A MODIFICATION TO THE K_G METHOD FOR ESTIMATING GAS AND VAPOUR EXPLOSION VENTING REQUIREMENTS

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Measurements of the reduced explosion pressures in vented gas explosions in compact and elongated vessels are reported. Measurements in enclosed vessels of the K_G factor are also reported. The measured explosion pressures are compared to values predicted by the K_G method equation given in NFPA 68. The results indicate that modifications can be made to the K_G method to produce more realistic pressure predictions. The same equation is used in vent area calculations but variants of the K_G factor are substituted in the equation. These variants characterise vented explosions more successfully than the usual values of K_G. This is because the usual measurement of the K_G factor takes place at a late stage in an enclosed explosion and in a relatively small volume and these are inappropriate conditions for characterising vented explosions in which pressures do not reach high values and when vessels have a larger volume. The modified K_G method uses K_G values derived from the present tests and satisfactorily predicts measured reduced explosion pressures for vessels with L/D ratios up to 5.

KEYWORDS: venting, gas explosions, vapour explosions, K_G factor

INTRODUCTION

Explosion relief venting is a technique for mitigating the effects of a gas or vapour explosion in items of industrial plant. It involves fitting into the walls of a vessel weak panels that burst early in the explosion and allow gas and combustion products to vent into the open air. As a result the internal pressure rise is considerably reduced, as is the potential for damage to the vessel and injury to people.

To apply the technique the size of the vent and its failure pressure have to be chosen so that the maximum internal pressure, the reduced explosion pressure (P_{red}), is below that which would cause failure of the enclosure. It may be acceptable to allow some damage to the enclosure, for example bowing of metal panels, provided this does not result in catastrophic failure of the vessel. Incorrectly sized relief vents will result in either the plant not being properly protected or impracticable or unnecessarily expensive vents being fitted.

There are various methods available for sizing explosion relief, ranging from empirical formulae and nomograph type methods to complex mathematical models of the venting process[1,2].

Recently, the Health and Safety Executive has funded a programme of work to generate data on vented explosions that can be used to assess the accuracy and range of application of vent sizing methods and to develop improved guidance where appropriate. This paper reports the analysis of the experimental data in a series of comparisons with vent sizing methods and the development of a modification of the K_G method for vent sizing.

EXPERIMENTAL

The data generated consists of reduced explosion pressures measured during gas explosions in vented compact, elongated and connected cylindrical vessels.

Three compact vessels were used, 2, 6.3 and 20 m^3 in volume. The effects of gas, gas concentration, vent area, bursting pressure of the vent, ignition strength, ignition position and the presence of internal obstacles on the reduced explosion pressure were studied[3].

The elongated vessels were cylindrical, with a diameter of 1.1 m and Length to Diameter (L/D) ratios in the range 5.5 to 11.8, and rectangular with a cross-section of 2.5 m ×2.5 m and Length to Width (L/W) ratios of 3 to 12[4].

The linked vessels were the ones used in the compact vessel tests. The effects of volume, volume ratio, diameter and length of connecting pipe, ignition position and distribution of vent area on the reduced explosion pressures were studied[5].

In addition, the effect of the vessel volume on the K_G factor has been studied. The K_G factor is a parameter, calculated from the equation

$$K_G = V^{1/3} (dP/dt)_{max}, \quad (1)$$

where $(dP/dt)_{max}$ is the maximum rate of pressure rise measured in a contained explosion at the optimum gas or vapour concentration in air (bar $sec.^{-1}$), and V is the vessel volume (m^3).

The K_G factor is essentially equal to the maximum rate of pressure rise at the optimum gas concentration measured under standard test conditions in a 1 m^3 vessel and can be used to estimate vent areas by using either Nomographs or equations. Pressure-time histories from enclosed gas explosions in vessels of 20 litres, 2, 4 and 20 m^3 in volume were analysed[6,7].

The outcome of these studies was a mass of data that quantified the dependency of the reduced explosion pressure on the different variables that can affect it. The analysis in this paper is limited to the compact and elongated vessel results.

DISCUSSION

COMPACT ENCLOSURES

Comparison of Predicted and Measured Reduced Explosion Pressures

The pressure-time histories of explosions in compact vessels exhibited a multi-peak structure, with usually three peaks. The first peak (P_1) is a result of the vent starting to open, and has a value approximately equal to the vent burst pressure. A second peak occurs if and when the rate of volume production due to combustion exceeds the volume rate of outflow through the vent. The second peak pressure, P_2, then occurs when the rate of combustion declines after reaching its maximum value and a situation is again reached where the rate of outflow exceeds the rate of volume production. The third peak (P_3) is acoustically induced and was, in most cases, the largest peak of the three. This peak is capable of causing damage to enclosures if the venting arrangement does not take it into account. In nearly all the HSL tests this large final peak was observed.

The measurements of maximum reduced explosion pressures obtained by HSL for near cubical vessels have been compared to predictions from a number of published vent sizing techniques[3]. In general it was found that the empirical methods, such as those of Cubbage and Simmonds[8] and Rasbash[9], underpredicted the peak reduced explosion pressures. The predictions of the K_G method published in NFPA 68[10], Bradley and Mitcheson's method[11] and Molkov's method[12], on the other hand, were in reasonable agreement with some of the experimental values. These comparisons generally show, however, that no calculation method gives accurate estimates of the reduced explosion pressures under all circumstances.

Modified K_G Factor Approach to Vent Sizing

Of the simpler vent sizing methods, the K_G factor approach from NFPA 68[10] appears to be the most flexible, but it requires modification if it is to be successful. It is clear from the qualifications written down in NFPA 68 that K_G is far from being a universal constant and that it can be affected strongly by alterations to important variables.

In this section a proposal for using a modified K_G method for estimating vent areas is described, based on the measurements of reduced explosion pressures in vented vessels and the K_G factor measurements derived from the enclosed explosion tests performed by HSL.

The original K_G method, based upon the cube root law, was in the form of nomographs for a number of gases (methane, propane, coke gas and hydrogen), that allowed the vent area to be calculated from a knowledge of the vessel volume, the maximum reduced explosion pressure allowed and the opening pressure of the vent. For other gases the vent area could be found by interpolation of the results from the four reference nomographs, provided the K_G value for the gas was known. These nomographs were developed for initial conditions of:

- No initial turbulence in the enclosure at the time of ignition
- No turbulence-producing internal obstacles
- An ignition energy of 10 J or less
- Atmospheric pressure in the vessel prior to ignition.

As an alternative to using the nomographs equation 92) can be used for L/D values of two or less:

$$A_v = [\{(0.1265 \log_{10} K_G - 0.0567)\, P_{red}^{-0.5817}\} + \{0.1754\, P_{red}^{-0.5772}\, (P_{stat} - 0.1)\}]\, V^{2/3} \quad (2)$$

The equation is valid for the following conditions:

$K_G \leq 550$ bar m s^{-1}
$P_{stat} \leq 0.5$ bar
$P_{red} \leq 2$ bar and $\geq P_{stat} + 0.05$ bar
$V \leq 1000$ m^3
Initial pressure before ignition of <0.2 bar

When the L/D ratio extends from 2 to 5, the vent area calculated from equation (2) has to be increased. The additional vent area ΔA is calculated from equation (3):

$$\Delta A = [A_v\, K_G\, (L/D - 2)^2]/750 \quad (3)$$

and applies when P_{red} is no higher than 2 bar.

K_G values are measured during a standard test but it cannot be considered as a constant that is unchanging with vessel volume. Data in NFPA68 show that the value of K_G for a given gas increases if it is derived from pressure-time traces measured in vessels of increasing volume[10]. The graph in NFPA68 is incorrectly labeled, however; the volume scale should read litres, not m^3.

Nevertheless, the K_G factor method is a relatively simple method to use, even if its straightforward application is not always successful if standard values of K_G are applied under all circumstances. This is because the K_G factor is measured at a point on the pressure-time curve where the explosion overpressure is several bar, well above the pressures likely to be reached in a vented explosion. If the reduced explosion pressure in a vented explosion does not exceed 0.5 bar, say, then it is inappropriate to apply the standard K_G factor, because it is a measure of the rate of pressure rise in circumstances that never occur in the vented explosion. A variation of the K_G factor based on the pressure-time history at a much earlier stage in the closed vessel explosion is likely to be more appropriate. Similarly, as the K_G factor is known to vary with vessel volume, a variation of the K_G factor relevant to larger volumes is more appropriate to vented explosions in larger volumes.

Thus, if a range of K_G factors can be specified, derived from pressure-time histories measured in enclosed vessel explosions, it may be possible to characterise a range of vented explosions with more flexibility than by simply using the standard K_G value.

Based on this idea three variations of the K_G factor have been used in an analysis of HSL's experimental results:

$K_{G(20\ litre)}$ is the K_G factor measured in the 20 litre sphere in a standard test and is shown to characterise vented explosions in small volumes in circumstances where the reduced explosion pressure is relatively high.

K_{GV} is the K_G factor measured in an enclosed vessel with the same volume and L/D ratio as the vented vessel, and is shown to characterise vented explosions in larger vessels in circumstances where reduced explosion pressures are relatively high eg ignition remote from the vent.

$K_{GV(0.5)}$ is the K_G measured at 0.5 bar g in an enclosed vessel of the same volume and L/D ratio as the vented vessel, $K_{GV(0.5)} = V^{1/3} \times (dP/dt)_{(0.5\ bar\ overpressure)}$, and is shown to characterise explosions in larger vessels in circumstances where the reduced explosion pressures are relatively low eg central ignition.

The values of the K_G variants measured in HSL's enclosed explosion tests are given in Tables 1 and 2.

Table 1. The $K_{G(20\ litre)}$ and K_{GV} values

Gas	20 l sphere $K_{G(20\ litre)}$[1]		2 m^3 vessel K_{GV}	4 m^3 vessel K_{GV}	20 m^3 vessel K_{GV}
	Kuhner*	HSL**	HSL	HSL	HSL
Ethylene	206	158	219	117	132
Propane	104	79	318	52	60
Methane	65	61	61	30	33

* Measurements reported by Kuhner.

** Measurements by HSL.

Table 2. The $K_{GV(0.5)}$ values for each vessel at a pressure of 0.5 bar gauge

Gas	20 l sphere	2 m^3 vessel	4 m^3 vessel	20 m^3 vessel
	HSL	HSL	HSL	HSL
Ethylene	24	30	32	40
Propane	12	15	16	29
Methane	10	11	12	15

The predicted pressures in the following analysis are obtained by applying equation (2) for the K_G vent sizing method substituted by either K_{GV}, $K_{G(20\ litre)}$ or $K_{GV(0.5)}$, as most appropriate to the experimental conditions and the behaviour of the vented explosion. The effect of vessel length to diameter ratio has been ignored in these calculations.

The reduced explosion pressures are the maximum values measured in each test, regardless of which pressure peak this is. The second peak is combustion controlled, whereas the third peak is influenced by the acoustic resonance of the vessel. Equation (2) is an empirical expression, however, and makes no distinction between these different mechanisms. The test here is whether the worst case pressures can be successfully predicted by Equation (2).

Comparisons between predictions and measurements are shown in figures 1 to 5, in which reduced explosion pressures are plotted against the vent coefficient, $K = (V^{2/3}/A_V)$,

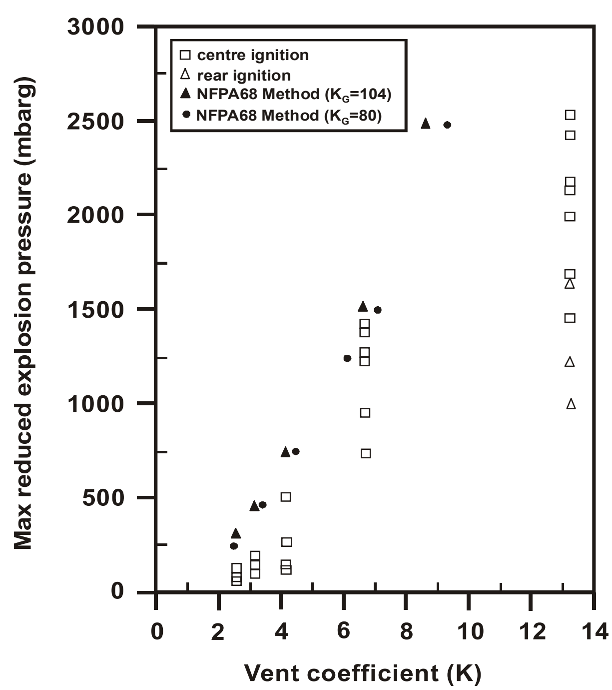

Figure 1. Comparison of predicted and measured maximum reduced explosion pressures for propane/air mixtures in a 2 m^3 vessel

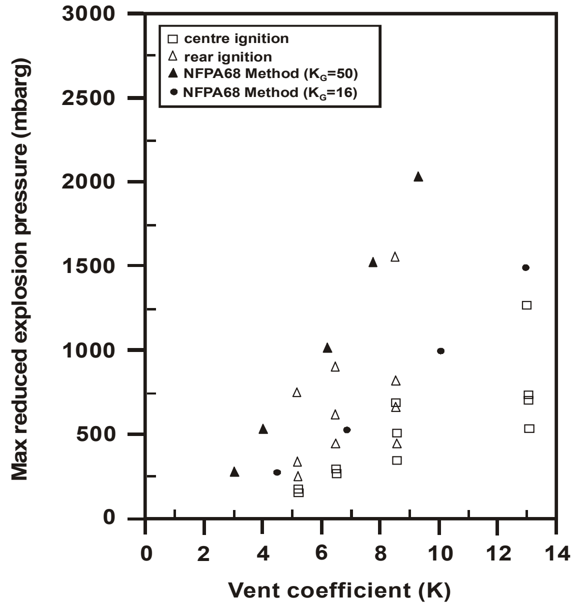

Figure 2. Comparison of predicted and measured maximum reduced explosion pressures for propane/air mixtures in a 6.3 m^3 vessel

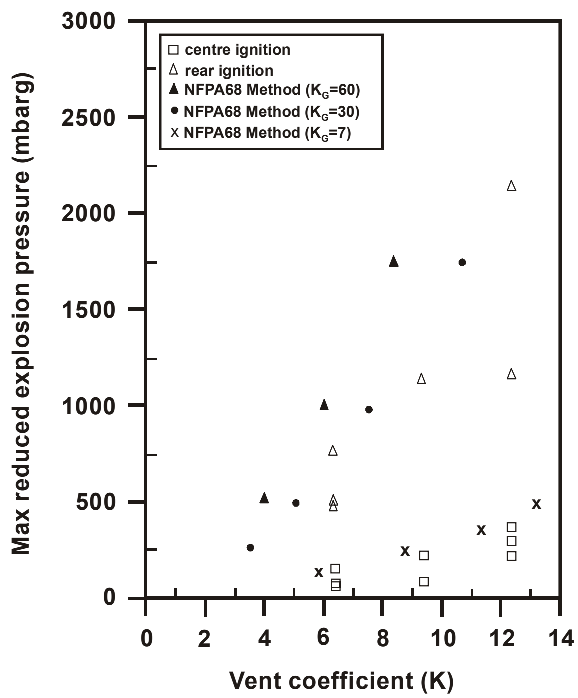

Figure 3. Comparison of predicted and measured maximum reduced explosion pressures for propane/air mixtures in a 20m3 vessel

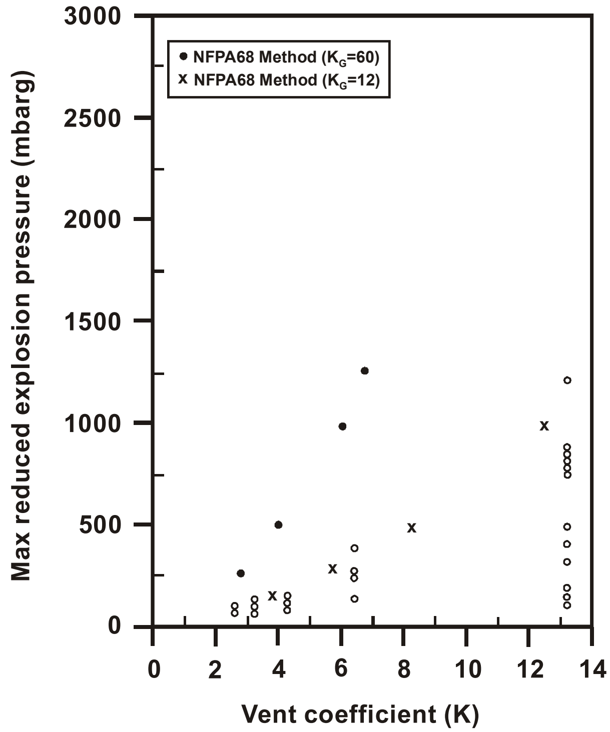

Figure 4. Comparison of predicted and measured maximum reduced explosion pressures for methane/air mixtures in a 2 m^3 vessel

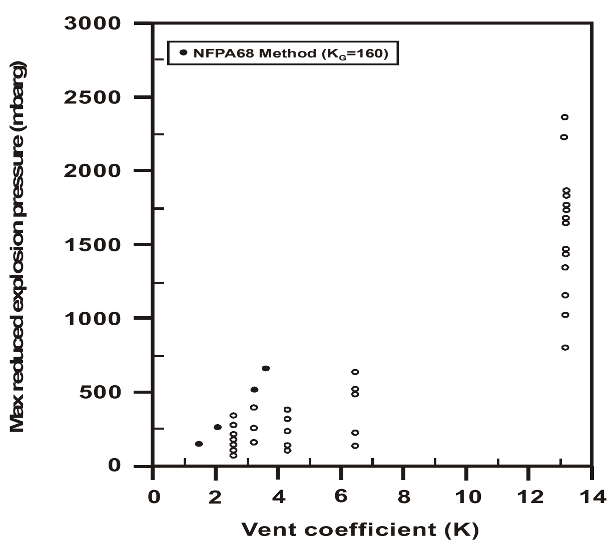

Figure 5. Comparison of predicted and measured maximum reduced explosion pressures for ethylene/air mixtures in a 2 m^3 vessel

where V is the vessel volume and A_V is the vent area. The K_G values used in the predictions are taken from Tables 1 and 2, using the value of K_{GV} or $K_{GV(0.5)}$ measured in circumstances that are closest to the conditions of the vented test. For example, K_{GV} and $K_{GV(0.5)}$ values from 4 m^3 enclosed explosions are used when predicting the vented explosions in the 6.3 m^3 vented tests.

These comparisons show that as the characteristics of a vented explosion are changed by such parameters as vessel volume and the K factor, then the value of K_G that characterises them also alters. If reduced explosion pressures are low then K_G values relevant to the early stages of an explosion are more in tune with the explosion behaviour in the vented explosion. If reduced explosion pressures are relatively high, K_G values derived from the later stages of an explosion are more appropriate.

Figure 1 shows the measured reduced explosion pressures for propane explosions in a vented 2 m^3 vessel and the calculated reduced explosion pressures using a $K_{G(20\ litre)}$ factor of 104 bar m s^{-1} and 80 bar m s^{-1}. The former value is the value recommended by Kuhner, the manufacturers of the 20 litre test apparatus; the latter the value measured by HSL in the 20 litre sphere (see Table 1). Both sets of predictions satisfactorily envelop the measured pressures.

Figure 2 shows measured reduced explosion pressures in propane explosions in the 6.3 m^3 vessel. Differences in these pressures arise depending on the position of the ignition source. For rear ignition, higher pressures are produced compared to when ignition is at the vessel centre. Comparisons are made using K_G values of 50 bar m s^{-1} and 16 bar m s^{-1}. The former is K_{GV} as measured in the enclosed 4 m^3 vessel and the latter is $K_{GV(0.5)}$ as measured at a 0.5 bar g explosion overpressure. Predictions using 50 bar m s^{-1} are a satisfactory envelope for the pressures generated with rear ignition and those using 16 bar m s^{-1} are a satisfactory envelope for the pressures following central ignition.

Figure 3 shows measured reduced explosion pressures from propane explosions in a 20 m^3 vessel. Predictions using K_G values of 60 bar m s^{-1}, 30 bar m s^{-1} and 7 bar m s^{-1} are also shown. The first two of these values are K_{GV} and $K_{GV(0.5)}$ derived from measurements in a 20 m^3 vessel (see Tables 1 and 2). The predictions using 60 bar m s^{-1} are conservative compared to measurement whereas those using 30 bar m s^{-1} are a satisfactory envelope for pressures generated following rear ignition. When the ignition source is at the centre of the vessel, a K_G value of 7 bar m s^{-1} satisfactorily envelops the experimental results.

Figure 4 shows measured reduced explosion pressures for methane explosions in a 2 m^3 vessel compared to predictions using K_G - values of 60 bar m s^{-1} and 12 bar m s^{-1}. These K_G values are the K_{GV} and $K_{GV(0.5)}$ values measured for methane in the 2 m^3 explosion vessels. A K_G value of 12 bar m s^{-1} gives close predictions of the higher reduced explosion pressures in the experimental results and clearly characterises these vented methane explosions.

Figure 5 shows the measured reduced explosion pressures for ethylene explosions in the 2 m^3 vessel. A comparison is made with predictions using a K_G value of 160 bar m s^{-1}, the K_{GV} value measured in the 2 litre vessel. The predictions of reduced explosion pressure satisfactorily envelop the measured values up to 0.5 bar overpressure; at higher reduced explosion pressures, the predictions are much higher than the measurements, although the experimental points are few in this region.

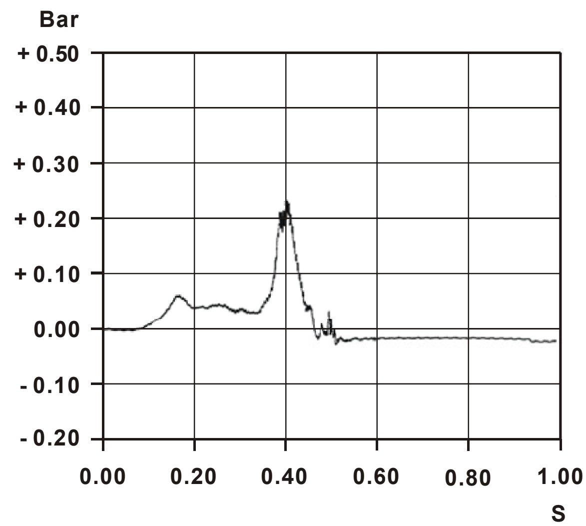

Figure 6. Pressure-time history: methane/air, 2m3 vessel, K factor = 6.5

The K_G approach to vent sizing implies that for a given K factor and a given K_G, vented explosions should produce the same reduced explosion pressure regardless of the vessel volume. In the present analysis, a K_G of 12 bar m s^{-1} successfully predicts the pressures in methane explosions in a 2 m^3 vessel while 16 bar m s^{-1} does the same for propane explosions centrally ignited in a 6.3 m^3 vessel. The pressure-time trace in Figure 6, for a methane explosion in the 2 m^3 vessel, for a K value of approximately 6.5 and central ignition, can be compared to the pressure-time trace shown in Figure 7 for a propane explosion in the 6.3 m^3 vessel with central ignition. The traces have similar shapes and values of the pressure peak, although the trace from the 2 m^3 vessel is of shorter duration, as would be expected. This similarity indicates that similar types of vented explosion in different vessels and with different gases are characterised by a given value of an appropriate value of K_G.

When the volume of the vented vessel increases, explosions tend to be slower and are characterised by decreasing values of K_G. An illustration of this is shown in Figures 7 and 8.

Figure 7 shows pressure traces for propane explosions in the three vented vessels at a K factor of approximately 6.5 with conditions for the worst case reduced explosion pressures, i.e central ignition in the 2 m^3 vessel, rear ignition in the other volumes. The K_G factors that predict these reduced explosion pressures are 80 bar m s^{-1}, 50 bar m s^{-1} and 30 bar m s^{-1} for, in order of vessel size, 2 m^3, 6.3 m^3 and 20 m^3.

Figure 8 is similar to Figure 7 except that the ignition position is central in all cases.

The K_G factors that predict these reduced explosion pressure are 80 bar m s^{-1}, 16 bar m s^{-1} and 7 bar m s^{-1}.

Figure 9 shows a pressure-time trace from an ethylene explosion in the 2 m^3 vessel with a K value of approximately 6.5. Although the reduced explosion pressure is relatively low, the explosion is much faster than with propane and methane under similar conditions.

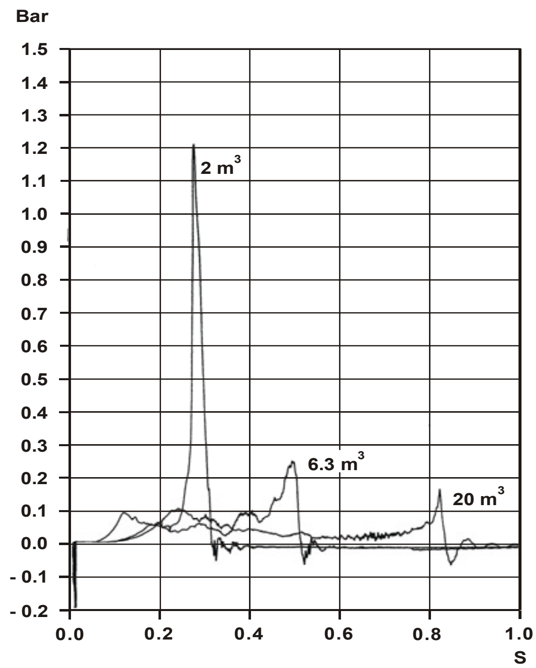

Figure 7. Pressure-time histories: 5% propane/air, central ignition, K factor = 6.5, various volumes

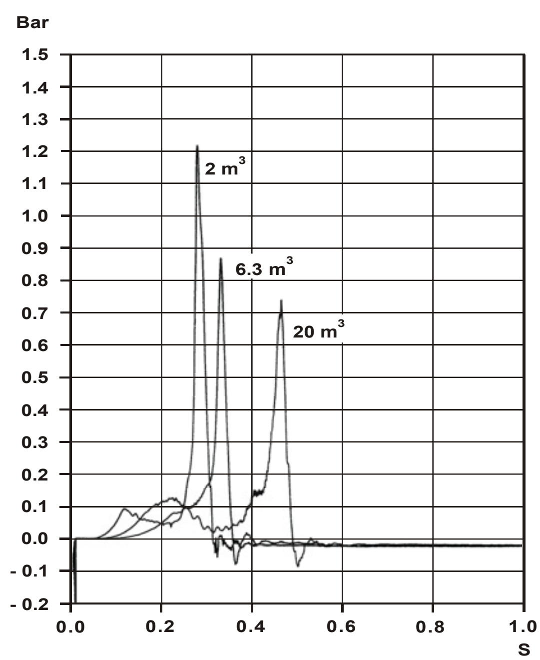

Figure 8. Pressure-time histories: 5% propane/air, rear ignition, K factor = 6.5, various volumes

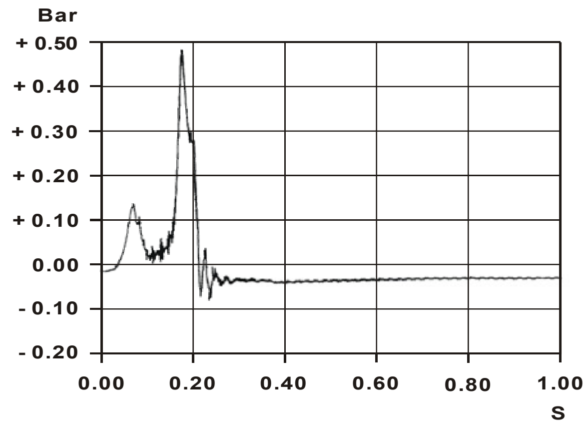

Figure 9. Pressure-time history: ethylene/air, 2 m^3 vessel, K factor = 6.5

This effect is the opposite of that described in NFPA68, where the K_G factor is shown to increase as vessel volume increases. This is because the K_G factor in NFPA68's data characterises enclosed explosions; but, as the data from vented explosions show, these values cannot be transferred across to vented explosions without modification.

In order to apply the modified K_G approach to other data the analysis of HSL's explosion tests has been summarised as shown in Table 3. The results suggest the trends shown in Figures 10 and 11 can be used to estimate values of $K_{GV(0.5)}$ at intermediate volumes.

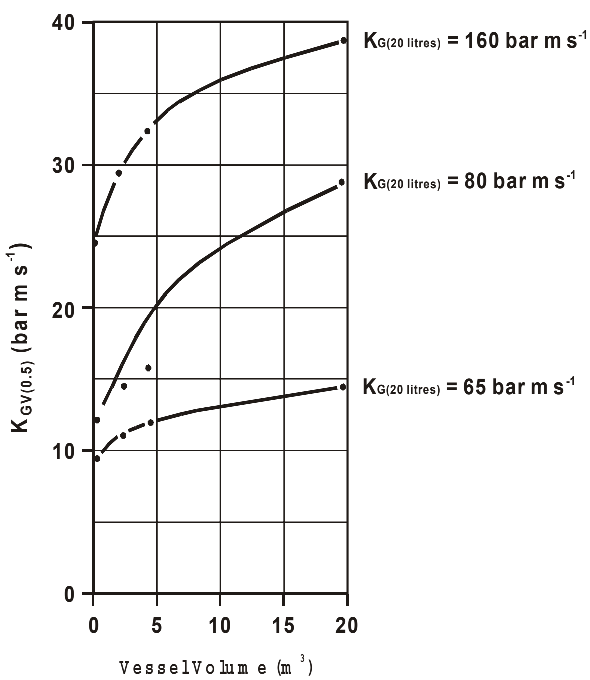

Figure 10. K_{GV}(0.5) values as a function of vessel volume

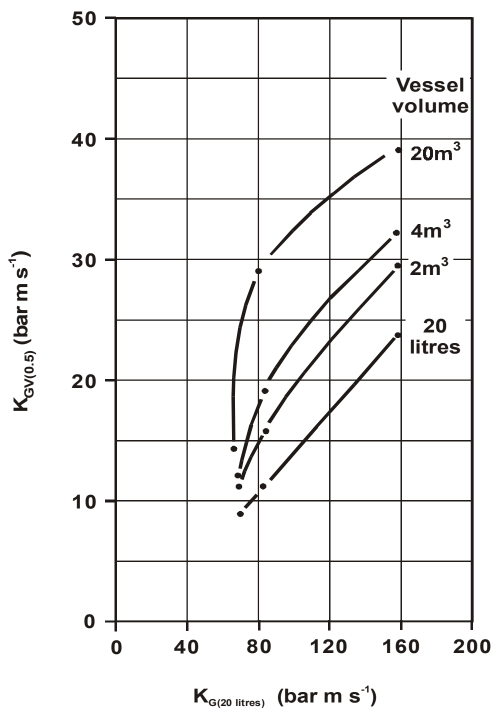

Figure 11. $K_{GV}(0.5)$ values as a function of $K_{G(20\ litres)}$ and vessel volume

Figure 10 shows the effect of vessel volume on $K_{GV(0.5)}$, at three values of $K_{G(20\ litre)}$ based on the HSL determinations from Table 1. For a known volume, three values of $K_{GV(0.5)}$ can be read from Figure 10 corresponding to the three values of $K_{G(20\ litre)}$. This data can then be plotted on Figure 11, which shows how $K_{GV(0.5)}$ changes with $K_{G(20\ litre)}$ and vessel volume, using the lines already there as a guide to connect the three points. For a vessel of known volume and a gas of known $K_{G(20\ litre)}$ value, the $K_{GV(0.5)}$ value can then be read off from the vertical axis.

Because the analysis shows that for the same degree of venting the appropriate value of K_G decreases as the vessel volume increases, data for K_{GV} and $K_{GV(0.5)}$ for vessels of a lower volume can be used if data is unavailable for a specific vessel size. The suggested modifications in Table 3 have been used to calculate reduced explosion pressures for comparisons with published data.

When the scheme given in Table 3 is followed using the K_G values from Tables 1 and 2 that most closely apply to the test conditions, the comparisons with published data listed in Table 4 are obtained. The predicted reduced explosion pressures are either close to or in excess of the measured values. Generally, the predictions for propane are satisfactory, and for methane the predictions mostly exceed the measured values and in those examples where there is an under-prediction the difference is small. Calculations using a K_G factor typical of hydrogen from a 20 litre sphere measurement produce reasonable predictions of P_{red} in these examples.

Table 3. Modifications of the K_G method

Gas reactivity (as measured by the K_G value in a 20 litre test, $K_{G(20\ litre)}$)	Vessel volume, V (m^3)	K_G value to be used for P_{red} prediction
$K_{G(20\ litre)} \leq 65$ bar m s^{-1}	$V < 2$	$K_{G(20\ litre)}$ as measured in the 20 litre sphere
	$2 \leq V$	$K_{GV(0.5)}$ as measured in a vessel with the same volume
$65 < K_{G(20\ litre)} \leq 80$	$V < 6$	$K_{G(20\ litre)}$ as measured in the 20 litre sphere
	$6 \leq V < 20$	Rear Ignition : K_{GV} for a vessel of the same volume Central Ignition: $K_{GV(0.5)}$ in a vessel of the same volume
	$20 \leq V$	Rear Ignition : $K_{GV(0.5)}$ in a vessel of the same volume Central Ignition: $K_G = 7$ bar m s^{-1}
$80 < K_{G(20\ litre)} \leq 160$	$V < 6$	$K_{G(20\ litre)}$ as measured in the 20 litre sphere
	$6 \leq V < 20$	Rear Ignition : K_{GV} for a vessel of the same volume Central Ignition : $K_{GV(0.5)}$ in a vessel of the same volume
	$20 \leq V$	$K_{GV(0.5)}$ in a vessel of the same volume
$160 < K_{G(20\ litre)}$	All V	$K_{G(20\ litre)}$ as measured in the 20 litre sphere

ELONGATED VESSELS

The reduced explosion pressures measured in elongated vessel tests are shown in Figures 12–15, where a normalised distance between the ignition point and vent (d), multiplied by the vent coefficient (K), is plotted against the maximum reduced pressure. The normalised distance d is obtained by dividing the horizontal distance between the ignition point and the centre line of the vent opening by the vessel diameter or width[19].

Figure 12 shows such a plot for the cylindrical vessel results, for propane with a single vent. Examination of the pressure-time profiles and test details for all the tests plotted in Figure 12 found that those tests in which high pressures were generated exhibited strong pressure oscillations, or there was an end vent rather than a side vent. An empirical equation that gives an upper bound that encompasses all the results, apart from the few tests that resulted in exceptionally high maximum pressures, is

Table 4. Measured reduced explosion pressures and predictions

Reference for experimental data	Fuel	Vessel volume V, m^3	Ignition position	Shape	Vent opening pressure P_V, atm	Vent area m^2	P_{red} measured mbar	P_{red} calculated mbar	K_G bar m s from Table
13	Propane	0.76	C	Cube	0	0.29	48	102	15
13	Propane	0.76	C	Cube	0.095	0.29	178	102	15
13	Propane	0.76	C	Cube	0.095	0.29	178	335	80
14	Propane	35	C	Rect	0	1	1,370	1,700	30
15	Propane	11	R	Cyl	0.05	1.36	90	163	16
16	Propane	4,000	R	Segment	0	563	10	74	30
16	Propane	4,000	R	Segment	0	563	15	74	30
16	Propane	30.4	C	Rect	0.04	0.58	700	745	7
17	Propane	2	C	Cyl	0.008	0.3	130	290	15
17	Propane	2	C	Cyl	0.068	0.3	145	290	15
17	Propane	2	C	Cyl	0.079	0.3	183	290	15
18	Propane	2	C	Cyl	0.03	0.3	170	290	15
19	Methane	0.95	C	Cyl	0.32	0.05	2,000	4,170	12
19	Methane	0.95	C	Cyl	0.16	0.1	1,000	790	12
20	Methane	33.5	C	Rect	0	2.57	150	183	15
21	Methane	49.1	C	Cyl	0	3.46	120	170	15
16	Methane	4,000	R	Segment	0	563	5	4	15
16	Methane	30.4	R	Rect	0.023	2.74	215	146	15
16	Methane	30.4	C	Rect	0.012	1.33	205	508	15

[illegible]	Methane	30.4	R	Rect	0.04	1.33	542	508	15
[illegible]	Methane	2	C	Cyl	0.22	0.3	33	227	12
[illegible]	Methane	2	C	Cyl	0.65	0.3	104	227	12
[illegible]	Methane	2	C	Cyl	0.83	0.3	112	227	12
[illegible]	Methane	2	C	Cyl	0.009	0.3	83	227	12
[illegible]	Methane	2	C	Cyl	0.002	2.16	30	41	12
[illegible]	Methane	2	C	Cyl	0.003	2.16	46	41	12
[illegible]	Methane	2	C	Cyl	0.005	2.16	47	41	12
[illegible]	Methane	2	C	Cyl	0.016	0.3	42	227	12
[illegible]	Hydrogen	0.95	C	Cyl	0.075	0.2	1,250	1,870	637
[illegible]	Hydrogen	0.95	C	Cyl	0.135	0.3	490	950	637

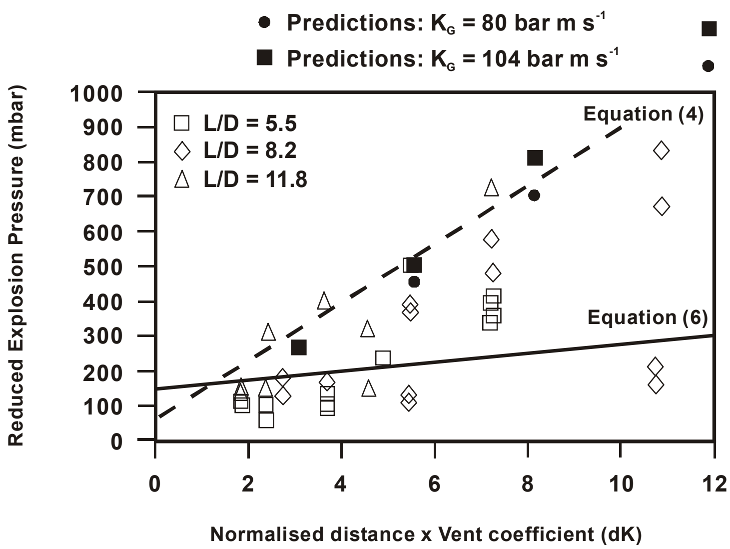

Figure 12. Cylindrical vessel with single vent: propane air

$$P_{max} = P_v + 85\ d\ K \tag{4}$$

A similar pattern emerged for the results for methane with a single vent as shown in Figure 13. For methane equation (5)

$$P_{max} = P_v + 70\ d\ K \tag{5}$$

provides an upper bound for all but one of the results.

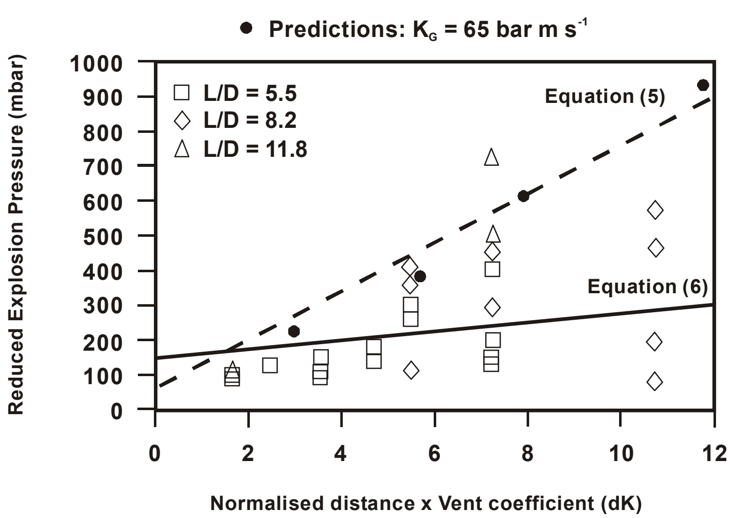

Figure 13. Cylindrical vessel with single vent: methane/air

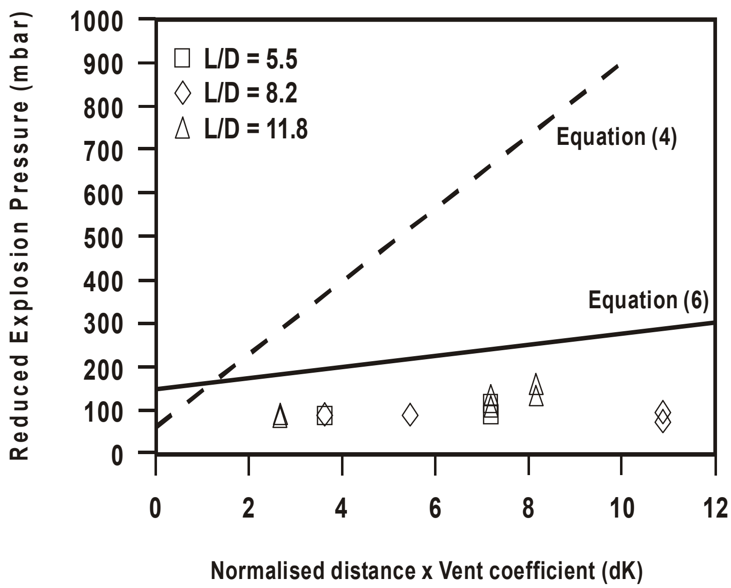

Figure 14. Cylindrical vessel with multiple vents: propane/air

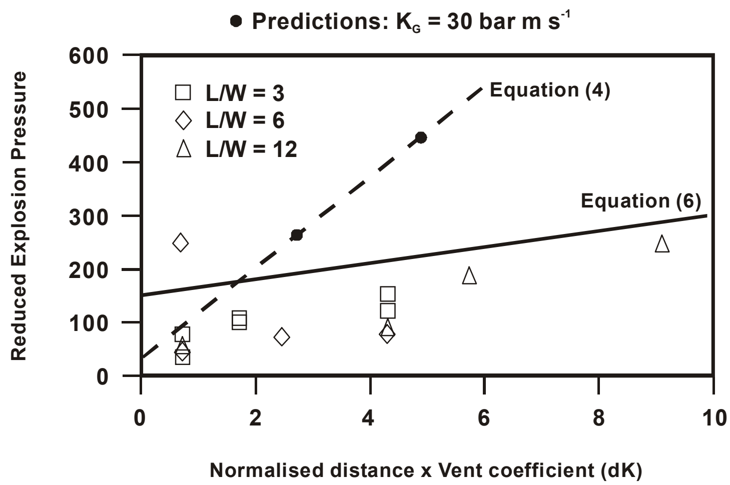

Figure 15. Rectangular vessel with multiple vents: propane/air

Results obtained for propane with the cylindrical vessel with multiple vents are plotted in Figure 14. For multiple vents the dK value used is that for the vent nearest the point of ignition. Hence the reduced explosion pressure for a given dK should be lower than that obtained for a single vent. In none of the tests with multiple vents were strong low frequency oscillations observed, or a strong third peak. The result is that all the measured maximum explosion pressures lie below the values predicted by an equation published by Tite et al.[19]:

$$P_{max} = 15\ d\ K + 150 \qquad (6)$$

The results obtained with the rectangular vessel for propane, with both single and multiple vents, are plotted in Figure 15. With one exception, the measurements lie below the predictions of equation (6). In this test the ignition point was in the middle of the vessel, with a vent on either side. Strong pressure oscillations were generated which resulted in a high maximum pressure.

Figures 12, 13 and 15 also contain predicted reduced explosion pressures from the K_G method derived for compact vessels in section 3.1. These calculations assume rear ignition and full end venting, i.e K = 1. No account of L/D ratio is taken in these calculations; the vessel volume is the only parameter involved. The calculations satisfactorily envelop almost all the experimental results, the only exceptions being tests in a vessel with an L/D of 11.8 and the vent positioned close to the ignition source. However, because no end venting experiments were performed above an L/D of 5.5, application of the modified K_G method was not tested beyond this value.

CONCLUSIONS

The K_G factor method for explosion vent sizing published in NFPA68 is a relatively simple method to use, but its straightforward application is not always successful if the standard value of K_G is applied under all circumstances.

The standard value of K_G may characterise enclosed gas explosions adequately but it does not characterise vented explosions well.

A variation of the K_G factor method based on deriving variants of the K_G factor from the earlier stages of a pressure-time history and from pressure time traces in larger volumes is more appropriate to vented explosions.

Three variants of the K_G factor have been used in an extensive analysis of experimental measurements of reduced explosion pressures. When the K_G factor most appropriate to the conditions of the vented explosion is substituted into the vent sizing calculation good agreement can be obtained between experiment and measurement.

For elongated vessels with length to diameter (L/D) or length to width (L/W) ratios in the range 3 to 20 and containing quiescent gas mixtures that are essentially free of turbulence inducing elements, vents should be spaced at regular intervals along the length of the enclosure and ideally there should be a vent at or very close to each end of the enclosure. The modifications to the K_G method shown in Table 3 worked well with elongated vessels with L/D ratios not exceeding 5 with the vent positioned at the end remote from ignition.

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