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An Inherent Technology to Mitigate Vapor Cloud Explosions

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Vapor cloud explosions have caused damage, injury, and death. Typically, an explosion of this type is the result of the ignition of a flammable cloud formed by the uncontrolled release of a flammable vapor into a semi-confined and congested area. One of the principal hazards of a vapor cloud explosion is the overpressure created. The overpressure can cause structural damage and, both directly (via body translation, etc) and indirectly (via missiles, collapsed roofs, etc), injuries and fatalities. Only recently has emphasis been placed on the dramatic effect that the degree of congestion and confinement has on the magnitude and extent of the overpressure hazard. It is generally acknowledged that the greater the confinement and the greater the congestion, all other things being equal, the more damaging and potentially injurious the explosion. However, in the limit, a process area that is completely confined and completely congested, a block of solid concrete, for example, will obviously not pose a vapor cloud explosion hazard. Nor would an area that is completely filled with the "crimped metal" material that is typically used in the manufacture of flame arresters. Theoretically at least, such techniques are classified as "passive" process risk management strategies and are classified as "moderate" or "attenuation and limitation of effects" Inherently Safer Processing approaches to mitigate the vapor cloud explosion hazard. While the impracticality of using either of the above in a real process area is obvious, it is advantageous to acknowledge the fact that there is a degree of confinement and congestion above which the explosion hazard is actually lessened and to conceptualize practical techniques to take advantage of this fact. One specific method that utilizes a commercially available component and that may be practical is presented. Encouraging results from small scale tests are presented. A large scale test program is outlined, the results of which could answer scale-up design questions.

AN INHERENT TECHNOLOGY TO MITIGATE VAPOR CLOUD EXPLOSIONS

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AN INHERENT TECHNOLOGY TO MITIGATE VAPOR CLOUD EXPLOSIONS

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Abstract

Vapor cloud explosions have caused damage, injury, and death. Typically, an explosion of this type is the result of the ignition of a flammable cloud formed by the uncontrolled release of a flammable vapor into a semi-confined and congested area. One of the principal hazards of a vapor cloud explosion is the overpressure created. The overpressure can cause structural damage and can cause injuries and fatalities. In the last several decades emphasis has been placed on the dramatic effect that congestion and confinement has on the magnitude and extent of the overpressure hazard. It is generally acknowledged that the less the confinement and the less the congestion, all other things being equal, the less damaging and potentially injurious the explosion. However, several techniques are proposed that would not lessen confinement and congestion (and, in fact, may actually increase either or both) and yet would decrease the consequences of a vapor cloud explosion. Such methods are "passive" process risk management strategies in that they are ever present and have no moving parts. And they are examples of "moderating" or "effect attenuating" Inherently Safer Processing approaches to mitigating vapor cloud explosions.

Introduction

For the purposes of this presentation, a vapor cloud explosion is an event in a process area that results from the ignition of a flammable gas-air mixture and that results in damaging overpressure. The variables affecting the answer to the question "Can a vapor cloud explosion occur?" are many. They include the homogeneity, geometry, and turbulence of the cloud; the type, strength, timing, and location of the ignition source; and the reactivity and concentration of the flammable vapor. Another variable is the overpressure that divides those events that will be counted as explosions and those that will not. This pressure is referred to below as the "Acceptable Severity Limit".

Generally, the severity of an explosion is proportional to the degree of 'confinement and congestion' (C/C). For example, two articles by Baker, et al, (References 1 and 2) discuss this relationship. "Confinement" refers to the extent to which walls, ceilings, and floors ... and large equipment ... constrict the openness of an area. The more degrees of freedom the flame has to expand (none (as in a box), one, two, or three (totally unconfined)), the less likely overpressures will result. "Congestion" (high, medium, low) refers to the extent and nature of equipment within and near the volume occupied by the vapor cloud. Such equipment (pipes, vessels, ladders, conduits, ducts, building steel, etc.) produces turbulence and higher flame speeds than would be encountered if the equipment was not present and, in turn, increases the likelihood and magnitude of overpressure. If "relative confinement and congestion" vs. "relative vapor cloud explosion severity" is graphed, the graph looks like Figure 1.

Figure 1" Severity as a function of Confinement and Congestion

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0 2 4 6 8 10 **Relative Confinement and Congestion**

Severity vs. C/C

---- Acceptable Severity **Limit**

The line may not be straight, but 'severity' increases as C/C increases.

While many factors need to be considered in the design of a process area in which a vapor cloud explosion might occur, an attempt is made to make a process area less congested and less confined than it might otherwise be. Thus an attempt is made to lower C/C such that the severity is at or below some arbitrarily chosen acceptability limit. It is generally good engineering practice to take advantage of the left lower side of this line. These are some obvious techniques to reduce C/C.

Confinement may be reduced by the opening of one or more walls or opening a roof.

Congestion may be decreased by reducing the density of equipment in a process area.

Imagine two identical, ground level, shoebox shaped process areas each with a hefty roof, one hefty side wall, and hefty end walls, but with one easily-blown-away side wall, perhaps made using damage-limiting construction. These areas differ only in that, in one, a row of tall electrical cabinets is located outside of the process area and in the other the cabinets form a partial wall lengthwise down the middle of one half of the process area. Imagine also a vapor cloud in each area is ignited in a comer that is far removed from the easily-blown-away wall. Figures 2 and 3 illustrate both the

geometries and the pressure gradients (in a cross horizontal se
the structures. (Note" Gexcon's CFD FLACS model was us
presented below.)

Figure 2 (without cabinets):

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Figure 3 (with

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The severity of a vapor cloud explosion in the area without the row of cabinets is less than in the area with the row of maximum peak pressure without the cabinets is .33 barg whereas with the cabinets it is 1.6 barg. The maximum flame former is 318 m/s whereas in the latter it is 800 m/s. The cabinets provide sufficient additional C/C to dramatically af severity. Choosing not to install the cabinets in the process area can be viewed as reducing C/C, in essence by slid severity vs. C/C line on Figure 1 toward the (0,0) point. *Placing only necessary equipment in an operating area can decr severity.*

Orientation

Equipment orientation within the process area is also an important factor influencing severity. If it is assumed that "C some nebulous factor based on equipment density and porosity, then, if there is no change in the type and quantity of e process area, there is no change in congestion, for better or worse, by reorienting the equipment in the structure one wa

However, imagine again the two, identical, ground level, shoebox shaped process areas and a vapor cloud in each. In o is oriented "widthwise" and in the other it is oriented "lengthwise". Figures 4 and 5 illustrate both the geometries an gradients (in a horizontal cross section) for each that result in and around the structures.

Figure 4 (widthwise orientation)"

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3 = I-4,5, K ~ 1-4.

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Figure 5" (lengthwise orientation)

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(s). I~-!-N!., J--1-4$, K-!-4.

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The severity of a vapor cloud explosion in one area will be different than the severity of a similar explosion in another a only in the orientation of the equipment. The maximum peak pressure in the "widthwise" orientation is .33 barg w "lengthwise" orientation it is .5 barg. The maximum flame velocity in the former is 318 m/s whereas in the latter it is 4 be that the widthwise orientation directs the pressure toward the easily-blown-away side walls in preference to directin toward the end walls, as would be the case with the lengthwise orientation. The side walls open earlier in the event th have otherwise. Taking advantage of one orientation over the other may be viewed as reducing C/C, in essence by sli severity vs. C/C line on Figure 1 toward the (0,0) point. Or it may be interpreted as simply shifting the whole severit downward such that the same degree of C/C yields a different, lower severity. Semantics aside, *attention to the detail orientation can decrease expected vapor cloud explosion severity.*

The Right Hand Side of the C/C vs. Severity Curve

With reference to Figure 1, it would appear that the greatest severity would be reached with the greatest C/C, and an arbi acceptable limit of severity would be reached only below some low degree of C/C. But is that necessarily true? What if of course and ignoring the complete lack of an explosive cloud, the voids were filled with concrete. Infinite C/C woul an explosion with an infinite, or even high, severity would not result. In fact, what would result is no explosion at practical (but not much more practical) vein, let it be assumed that the voids in the process area are filled with the inn from a multitude of flame arresters and let the impracticality of such a process area be ignored. The process area is thu walls, floors, ceilings, and equipment, with the voids filled with a maze of crimped metal with aperture sizes so s flammable cloud is ignited, any flame would be quickly quenched. As with the 'filling with concrete' example, ignit cause a vapor cloud explosion, even though the C/C is very high indeed. The "relative confinement and congestion" actually looks like Figure 6"

lO "~, **8 6 4**

Figure 6"

s. "expected vapor cloud explosion severity" graph

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0 2 4 6 8 10

Relative Confinement and Congestion

Severity vs. C/C ......

Severity as a function of Confinement and Congestion

Acceptable Limit Severity

At the limits, both at zero C/C and at the greatest degree of C/C, there is no explosion. The maximum severity occurs not at degree of C/C, but at some intermediate degree. If one accepts the presumption that a pressure producing vapor cloud ex occur in a totally open, unconfined and uncongested area, the beginning and end of this 'line' or 'curve' both cross the y axis severity. Thus, the lower left hand side of the curve may not be the only portion of the curve that can be taken advantage of. T hand side of the curve is also below the acceptability limit.

The question then remains: Are there practical ways to take advantage of the fight hand side of this curve ... ways to design such that increasing C/C actually lowers severity?

Imagine again the two identical process areas and their respective vapor clouds. In one, the 2x4 bay area is open and in the other divided by a hefty wall such that there are actually two 2x2 bays. Figures 7 and 8 illustrate both the geometries and the pres (in a horizontal cross section) for each that result in and around the structures.

Figure 7 (without the wall)"

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Figure 8 (with the wall)"

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Although the process area with the center wall gives the appearance of being more confined than the process area wit the severity of a vapor cloud explosion in the area without the center wall is higher than in the area with the wall. The m pressure without the wall is .33 barg whereas with the wall it is .2 barg. The maximum flame velocity in the former is 31 in the latter it is 242 m/s. The easily-blown-away side wall, at least that portion on the 2x2 bay area in which ignition earlier in the 'walled' case that it does in the 'unwalled' case. In turn, this makes the venting of the explosion more effecti overpressure and minimizing flame speed. Increased C/C by adding a wall decreased severity. Not only were the pr flame speed reduced but the area exposed to overpressure was reduced as well. In essence, by sliding down the right ha severity vs. C/C line on Figure 6 toward the (10,0) point, severity is reduced ... perhaps to a point below the "Accep Limit". *For some situations an apparent increase in C/C can decrease expected severity.*

DuPont has conducted a series of very small scale tests in its Explosion Hazards Laboratory, the results of which impl at least one other method that takes advantage of the lower right hand side of this curve. There is in the public marketp material called "EXPLO-CONTROL". It has been promoted publicly by Fauske & Associates, Inc. (Reference suppressing or eliminated deflagration events within the vapor spaces of tanks and within fuel tanks on military aircraf (Globally, it bears the name "DETOSTOP" as well.) It is also recognized as a means to prevent BLEVEs.) It is a mecha relatively chemically inert, expanded metal foil/mesh with very low density, low volume displacement, and very hig per unit volume.

A vertical, open topped, 55 gallon drum was used to model a 'confined process area'. A web of PVC piping was placed provide 'congestion'. The drum was outfitted with pressure transducers and pressure recording equipment, a gas supply s of making and homogenizing a stoichiometric flammable vapor - air mixture, and a hot wire igniter (in the bottom). Flar were ignited 1) in the empty drum, 2) in the drum with the PVC piping installed but without any foil/mesh in the drum drum with the PVC piping installed and with the foil/mesh occupying a portion of the volume.

Figures 9 and 10 are views of the drum from the top. Figure 9 is with the upper lattice of turbulence-producing pipin that the 3" thick mat of mesh, located horizontally in the drum at the midpoint and with a gap of 1/4" to 1/2" around the c can be seen clearly.

Figure 9"

Figure 10 is with the upper lattice installed so that the congestion can be visualized.
Figure 10:

Figure 11 presents the pressure as a function of time for 'baseline' cases, with the lattice of piping in the drum but with n installed:

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Figure 12 presents the pressure as a function of time for cases in which both the lattice of piping and the mesh were installe drum.

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While the mesh *increases* the confinement in the lower half of the drum and *increases* the overall congestion in the drum of vapor cloud explosions, as measured by the pressure produced, is *reduced.* While the rate of pressure rise data is these data similarly show a reduction in severity. *Thus, there may be opportunities to use this or similar material in pr artificial 'walls' or as 'under-grating layers' or 'under-roof-or-ceiling layers' such that they become ever-present, passiv* *explosion mitigation equipment.* DuPont has applied for a patent on the use of this and similar material for the control o explosions in semi-confined, congested operating areas.

Summary and Conclusions

A close examination of the 'relative confinement and congestion' vs. 'relative vapor cloud explosion severity' graph in relationship between these variables is not as clean cut, obvious, or direct as might first appear. It is, in fact, a messy re easily generalized. While the adage "Congestion and Confinement is bad." is still a great general principle to bear in m exceptions to the rule. There may be opportunities for process safety improvement in those exceptions.

There are opportunities to reduce severity without reducing confinement and congestion, for example by rearranging ar reorienting process equipment.

And there are opportunities to reduce severity by increasing confinement and congestion, thereby taking advantage of t side of the 'relative confinement and congestion' vs. 'relative vapor cloud explosion severity' curve. One way may be to increase confinement *by judiciou* hefty walls. Another way may be to install 'pseudo walls and ceiling panels' constructed in such a way that they actua pressures and rates of pressure rise that would otherwise be generated without their installation.

Some of the above mentioned opportunities fall into a category that can be generally classified as "inherent safety technol of the fact that they are passive and ever-present (and therefore 'inherent') in the overall process scheme.

There has been a great deal of research done on vapor cloud explosions. However, more theoretical and experimental w useful to clarify the phenomenon and to identify a broader range of tools that could be used by the industrial commu vapor cloud explosion risk.

References:

1) Baker, Q. A. Tang, M. J. Scheier, E. A, and Silva, G. J., "Vapor Cloud Explosion Analysis," 28th Annual AIChE Lo Symposium, Atlanta, GA, April 19, 1994. 2) Baker, Q. A., Doolittle, C.M., Fitzgerald, G. A., Tang, M. J., "Recent Dev the Baker-Strewlow VCE Analysis Methodology," Process Safety Progress, Vol. 17, No. 4, Winter 1998, pages 297-3 st Loss Prevention Symposium, Houston, TX, March 9 through 13, 1997. 3) Fauske and Associates, Inc., 16W070 We Burr Ridge, Illinois 60521