RELIEF SIZING FORMULA FOR
GAS AND DUST EXPLOSIONS

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ABSTRACT

A theoretical based generalized vapor and dust deflagration vent sizing formula is provided that
provides good agreement with available experimental data. In contrast to empirical guidelines, given
the theoretical basis for the formula allows reliable predictions outside the available data base.

INTRODUCTION

A large number of analytical and highly empirical correlations including nomograms reflecting
changing standards have been or are being proposed separately for gas and dust explosion relief venting.
An example of dust explosion predictions and data is illustrated in Figure 1 (reproduced from Eckhoff,
1998).
In principle modeling developed for gas explosions venting should also apply to dust explosion venting. The difference in approach arise mainly because the models or correlations for gas explosions involve the use of the laminar or fundamental burn velocity and a turbulence correlation factor which are more difficult to specify separately for dust explosions. Here we offer a generalized formula that is applicable to both gas and dust deflagrations including subsonic and sonic pressure relief conditions and is consistent with available experimental data and industry experience. Application of the model is illustrated for dust explosions.

**GENERALIZED VENT SIZING FORMULA**

The volumetric venting rate, $\dot{Q}_g$ (m$^3$ s$^{-1}$), from a deflagration event can be estimated from

$$\dot{Q}_g = \frac{V^{2/3} K (P_{\text{max}} - P)}{P (P_{\text{max}} - P_i) - P_{\text{max}} (P_s - P_i)}$$

(1)

where

- $P$ (bar a) = final venting pressure,
- $V$ (m$^3$) = vessel volume,
- $P_{\text{max}}$ (bar a) = maximum unvented pressure,
- $P_s$ (bar a) = relief set pressure,
- $P_i$ (bar a) = initial pressure,
- $K$ (bar m s$^{-1}$) = deflagration index measured in a standard non-vented spherical vessel (such as the 20P vessel) with quiescent initial conditions and central ignition and is given by

$$K = v^{1/3} \dot{P}_{\text{max}}$$

(2)

where $v$ (m$^3$) is the standard test vessel volume and $\dot{P}_{\text{max}}$ (bar s$^{-1}$) is the maximum measured rate of pressure rise.
The form of Eq. 1 results from an approximation of Epstein et al. [1] high pressure vent model by setting the heat capacity ratio of the burned gas or dust ($\gamma_b = 1.1$) equal to 1.0 [2]. As $P$ approaches $P_{max}$ the volumetric gas generation rate to be vented, $\dot{Q}_g$, goes to zero as it should. The reason for the smaller value of $\dot{Q}_g$ at a higher final venting pressure $P$ for a given opening pressure $P_s$, is due to more time available to vent the unburnt gas. Similarly, the larger values of $\dot{Q}_g$ at higher set pressures $P_s$ are due to less time to vent the unburnt gas.

The required vent area, $A_v (m^2)$, is then given by

$$\frac{A_v}{V^{2/3}} = \left[ P \left( 1 + \frac{18.37}{P^{1.75}} \right)^{0.286} \right]^{-1} \left[ \frac{K}{0.61 \left( \frac{M_w}{RT} \right)^{1/2}} \right] \left[ \frac{P (P_{max} - P)}{P (P_{max} - P_i) - P_{max} (P_s - P_i)} \right]$$  \hspace{1cm} (3)

where, the unit of $P$ in the first bracket of Eq. 3 is now bar g, $M_w$ is the molecular weight, $R$ (8314 Pa-m$^3$/K-kg mole) is the gas constant, and $T$ (K) is the initial temperature.

**DUST DEFLAGRATION VENTING**

Of necessity, in contrast to gas mixtures, the measurement of $\dot{P}_{max}$ or $K_{st} (\text{bar m s}^{-1}) = \dot{P}_{max} V^{1/3}$ is made with initially highly turbulent conditions where the degree of turbulence is of the order of 6 relative to quiescent conditions [3]. Therefore, in order to represent similar initial conditions to that for quiescence gas mixtures, $K$ in Eq. 3 is set equal to $K_{st}/6$. This approach provides predictions consistent with industrial dust conditions as discussed by Eckhoff [4], and illustrated in Figures 2 and 3\(^1\) (where predictions from Eq. 3 are shown to be consistent with envelope of experimental data).

\(^1\) It is of interest to note that an exceptional maize starch explosion named “turbulent jet” shown in Figure 2 was sufficiently violent to rupture part of the silo wall (~ 50 m$^2$) at 0.6 bar g. In this case, setting $K$ in Eq. 3 equal to $K_{st}$ rather than $K_{st}/6$ results in the same order of magnitude required vent area.
Figure 2. Experimental data between vent area and maximum explosion pressure for grain dust explosions in a 2.8 m³ cubical vessel [3] and comparison with Eq. 3.

Figure 3. Results from vented maize starch and wheat grain dust explosions in 500 m³ silo cells in Norway. Comparison with predicted $P_{\text{red}}$/vent area correlations by various vent sizing methods in current use [3]. $P_{\text{red}}$ means the maximum pressure in the vented enclosure during the explosion. Prediction from Eq. 3 setting $K = 115/6$ bar m/s is consistent with the noted envelope of experimental data.
It is of interest to compare the 500 m³ silo envelope of experimental data to the highly empirical NFPA 68 (North America) and EN 14491 (Europe) guidelines.

As an example considering $P_{\text{red}} = 0.1$ bar g with $P_{\text{max}} = 9$ bar g, $K_{st} = 115$ bar m/s and $P_{stat} = 0.02$ bar g, the theoretical based Eq. 3 results in

$$A = 9.42 \text{ m}^2$$  \hspace{1cm} (4)

which compare to the envelope experimental data of

$$A_{\text{exp.}} = 9.3 \text{ m}^2$$  \hspace{1cm} (5)

Considering an aspect ratio (L/D) of 2 the NFPA 68 (5) predicts

$$A = 11.5 \text{ m}^2$$  \hspace{1cm} (6)

and EN 14491 (6) predicts

$$A = 34.05 \text{ m}^2$$  \hspace{1cm} (7)

While for an aspect ratio of 4 for the 500 m³ silo, NFPA 68 leads to

$$A = 23 \text{ m}^2$$  \hspace{1cm} (8)

and EN 14491 suggests

$$A = 54.6 \text{ m}^2$$  \hspace{1cm} (9)

Clearly the empirical guidelines, especially EN 14491, lead to impractical large vents for high aspect ratio large volume silos and low design pressures.
REFERENCES


6. EN 14491 (2006), Dust Explosion Venting Protective Systems, CEN.