A PROCEDURE FOR DESIGNING GAS COMBUSTION VENTING SYSTEMS

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This paper presents a procedure for calculating plant combustion venting requirements for gas deflagrations. The procedure has been developed from an analysis of the needs of the vent designer and a review of available published experimental data. It attempts to relate required vent areas to fundamental burning velocities over a range of initial pressures, temperatures and conditions of turbulence. Four sets of original combustion venting data are also presented.

INTRODUCTION

The design engineer who is working with a process in which a flammable fuel/oxidant mixture can form must usually protect his plant against explosion. Unless enclosures in which the flammable mixtures can form are strong enough to contain the effects of violent combustion without rupturing, some form of combustion venting will normally be provided. Successful combustion venting must:

(1). Protect the plant from significant physical damage when a violent combustion reaction occurs.

(2). Protect people from injury.

(3). Operate only when it is supposed to.

The system should also be low cost, consistent with dependable performance.

Assuming dependable mechanical performance, successful venting depends on the correct specification of vent size, closure design, and discharge duct length and shape. Correct determination of these values must be based on a correct definition and analysis of the conditions which influence the combustion venting process. Definition of process conditions is the job of the design engineer; the analysis and specification must be supplied by the expert in combustion venting technology.

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CONDITIONS WHICH INFLUENCE COMBUSTION VENTING

The Explosion Venting Guide of the National Fire Protection Association (1954) lists thirteen conditions which influence the combustion venting process. Other publications offer analogous sets of conditions. The conditions can be grouped according to whether they are defined by the process to be protected or whether they relate to the combustion reaction and attendant combustion venting technology. A grouping of process-defined conditions as understood by a process designer is made as follows:

(1). The fuel and oxidant available in the process.

(2). The minimum pressure at which the relieving device can be set to open. This is the static burst or opening pressure.

(3). The maximum pressure which the weakest component in the process facility to be protected can withstand. This is the maximum pressure allowable during venting.

(4). The conditions existing at the onset of ignition. These include: the fuel/oxidant concentration; the initial pressure; the initial temperature; and the initial condition of turbulence.

(5). The size of the container.

(6). The location of the vent.

(7). The length of the discharge duct.

(8). The type of vent closure.

(9). The shape of the container.

(10). The size, location and intensity of the ignition source or sources.

This is the list of information that the process design engineer must expect to prepare before he asks the combustion technologist the question, "How big a vent do I need for my process?"

For the purposes of vent design, combustion venting technology can be defined according to the following concepts:

(1). The fundamental response of a fuel/oxidant mixture to ignition.

(2). The effect of variation of initial conditions (pressure, temperature, etc.) on the basic response.

(3). The effect of process facility and vent system configuration and operation on the basic response.

If appropriate combustion venting technology is available, the information supplied by the process designer can be analyzed and a vent size specified.

A process design engineer can rarely work directly with an expert in combustion venting to solve a specific venting problem, but he has recourse to the literature. He can try to adapt some of the existing published information to fit his particular set of conditions. He will find that published methods are not in close agreement with each other, and do not cover a very wide range of operating conditions. C. Donat (1973) reports that different published calculation methods yield a range of calculated vent areas with a hundredfold difference from smallest to largest.

As an alternate to reliance on published calculation methods, a designer can try to get management authorization for a series of venting experiments which approximate the conditions encountered in his process. At Monsanto we favor this approach for cases when process conditions differ widely from those covered in published information. Experimental data which we have obtained are presented in Tables 1 and 2. However, experimental programs are costly and require considerable expertise in combustion venting technology both for definition and interpretation. The data obtained are limited in scope since they represent the minimum sets required to define the design of particular plant-scale facilities. We have tried to extend the usefulness of such data by means of a calculation procedure developed from literature. This procedure is described in the following section.

SUGGESTED CALCULATION PROCEDURE

The calculation procedure was developed from literature and applies to deflagration only. It uses the set of combustion venting curves reported by Cousins and Cotton (1951) for 5 mole % propane in air at 15 psig initial pressure (205 kN/m^2 abs) as the reference or base case. This set of curves is reproduced in Figure 1. The units for pressure are kN/m^2 absolute in this paper. Most of the data cited in this paper were originally in English units. Pressure conversion to SI units was made according to the formula, 1 psi = 6.9 kN/m^2.

The procedure is summarized below. Literature sources, premises, assumptions and limitations are discussed in the next section of the paper.

(1). Find the ratios of static burst pressure, Ps, and maximum venting pressure, Pr, to initial pressure, Pi, for the process to be protected. The "maximum venting pressure" is the maximum pressure which occurs during the venting process.

(2). Multiply the ratio of static burst pressure to initial pressure, Ps/Pi, of the process to be protected by the initial pressure of the reference case to find the burst pressure of the reference case. The expression is:

$$Psb = 205(Ps/Pi) \quad \ldots\ldots\ldots\ldots \quad (1)$$

TABLE 1 - Monsanto combustion venting data for ethylene

Experimental Conditions

Test Vessel - 1.9 m^3 sphere, externally heated and insulated metal rupture discs. No vent duct.

Ignition - 100 joules spark at vessel center.

Turbulence - Set I: Quiescent
Set II: Two 20.3 cm diameter fans mounted opposite each other on horizontal line approximately at vessel equator. Blade distance about 10 cm from walls. Speed 1500-2000 rpm. In operation for entire duration of each run.

Initial Pressure - 311 kN/m^2 absolute

Set and Run No.	Mole % Fuel	Mole % O_2	Mole % N_2	Initial Temp. °C	Disc (Vent) Dia. cm	Disc Burst Pressure kN/m^2 abs: Static or (Rated)	Disc Burst Pressure kN/m^2 abs: Dynamic
I-1	19.0	11.2	69.8	100	20.3	350	405
2	19.0	12.7	68.3	100	20.3	350	405
3	19.0	15.7	65.3	100	20.3	350	412
4	30.0	15.0	55.0	100	20.3	350	433
5	30.0	17.0	53.0	100	20.3	350	419
6	30.0	19.0	51.0	100	20.3	350	412
II-1	7.0	19.5	73.5	120	20.3	426	488
2	7.0	19.5	73.5	120	20.3	426	488
3	27.1	15.3	57.6	120	20.3	426	433
4	7.0	19.5	73.5	120	35.6	433	667
5	7.0	19.5	73.5	120	35.6	433	626
6	9.0	19.1	71.9	118	35.6	433	584

Experimental Results

Set and Run No.	First Pressure Peak: Max. Press. kN/m^2	First Pressure Peak: Rate of Press. Rise kN/m^2-sec Ave.	First Pressure Peak: Rate of Press. Rise kN/m^2-sec Max.	Second Pressure Peak: Max. Press. kN/m^2	Second Pressure Peak: Rate of Press. Rise kN/m^2-sec Ave.	Second Pressure Peak: Rate of Press. Rise kN/m^2-sec Max.
I-1	405	110	186	None	-	-
2	412	124	207	None	-	-
3	412	248	1,007	None	-	-
4	571	1,235	2,898	None	-	-
5	405	496	1,132	1,343	10,971	44,850
6	419	448	862	1,447	12,848	69,000
II-1	1,482	11,068	-	None	-	-
2	1,509	11,785	-	None	-	-
3	433	292	-	None	-	-
4	1,088	7,728	-	None	-	-
5	978	6,693	-	None	-	-
6	860	4,092	-	None	-	-

TABLE 2 - Monsanto combustion data for methanol

Experimental Conditions and Results

Test Vessel	- 1.9 m^3 sphere, externally heated and insulated. Metal rupture discs.
Ignition	- Grid of 16 electric matches on 30 cm centers in a horizontal plane located one-third of the vessel diameter from the bottom of the vessel. Wired in series with virtual simultaneous ignition from single power supply.
Turbulence	- Two 10.2 cm dia. fans; 1 near vessel top blew downward, 1 at bottom blew horizontally; speed, 1500 rpm; operated for duration of each run.
Oxidant	- Air
Initial Pressure	- 186 kN/m^2 abs
Initial Temp.	- 120°C

Set and Run No.	Mole % Fuel	Disc (Vent) Dia. cm	Disc Burst Press. kN/m^2 Static	Disc Burst Press. kN/m^2 Dynamic	Max. Press. kN/m^2	Pressure Peak Rate of Press. Rise kN/m^2-sec. Ave.	Pressure Peak Rate of Press. Rise kN/m^2-sec. Max.
III-1	21.6	10.2	237	264	791	4,812	6,900
2	21.6	20.3	224	248	509	6,357	6,583
3	21.6	45.7	239	229	274	2,008	3,450
4	15.0	20.3	224	239	791	5,520	20,700
IV-1	15.0	10.2	239	-	929	6,776	13,110
2	15.0	20.3	239	-	509	6,389	23,184
3	15.0	45.7	239	-	267	1,622	2,843

No second pressure peaks on either set III or IV. Run III-4 had a vent discharge duct 20.3 cm diameter by 305 cm long.

The number, 205, is the reference case initial pressure in kN/m^2 absolute.

(3). Find the effect of process initial pressure, Pi, and fundamental burning velocity, U, on the maximum venting pressure of the reference case, Prb:

$$Prb = Pr(205/Pi)^{1.5}(40/U)^{0.2} \quad \ldots\ldots\ldots\ldots \quad (2)$$

The number, 40, is the fundamental burning velocity for the propane/air mixture of the reference case in cm/sec.

(4). Using Psb and Prb find the vent ratio, Fq, for a quiescent mixture from Figure 1. The units of Fq are m^2/m^3.

(5). Find the vent ratio under turbulent conditions, Ft, for the reference case according to the following formula:

$$Ft = 2\ Fq \quad \ldots\ldots (3)$$

(6). Find F, the vent ratio for the process container to be protected, by evaluating the effect of the volume, V, of the process container on the reference case vent ratio, Ft.

Two ways of proceeding which give different results are inferred from an analysis of experimental evidence from different sources. "Tuning" the procedure against data reported by Donat (1973) yields the curve shown in Figure 2 which relates a volume correction factor to the volume of the container in which the ignition occurs:

$$F = Ft \times \text{volume correction factor} \quad \ldots\ldots (4)$$

Analysis of Sets II and IV of the Monsanto data indicates that the classical "1/3 power law" may be the appropriate factor to apply in some cases. That is:

$$F = Ft\ (0.032/V)^{1/3} \quad \ldots\ldots (5)$$

The constant, 0.032, is the volume in m^3 of the test vessel used by Cousins and Cotton.

DISCUSSION

The proposed calculation procedure applies to a simplified version of the list of process-dependent venting variables develooped earlier.

(1). Flame Speed of Fuel/Oxidant Mixture The procedure applies to gas/air mixtures, with the gas at a concentration which gives the maximum burning rate. A premise of the procedure is that the flame speed of the mixture is related to the fundamental burning velocity of the mixture.

The relation of flame speed to maximum venting pressure was found by a comparison of Cousins and Cotton curves for hydrogen and for propane. The form of the relationship was taken to be:

$$Pr/Prb = (U/Ub)^y \quad \ldots\ldots (6)$$

The exponent, y, was found to range in value from 0.01 to 0.2, and was taken to be 0.2 for this procedure. The term, Ub, represents the fundamental burning velocity of the reference case (i.e., 40 cm/sec for 5% propane in air).

Fundamental burning velocities for some materials can be obtained from literature; for example, from the British Ministry of Labour's Safety Health and Welfare publication, Guide To The Use Of Flame Arrestors And Explosion Reliefs (1965). If it is assumed that fundamental burning velocities relate to maximum rates of pressure rise in nonvented combustions, the data prepared by Eastman Kodak Company, Rochester, N. Y., U.S.A., can be used. These data are reported in the National Fire Protection Association's Explosion Venting Guide (1954), and elsewhere. Use of different data sources will give different ratios of U/Ub. Fortunately, the variations are minimized by the small fractional exponent calculated to relate this effect to venting pressure.

(2). Static Burst Pressure A premise of the procedure is that the ratio of static burst pressure to initial pressure defines equivalent states in the progress of a combustion reaction for both the process case and the reference case. In this, the procedure follows considerations developed by Munday (1963).

(3). Maximum Venting Pressure The premise of equivalency as described above is also applied to the ratio of maximum venting pressure to initial pressure.

(4). Initial Conditions

Pressure The relationship between maximum venting pressures and initial pressures at equal vent and static burst pressure ratios is taken to be adequately defined by the relationships reported by Cousins and Cotton. These investigators present combustion pressure curves for 5 mole % propane in air at 15 psig and 45 psig initial pressures and for 40 mole % hydrogen in air at the same two initial pressures.

The relationship of maximum venting pressures to initial pressures at equal vent and static burst pressure ratios was taken to be of the form:

$$Pr/Prb = (Pi/Pib)^x$$

The exponent, x, was found to range from 1.1 at large vent ratios to 1.5 at small vent ratios. For this procedure it was taken to be 1.5. The exponent calculated from Cousins and Cotton data on hydrogen ranged from 1.1 to 1.2. The data indicate that the effect of initial pressure on venting pressure diminishes as flame speeds increase.

Temperature As shown by Maisey (1965) and others, an increase in initial temperature for a given volume and initial pressure results in an increase in the rate of pressure rise in a nonvented deflagration. However, the maximum pressure attained is decreased. Data which cover ranges of venting pressures, burst pressures and initial temperatures are not available for working out a relationship to use in the procedure. For this reason it was simply assumed that the temperature effect can be neglected without serious prejudice to the results obtained by the procedure.

Turbulence The quantitative relationship for two conditions of turbulence, "high" and quiescent, was obtained from inspection of data reported by Harris and Briscoe (1967) and by Bartknecht (1971). It does not seem possible at present to relate maximum venting pressure to a turbulence continuum. However, by assuming simply the two states, it appears that data are fairly adequately and conservatively expressed by doubling the quiescent vent ratio, at least at small vent ratios. The effect of turbulence seems virtually to disappear at large vent ratios, but the data scatter is too great for deducing a quantitative relationship.

Since the procedure is based on experimental data, it ought inherently to account for the effects of the turbulence induced by the venting process itself, including the occurrence of second pressure peaks. Second peaks are associated with induced turbulence and are known to occur at quiescent initial conditions and low vent ratios. Not enough data are available to permit a direct treatment of second peaks at the conditions which this procedure attempts to handle. However, Donat reports the occurrence of second peaks in his work; their occurrence is presumed in the Cousins and Cotton data.

(5). Container Size The data reported by Donat are for quiescent propane/air mixtures at maximum explosive concentration in containers ranging from 1 m^3 to 60 m^3. They represent the most complete survey of the effect of container volume on vent ratios which has been published. The data are given in Table 3, and are the basis for the curve shown in Figure 2.

The procedure described here was applied to the conditions reported by Donat so that a comparison of calculated-to-observed results could be made and a volume correction factor obtained. The calculated results were also compared to data reported by Harris and Briscoe (1967) for a 1.7 m^3 vessel. The comparison, including a sample calculation, is shown in Table 4. The comparison seems to indicate that the best way to relate the reference case to the Donat data is to disregard the effect of volume on vent ratios for containers smaller than 1 m^3. For container volumes between 1 m^3 and 100 m^3 it seems reasonable that the relationship observed by Donat and indicated by the "normalized" curve in Figure 2 should be applied.

However, use of the volume correction factor inferred from Donat data can lead to much larger calculated vent ratios than those observed experimentally. This is shown in Tables 5 & 6 for ethylene and methanol data, where calculated and observed results are compared. The relatively low initial turbulence of the experimental mixtures may be a factor in causing the discrepancy, but this cannot be verified. It is interesting that use of the "1/3 power law" relationship decreased the difference between calculated and observed results. However, the data do not provide any clues for deciding when to use the "1/3 power law" in preference to the volume correction factor based on Donat data. The unexplained discrepancies between data from different experimenters are a serious hindrance to the development of a reliable calculation method.

In spite of the difficulties, a designer is still obliged to provide a safe venting system. He should use the Donat data shown in Table 3 or Figure 2, unless he has specific indication that the "1/3 power law" (or some other relationship) is more appropriate.

(6). Vent Locations The procedure assumes a symmetrical container with a single vent. For cases of assymmetry, the calculated vent area can be obtained by multiple vents located as symmetrically as possible on the container.

Table 3 - Data relating vent areas to container volume, static burst pressure and maximum venting pressure for combustion of propane/air mixtures in containers of L/D approximately 1

Reference: C. Donat (1973)

Vent areas, m^3, are given in the columns beneath the entry entitled "Vent burst pressure."

Max. press. during venting kN/m^2 / Container Vol. m^3	30	50	100	150	200	250
	Vent burst pressure = 10 kN/m^2					
1	0.31	0.25	0.15	0.09	0.045	-
10	2.10	1.50	0.80	0.55	0.400	0.30
30	3.00	2.25	1.50	0.90	0.600	0.45
60	4.80	3.00	1.20	-	-	-
	Vent burst pressure = 20 kN/m^2					
1	0.355	0.30	0.21	0.145	0.095	0.07
10	2.180	1.70	1.07	0.740	0.470	0.37
30	2.700	2.03	1.35	0.970	0.720	0.53
60	-	3.76	-	-	-	-
	Vent burst pressure = 50 kN/m^2					
1	-	-	0.195	0.12	0.085	0.065
10	-	-	1.210	0.79	0.560	0.420
30	-	3.48	1.880	1.35	0.970	0.720
60	-	5.22	2.220	-	-	-

TABLE 4 - Comparison of Donat data and Harris and Briscoe data on combustion venting with calculated results

	Initial Press. kN/m^2abs	Static Burst Press. kN/m^2abs	Max. Venting Press. kN/m^2abs	Vent Ratio m^2/m^3
Donat (quiescent)	100	152	202	0.195
Harris & Briscoe (quiescent)	100	152	202	0.131
Harris & Briscoe (turbulent)	100	152	202	0.248
Calculated (turbulent)				0.256
Donat (quiescent)	100	122	152	0.301
Harris & Briscoe (quiescent)	100	122	152	0.181
Harris & Briscoe (turbulent)	100	122	152	0.328
Calculated (turbulent)				0.360
Donat (quiescent)	100	152	352	0.065
Harris & Briscoe (quiescent)	100	152	352	0.082
Harris & Briscoe (turbulent)	100	152	352	0.181
Calculated (Turbulent)				0.032
Donat (quiescent)	100	122	252	0.145
Harris & Briscoe (quiescent)	100	122	252	0.092
Harris & Briscoe (turbulent)	100	122	252	0.146
Calculated (turbulent)				0.108

Donat vessel volume: 1 m^3. Harris & Briscoe vessel volume: 1.7 m^3.

Sample calculation, first data set:

1. From equation (1), find static burst pressure, Psb, for reference case. This is the "disc burst pressure" of Figure 1.

   $$Psb = 205(Ps/Pi) = 205(152/100) = 312\ kN/m^2$$

2. From equation (2), find maximum venting pressure for reference case. This is the "maximum venting pressure" of Figure 1.

   $$Prb = Pr(205/Pi)^{1.5} = 202(205/100)^{1.5} = 592\ kN/m^2$$

   There is no flame speed correction for propane or pentane.

3. From Figure 1, read "maximum venting pressure" on the ordinate. Project horizontally to the intercept of the curve representing "disc burst pressure." From this point project downward to the abscissa. This is the vent ratio, Fq, for the "quiescent" reference case.

   $$Fq = 0.128$$

4. From equation (4), the vent ratio for the "turbulent" reference case is found by

$$Ft = 2\ Fq = 2 \times 0.128 = 0.256$$

TABLE 5 - Comparison of vent ratios obtained experimentally for ethylene (see Table 1, Set II) with calculated vent ratio

Run No.	Initial Press. kN/m^2abs Pi	Static Press. kN/m^2abs Ps	Venting Press. kN/m^2abs Pr	Vent Ratio, m^2/m^3 Experi-mental	Calculated Norm-alized Factor	Calculated 1/3 Power Law
II-1	311	426	1,482	0.017	0.113	0.031
2	311	426	1,509	0.017	0.113	0.031
4	311	438	1,088	0.052	0.257	0.076
5	311	433	978	0.052	0.359	0.106

Sample calculations, Run No. II-1 data:

1. From equation (1), find static burst pressure, Psb, for reference case. This is the "disc burst pressure" of Figure 1.

$$Psb = 205(Ps/Pi) = 205(426/311) = 282\ kN/m^2$$

2. From equation (2), find maximum venting pressure, Prb, for reference case. This is the "maximum venting pressure" of Figure 1. Ethylene burning velocity = 80 cm/sec.

$$Prb = Pr(205/Pi)^{1.5}(40/U)^{0.2} = 1{,}482(205/311)^{1.5}(40/80)^{0.2} = 716\ kN/m^2\ abs$$

3. From Figure 1, reference case "quiescent" vent ratio:

   Fq = 0.064 (see item 3 of sample calculation of Table 4 for explanation of use of Figure 1)

4. From equation (3), the vent ratio for the "turbulent" reference case.

$$Ft = 2\ Fq = 2 \times 0.064 = 0.128$$

5. The volume of the actual container is $V = 1.9\ m^3$. The effect of volume on vent ratio is calculated in the following ways:

   a. For equation (4), the "volume correction factor" is read from the middle line of the "normalized Donat vent ratio - volume curve", at $V = 1.9\ m^3$. The volume correction factor is 0.88. The vent ratio at $V = 1.9\ m^3$ is:

$F = Ft \times$ volume correction factor $= 0.128 \times 0.88$
$= 0.113$

b. For equation (5), based on the "1/3 power law" is correction factor $= (F/Ft) = (0.032/1.9)^{1/3} = 0.26$
The vent ratio at $V = 1.9\ m^3$ is:

$F = 0.128 \times 0.26 = 0.031$

The calculation procedure is conservative especially if equation (4) is used. Smaller exponents selected for equation (2), and a lower coefficient of turbulence in equation (4) would result in a smaller vent.

TABLE 6 - Comparison of vent ratios obtained experimentally for methanol (see Table 1, Set IV) with calculated vent ratios

Run No.	Initial Press. kN/m^2abs Pi	Static Press. kN/m^2abs Ps	Max. Venting Press. kN/m^2abs Pr	Vent Ratio, m^2/m^3 Experi-mental	Calculated Norm-alized Factor	1/3 Power Law
IV-1	186	239	929	0.004	0.018	0.005
2	186	239	791	0.017	0.035	0.010
3	186	239	267	0.086	0.500*	0.160*

Methanol flame speed estimated from Eastman Kodak data to be 48 cm/sec.

*At virtual limit of Figure 1.

(7). Discharge Duct Length Duct length has been reported by Tonkin and Berlemont (1972) to have an important influence on venting pressure. Data were for dust/air combustions where the maximum venting pressure is less than about 5% of the maximum pressure which would be obtained in a nonvented container. However, no data appear to be available for gas/air combustions in the range of pressures treated by this procedure; no provision is made for quantifying the effect of ducts on venting pressure. The use of our procedure must be accompanied by advice to make the duct as large, as straight and as short as possible to minimize pressure drop. These design principles reduce the chances of transition from deflagration to detonation in the duct. It is also important that the duct be well anchored, and strong enough to withstand the calculated maximum vent pressure.

A long duct should be avoided because it may significantly increase the back pressure on the container to be vented. K.N. Palmer referred to this at the 66th Annual Meeting of the American Institute of Chemical Engineers in Philadelphia, Pennsylvania U.S.A., November 13, 1973. He said that combustion can occur within the duct itself during venting of dust deflagrations.

The added combustion causes an increase in the maximum pressure developed during venting. Burning within the duct might also occur during the venting of gases. Based on current technology, it would seem that a safe duct ought to have a length-to-diameter ratio of no more than 3, because of the orifice effect of the vent opening. Longer ducts could be vented at intervals indicated in the Ministry of Labour's Guide to Flame Arrestors And Explosion Reliefs. Conceivably the duct could be a truncated 15-20° cone to maximize its own vent area and minimize turbulence.

(8). Type of Vent Enclosure The type of vent enclosure, primarily its property of inertia, is reported by Maisey (1965) and Palmer (1971) to have a significant effect on venting pressure. However, data which could relate this effect to the pressure ranges covered by the procedure here do not appear to be available. For this reason use of the procedure can only be accompanied by the strong recommendation to keep vent closure inertia as low as possible.

(9). Container Shape The lack of experimental data for a variety of container shapes imposes the premise of a process container of essentially spherical, cubical or cylindrical shape with a ratio of length to diameter of less than 3. It should be noted that many containers and enclosures used industrially do not conform to this premise.

(10). Ignition Source The procedure presumes an ignition source which has a maximum effect on the rate of combustion. This appears to be a strong, centrally located point or surface source but some other configuration may in fact result in higher vent pressures.

CONCLUSIONS

We believe that our procedure can be successfully applied to cases which fall within the limitation of its experimental and theoretical framework. The procedure will tend to overestimate venting requirements, especially if Donat data are used to account for the effect of container volume. This may be acceptable as long as the cost of the system is not considered by management to be excessive.

The chief disadvantage of our procedure is its inadequate theoretical and experimental bases. Not enough data are available to develop a procedure which covers the range of real cases in an adequate manner. We have treated the various factors that affect venting as though they were mutually independent. However, these factors - burning velocity, pressure, temperature, mechanical turbulence induced by the combustion and by the venting operation itself - are all known to be interrelated.

More experimental work is needed in all areas of combustion venting, in the form of a coordinated program to explore all the complexities and interactions of the basic variables. The development of a full-scale program of well-planned and coordinated experimentation is beyond the means of a single agency. This activity needs to be carried out jointly by the national and international organizations which can contribute technically and financially. Uncoordinated efforts by individual agencies tend to leave large gaps in the state of our knowledge. A joint, comprehensive program will be much more effective. The execution of the various parts of the program can be assigned to the agencies best suited for the work. Members and friends of the Northwestern Branch of the Institution of Chemical Engineers are in excellent position to work for the realization of this program.

SYMBOLS USED

F = Vent ratio, process container (m^2/m^3).

Fq = Vent ratio, reference case, initial quiescence (m^2/m^3).

Ft = Vent ratio, reference case, initial turbulence (m^2/m^3).

Pi = Initial pressure, process container (kN/m^2 abs).

Pr = Maximum venting pressure, process container (kN/m^2 abs).

Prb = Maximum venting pressure, reference case (kN/m^2 abs).

Ps = Vent static burst pressure, process container (kN/m^2 abs).

Psb = Vent static burst pressure, reference case (kN/m^2 abs).

U = Fundamental burning velocity, process fuel in air (cm/sec).

Ub = Fundamental burning velocity, propane (40 cm/sec).

V = Volume of process container (m^3).

x = Exponent relating initial pressure to maximum venting pressure.

y = Exponent relating flame speed to maximum venting pressure.

REFERENCES

Bartknecht, W., and Kühnen G., 1971, "Brenngas - und Staubexplosionen", Forschungsbericht F45 (Koblenz, West Germany: Bundesinstitut für Arbeitschutz)

Cousins, E. W., and Cotton, P. E., 1951, Chemical Engineering, 58-8, 133

Donat, C., 1973, "Release Of The Pressure Of An Explosion With Rupture Discs And Explosion Values," paper presented at Achema 73, Frankfurt, West Germany

Harris, G. F. P., and Briscoe, P. G., 1967 Combustion And Flame, 11-4, 429

Maisey, H. R., 1965, Chemical And Process Engineering, 46-12, 662.

Ministry of Labour: Safety, Health and Welfare, "Guide To The

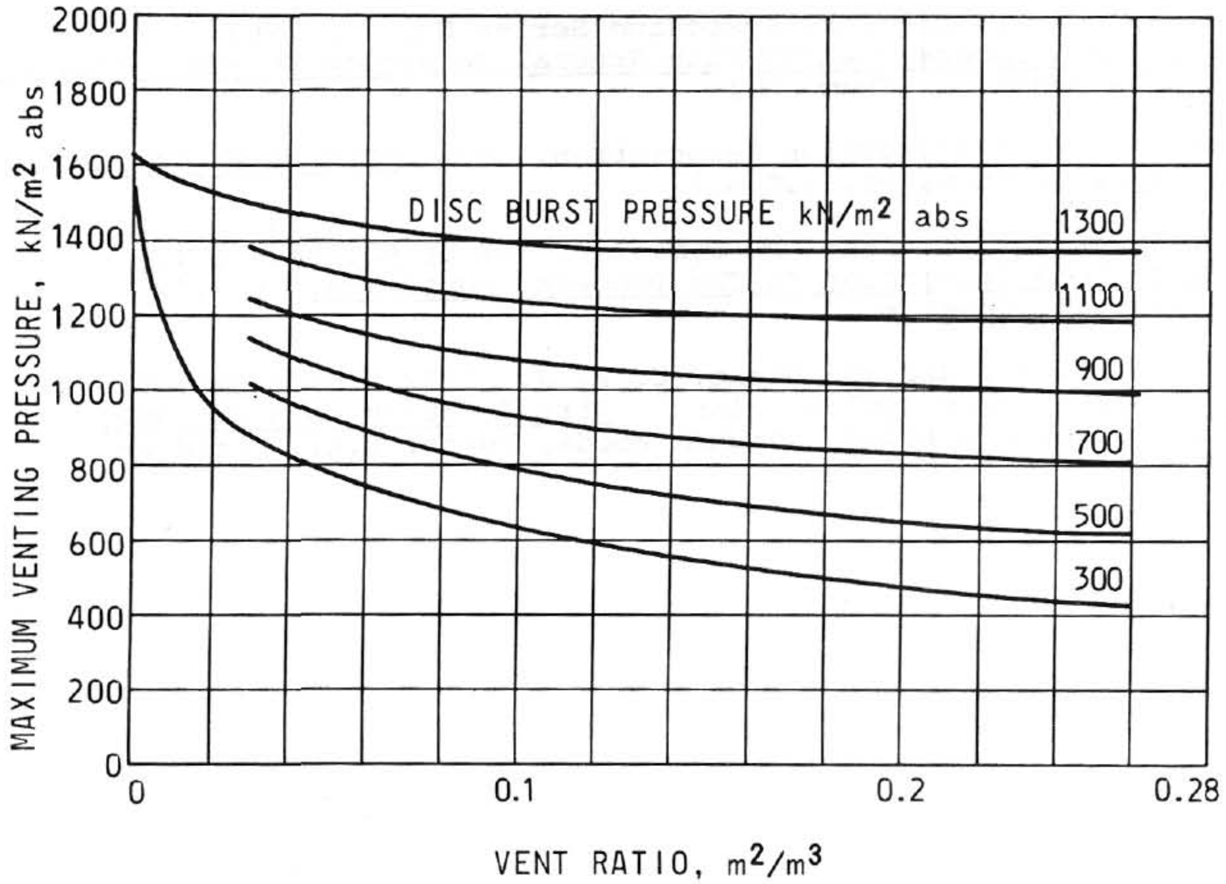
Use Of Flame Arrestors And Explosion Reliefs, "New Series No. 34, 1965, (London: Her Majesty's Stationery Office)

Munday, G., I. Chem. E. Symposium Series No. 15, 1963, "Chemical Process Hazards With Special Reference To Plant Design, p. 46 (London: I. Chem. E.)

National Fire Protection Association, 1954, NFPA 68 Explosion Venting, (Boston, Ms, U.S.A.)

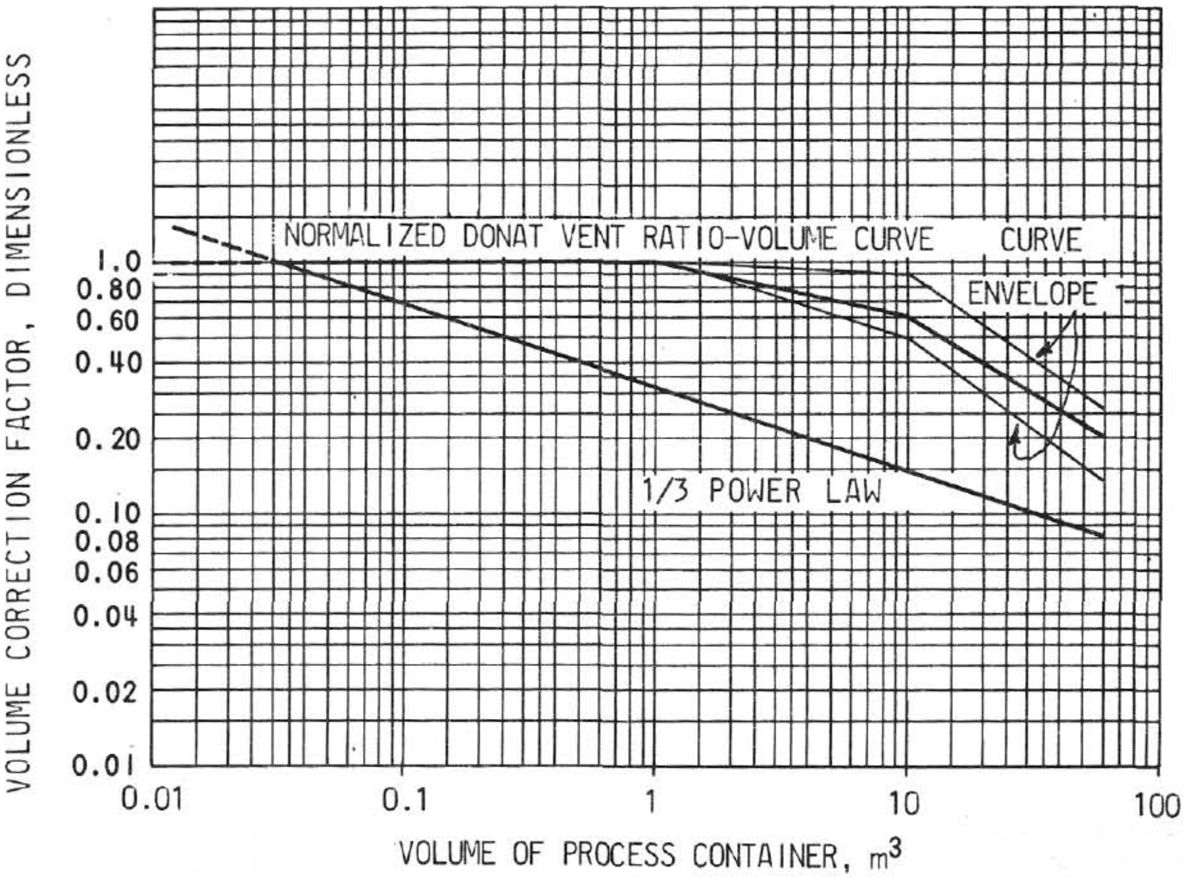
Palmer, K. N., I. Chem. E. Symposium Series No. 34, 1971, "Major Loss Prevention In The Process Industries," p. 142 (London: I. Chem. E.)

Tonkin, P. S., and Berlemont, C. F. J., 1972, "Dust Explosions In A Large Scale Cyclone Plant", Fire Research Note No. 942, Fire Research Station, Boreham Woods, Herts, U.K., Cited by permission.



Fuel - 5 mole % propane in air
Vessel - 0.032 m^3 with length to diameter ratio of 1.54
Initial pressure - 205 kN/m^2 absolute (15 psig)
Initial temperature - not reported, assumed ambient
Initial turbulence - quiescent
Ignition - Electric match. Location not given
Vent discharge duct length - none
Rupture discs - 25-0 alumimum, hard monel, spring-temper brass and soft copper.
Source - Cousins & Cotton (1951)
Disc Burst Pressure - Psb in Equation 1
Maximum Venting Pressure - Prb in Equation 1
Vent Ratio - Fq, used in Equation 2

Fig 1: Base case graph of maximum venting pressure plotted against vent ratio at various disc static burst pressures.



The normalized Donat data curve and envelope reflect the variation of vent ratio to volume at container volumes of 1, 10, 30 and 60 m^3 for the range of static burst pressures (110 to 150 kN/m^2 abs) and venting pressures (120 to 300 kN/m^2 abs) covered by the data. The assumption that the vent ratio is independent of volume between 0.032 m^3 and 1 m^3 is supported by the comparison of experimental and calculated results shown in Table 3. The curve envelope reflects the range of data at given container volumes. The middle line represents an estimated mean effect.

The 1/3 power law curve equates the volume correction factor to the relation $F_2/F_1 = (V_1/V_2)^{1/3}$. Its use is indicated by comparison to Monsanto experimental data, Tables 1 and 2.

Fig 2: Graph of the volume correction factor against container volume.