined and has given place to various developments or methods [8][9], the reverse approach of predicting the effects of a solid explosive detonation by the use of experiments with gaseous charges is not totally finalized yet. Nevertheless this idea is not a new one: Dewey [10] reports experiments performed in Canada in late 1950's and throughout the 1960's, where TNT was initially used in massive quantities, then replaced by mixtures of propane or methane and oxygen with the objective of reducing the cost of the experiments; the report by Dewey also illustrates the difficulties met in the experimental process and also the risks associated with manipulating important volumes of flammable gases. These comments made by Dewey emphasize the interest of performing small scale experiments rather than full scale experiments, as long as the subject is focusing on detonations for which the scalability of phenomena is guaranteed.

More recently, the most important effort on the subject of gaseous detonations and how they compare with TNT detonations is due to Tang and Baker [2][3][5]: these studies are based on the statement that blast waves obtained after a gaseous detonation and after a TNT detonation would produce different loadings on a structure impacted by the shock wave or different pressure profiles on a gauge placed at a distance of the charge; for instance, the smaller the distance to the charge is, the more important the discrepancies between a gaseous detonation blast wave profile and a solid explosive detonation blast wave profile are. Which corroborates Dorofeev's conclusions [11]: "there is no reason to use TNT equivalents estimating the blast effect from gaseous detonation". In conclusion to these observations, Baker [2] have proposed an approach to replace the simple TNT equivalency constant generally used, also called "TNT equivalent": they have introduced a series of charts or – "blast curves" – giving peak positive overpressure or impulse as a function of the distance from the ignition and as a function of the flame speed. These charts were established using 1D numerical simulations of fuel vapour-air propagation of the blast generated by combustion, deflagration and detonation. They are typically an alternative to the systematic use of the widespread TNT blast curves when the effects of gaseous explosions and not solid explosive detonation effects are studied. Subsequently, if confirmed experimentally the blast curves exhibited by Tang et al., also known as the Baker-Strehlow-Tang curves, would constitute a very powerful tool to derive a parameter-dependent TNT equivalency.

Because the Baker-Strehlow-Tang curves have been constructed from a theoretical stand point, the authors have looked for experimental data to examine the validity of their model. This has been done for instance in reference [4] using the results by Brossard et al. [12]. In this work by Brossard et al., the results of three different experiments were summarized, covering a gaseous volume varying from 520 cm³ to several m³. This comparison concluded to a good agreement between the experimental results and the blast curves.

In the present paper, we want to reproduce the comparison made in reference [4] considering very recent results obtained by Trélat et al. at the Laboratoire Energétique Explosion et Structures in Bourges. These experiments have been realized at small scale with relatively low gas volumes, ranging from 113 cm³ to 905 cm³. As shown in this paper, the use of these new experimental results allows a full comparison with the Baker-Strehlow-Tang curves considering every parameter representative of the pressure pulse induced by the blast wave; say peak overpressures, positive and negative impulses, positive and negative durations, as well as the arrival time. But first of all, as detailed in the following, the post processing of the results raises the issue of the choice for a correct value of the energy producing the blast wave after a gaseous detonation, used for scaling the results. Thus we show that the approach chosen to obtain the value of this energy has a significant influence on the adequacy of the results with the theoretical curves. In conclusion, from an engineering statement, we would like to attract researcher's attention on this energy quantity, difficult to define from a physics stand point, but of major importance when used in engineering applications.

2 The reference energy or energy producing the blast wave after a gaseous detonation

The Baker-Strehlow-Tang blast curves are established using Sach's scaling. Nevertheless, most authors do not precisely give the value of the energy used in the Sach's scaling. For instance, in reference [4] there is no particular precision on the energy used to compare the theoretical results and Brossard's experimental results from reference [12].

As a matter of fact, different methods may be used to evaluate this energy. Among the existing different energetic models, six of them have been investigated in this paper. In addition, the chemical reaction associated with the detonation can be considered in a simplified form (see [1]), or completed with secondary products of detonation. In the following, the gas mixture is generalised to a mixture composed of ϕ moles of propane and 5 moles of oxygen dioxide. Reactants and products of detonation are considered to be in a gaseous phase. The energy values are expressed in MJ/m³, and named Ev.

The methods that have been investigated for this paper are:

- Enthalpy variation method
- Explosion energy calculation described in Kinney and Graham [13]
- Shultz and Shepherd's method [14], based on a two-gamma model [15][16]
- Thouvenin's method [17]

The curve labelled Sheperd (publication) refers to values taken from reference [14], the curve labelled Sheperd (calculations) refers to our own calculations using formula found in [14]

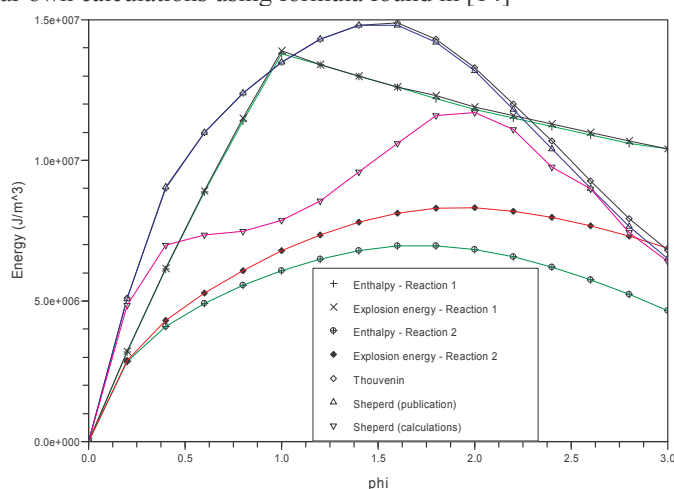


Figure 1 : Comparison of 6 approaches to estimate the energy delivered by the detonation of a propane oxygen mixture

The enthalpy variation method and the explosion energy method are used with the two different assumptions described above: in a first case, a complete chemical reaction with two reaction products (carbone dioxide and

water) is considered, and in a second case, several secondary products of detonation are considered. The Thouvenin's and Shepherd's methods implicitly consider secondary products of detonation, without which Chapman-Jouguet conditions cannot be calculated. The calculation of the equilibrium is done with the computer program STANJAN [18].

The values of energies calculated by the different approaches are shown on figure 1. As a first observation, it comes out of this comparison that the maximum energy delivered is not always obtained in the stoichiometric conditions. For instance, the maximum energy is obtained $\phi = 1.5$, using Thouvenin's or Shepherd's methods, whereas the maximum is obtained for $\phi = 2$, using the Kinney and Grahams's explosion energy.

3 Comparison of the experimental data with the blast curves

Although Baker-Strehlow-Tang blast curves were established from numerical calculations of fuel-air mixture detonations, propane-oxygen detonation experimental data are compared with this curve in order to see if scaled results could be summered as a function of the Mach number independently of the nature of the gas mixture.

The peak positive overpressure, the time of arrival of the blast, the positive impulse, the peak negative overpressure and the negative phase impulse obtained from Trélat et al. experiments [1] are superimposed on the Baker-Strehlow-Tang blast curves, using $E_v = 13.8 \text{ MJ/m}^3$ (enthalpy variation method) and $E_v = 6.8 \text{ MJ/m}^3$ (Explosion energy method). It has to be noticed that for scaled overpressure the difference between these two values of volume energy implies a translation of the experimental points upon the axis x representative of the scaled distance. The peak positive overpressure and positive impulse are also compared to Dorofeev's empirical model according to its domain of validity (see in [3]), using the two above values of energy.

Concerning the peak positive overpressure, and although it is known to be a rather not very reliable property because of the peak and its treatment, a good agreement with the reference curve named « Tang $M_f = 5.2$ » is obtained for the two values of volume energy involved in the comparison on figure 2 and 3. It can be noticed that this agreement is better for the volume energy $E_v = 6.8 \text{ MJ/m}^3$, which corresponds to the mechanical energy involved to create the blast, according to Kinney and Graham[13]. Moreover, when plotting Dorofeev data, a convergence of Trélat's experimental data to Dorofeev's empirical model is observed for $E_v = 6.8 \text{ MJ/m}^3$. As far as the positive impulse is concerned, a spread of data, which intensity reaches 4, is observed.

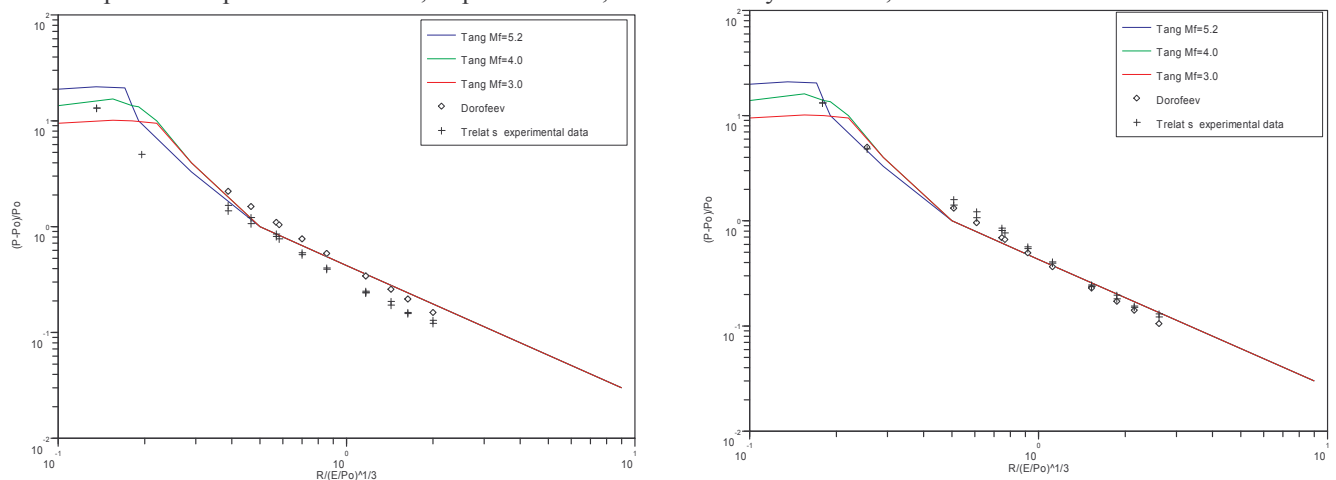


Figure 2 : Peak positive overpressure ($E_v = 13.8 \text{ MJ/m}^3$ (left) - $E_v = 6.8 \text{ MJ/m}^3$ (right))

As a comparison to the preceding Trélat's paper [1], the use of scaled distance and scaled impulse reduces the spread of data. The spread of data concerning impulse remains rather strange since the arrival time, the peak positive overpressure and the duration of the positive phase seem not to be dispersed data. The spread of data of the negative impulse as well as the spread of data of the negative peak overpressure can be illustrated using Hopkinson's law for two pressure time-history. These spread of data are consistent with the results in reference [3] comparing his abacuses to Brossard's experimental results. The comparison of the arrival time obtained from calculations (Baker) and experiments (Trélat) shows a good agreement.

4 Conclusion

Within an industrial engineering framework, the comparison of charts found in open literature and available experimental data is essential. The comparison of experimental data with Baker-Strehlow-Tang blast curves was

originally based on the hypothesis that there exists a unique curve independently of the nature of the gaseous mixture. The comparison presented in this paper shows that the positive phase of experimental signals is representative of detonation even if the conclusion is less obvious with the negative phase. Nevertheless, this comparison does not make it possible to rule on energy to choose from an engineer stand point. As far as gaseous detonation is concerned, lots of authors presented numerical or experimental results as a function of the energy liberated by the gaseous cloud. The evaluation of this energy seems to be proper to each author and does not allow easy comparisons. Moreover it raises the question of the utility of scaling gaseous detonation. As a matter of fact, the precise knowledge of released energy depends on the kinetics of the chemical reaction. Some authors [19] presented an approach to estimate this energy but some complementary research should be led. The aim of complementary researches upon the energy liberated to create gaseous blast waves is to determine a TNT equivalency for every parameter as a function of the reduced distance. To be more precise, either the equivalency is based upon energy considerations and therefore the energy used must be consistent for the gaseous and solid substance, or the equivalency has to be based upon mass considerations, which is a well-known parameter from the experimental conditions, but will lead to a TNT equivalency depending on the used gaseous substance as in Dewey [10]. This question needs to be answered if the objective of claiming that solid explosive blast effects at full scale can be predicted from gaseous detonation small scale experimentations.

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