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(54) **METHOD FOR REDUCING THE SEVERITY OF VAPOR CLOUD EXPLOSIONS**

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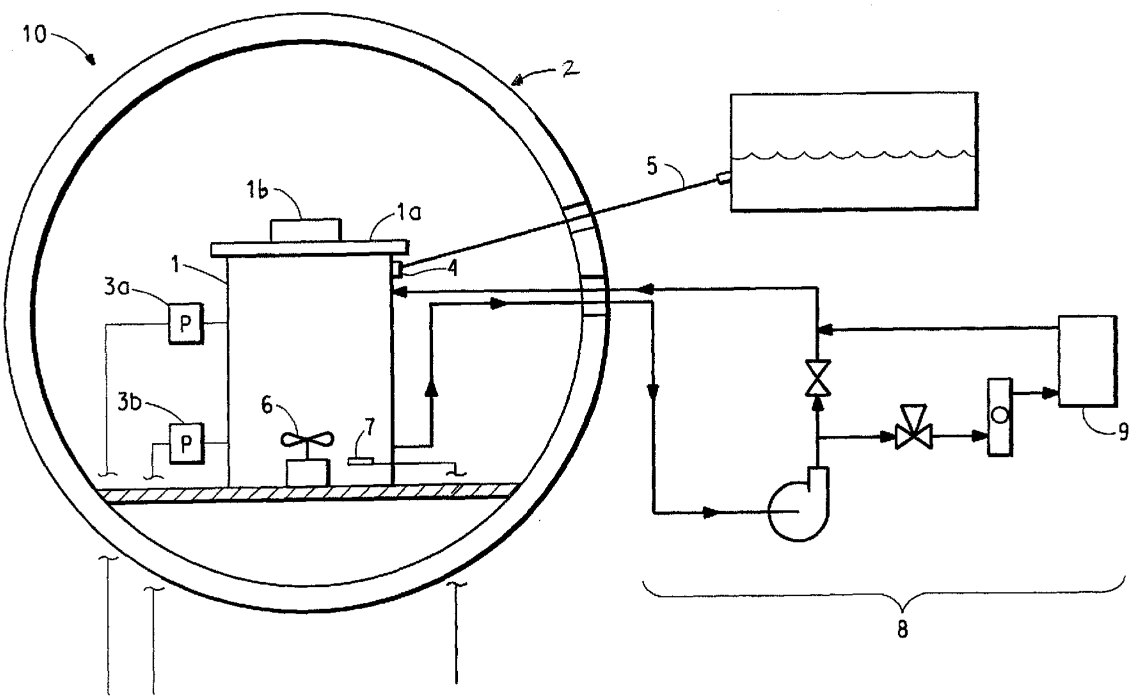
(57) **ABSTRACT**

It has been found that high porosity, high surface area protective materials such as expanded metal foil can be used in places such as the semi-confined, congested operating areas of chemical process plants to reduce or eliminate the hazard caused by the sudden accidental release and ignition of large quantities of potentially flammable vapors into the area.



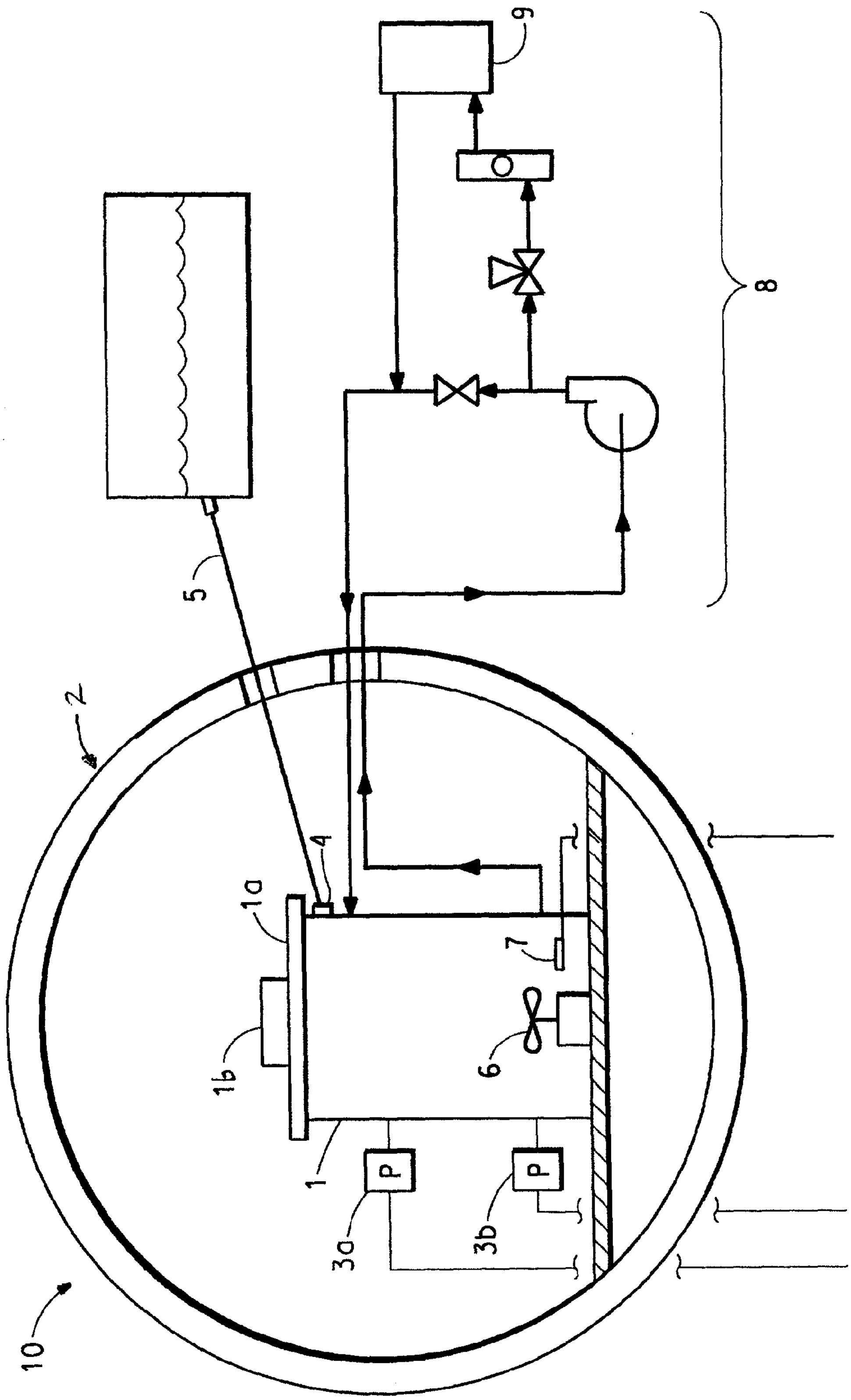


FIG. 1

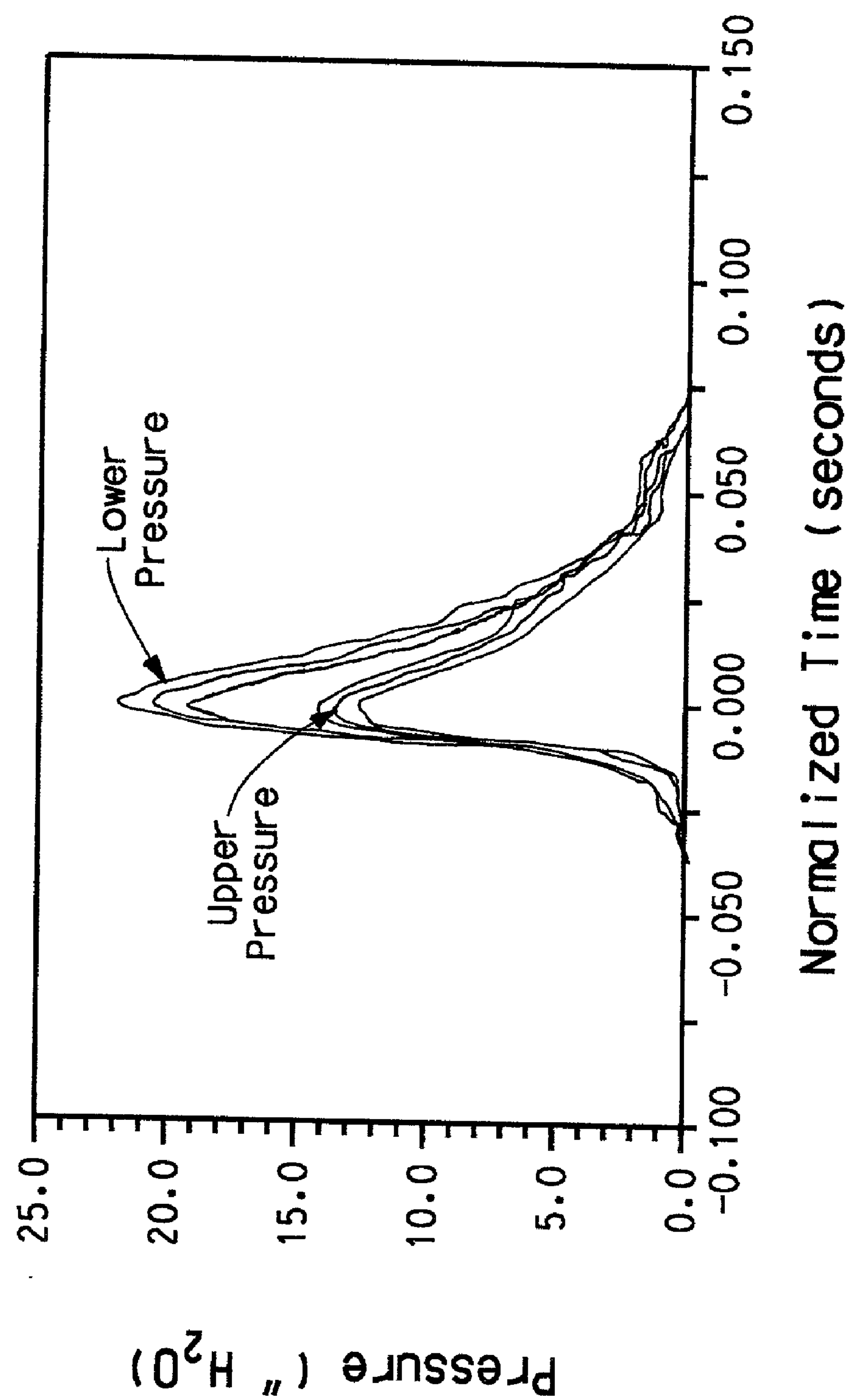
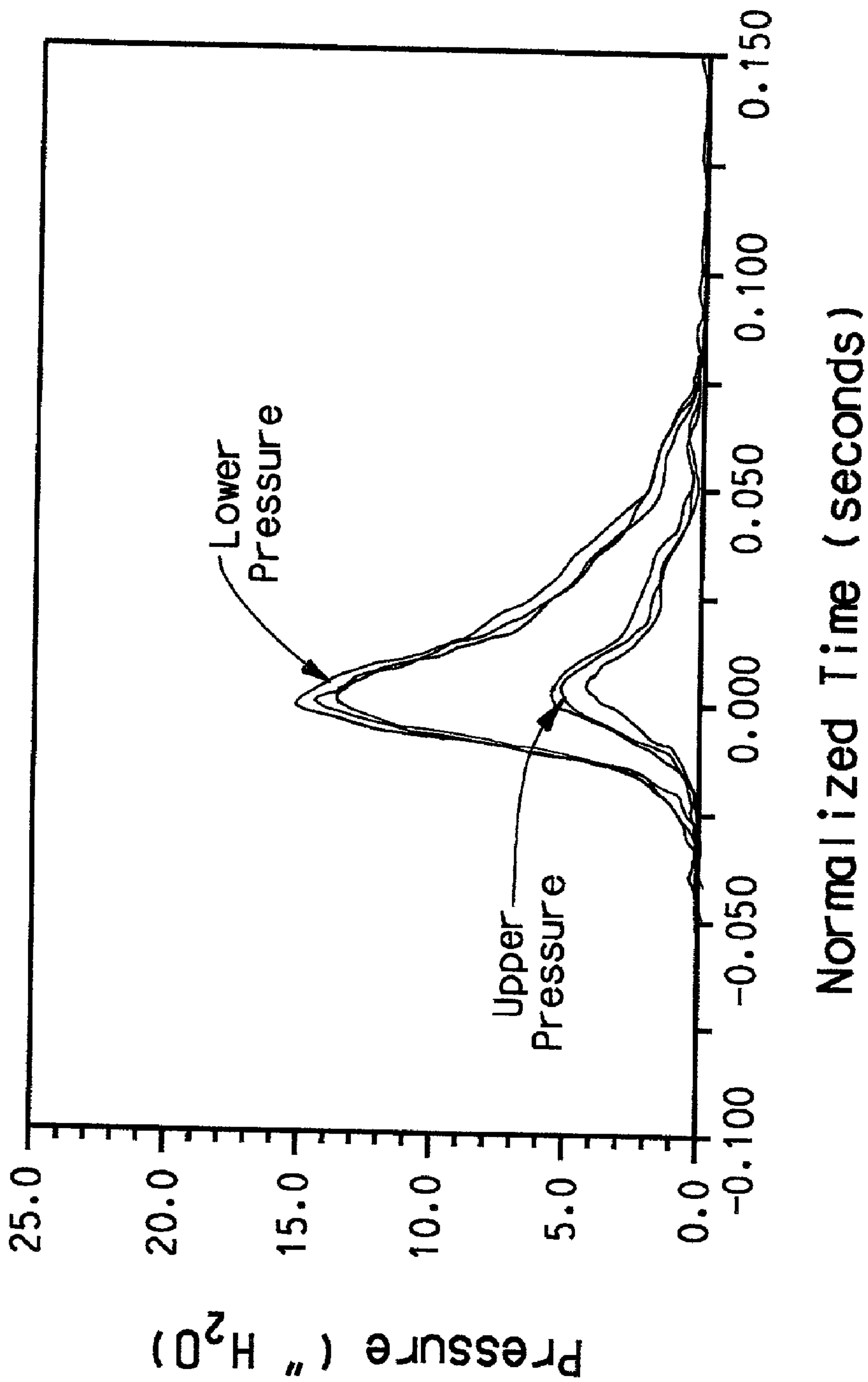

Lower Pressure
Upper Pressure
Normalized Time (seconds)
Pressure (" H2O)
-0.100
-0.050
0.000
0.050
0.100
0.150
0.0
5.0
10.0
15.0
20.0
25.0

FIG. 2



Lower Pressure
Upper Pressure
Pressure (" H_2O)
25.0
20.0
15.0
10.0
5.0
0.0
-0.100
-0.050
0.000
0.050
0.100
0.150
Normalized Time (seconds)

FIG. 3

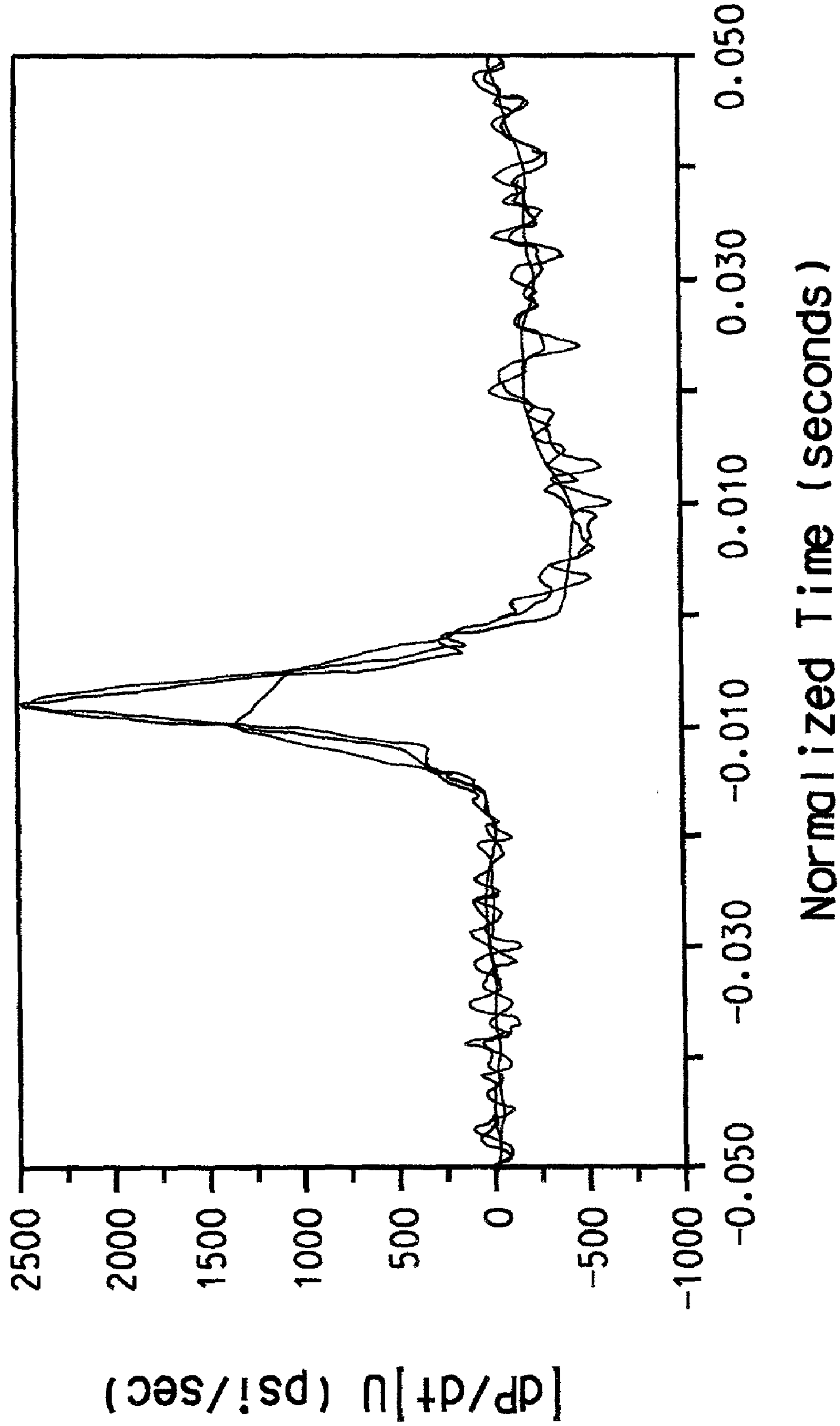

Normalized Time (seconds)
-0.050
-0.030
-0.010
0.010
0.030
0.050
[dP/dt]U (psi/sec)
2500
2000
1500
1000
500
0
-500
-1000

FIG. 4

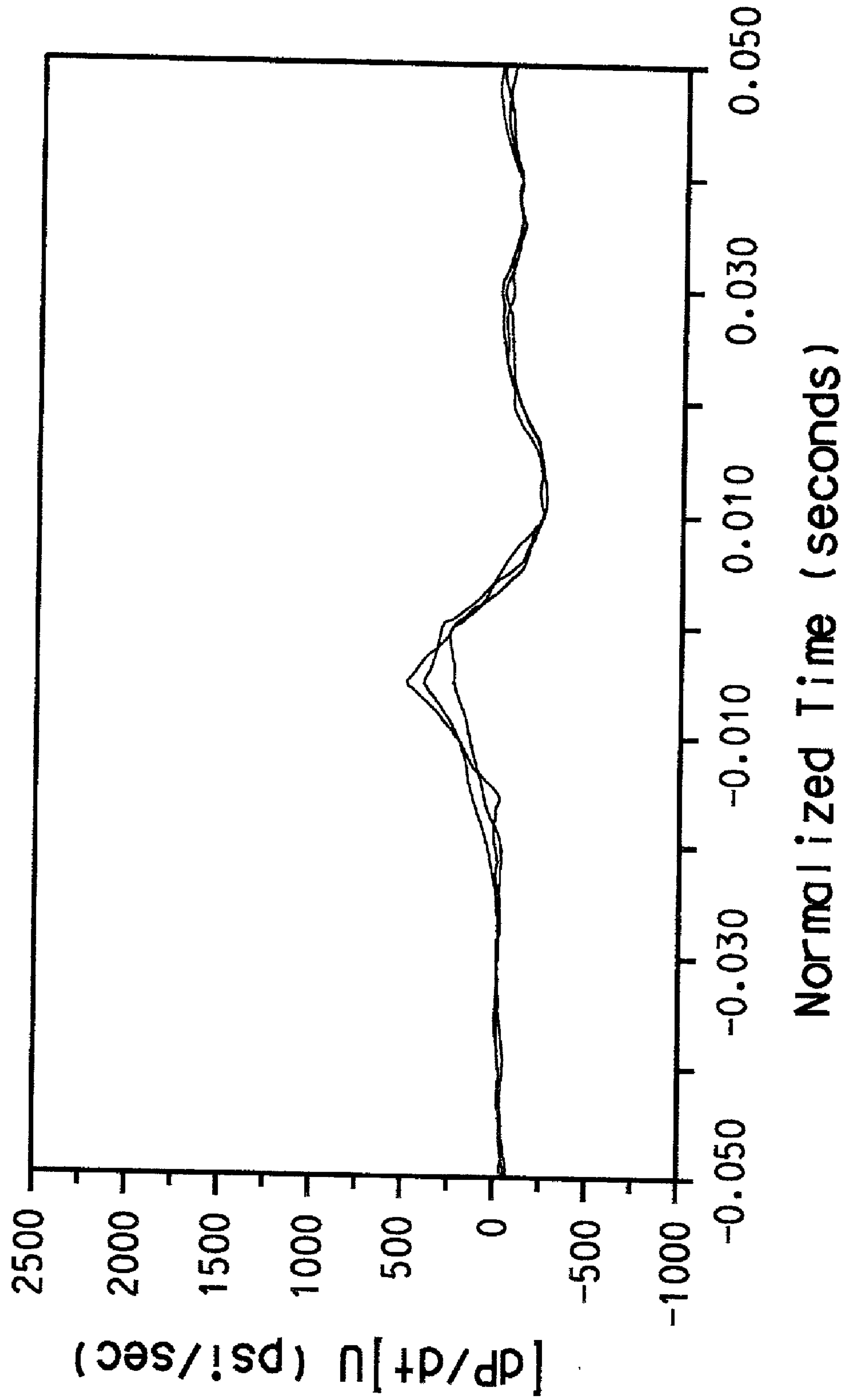

[dP/dt]U (psi/sec)
2500
2000
1500
1000
500
0
-500
-1000
-0.050
-0.030
-0.010
0.010
0.030
0.050
Normalized Time (seconds)

FIG. 5

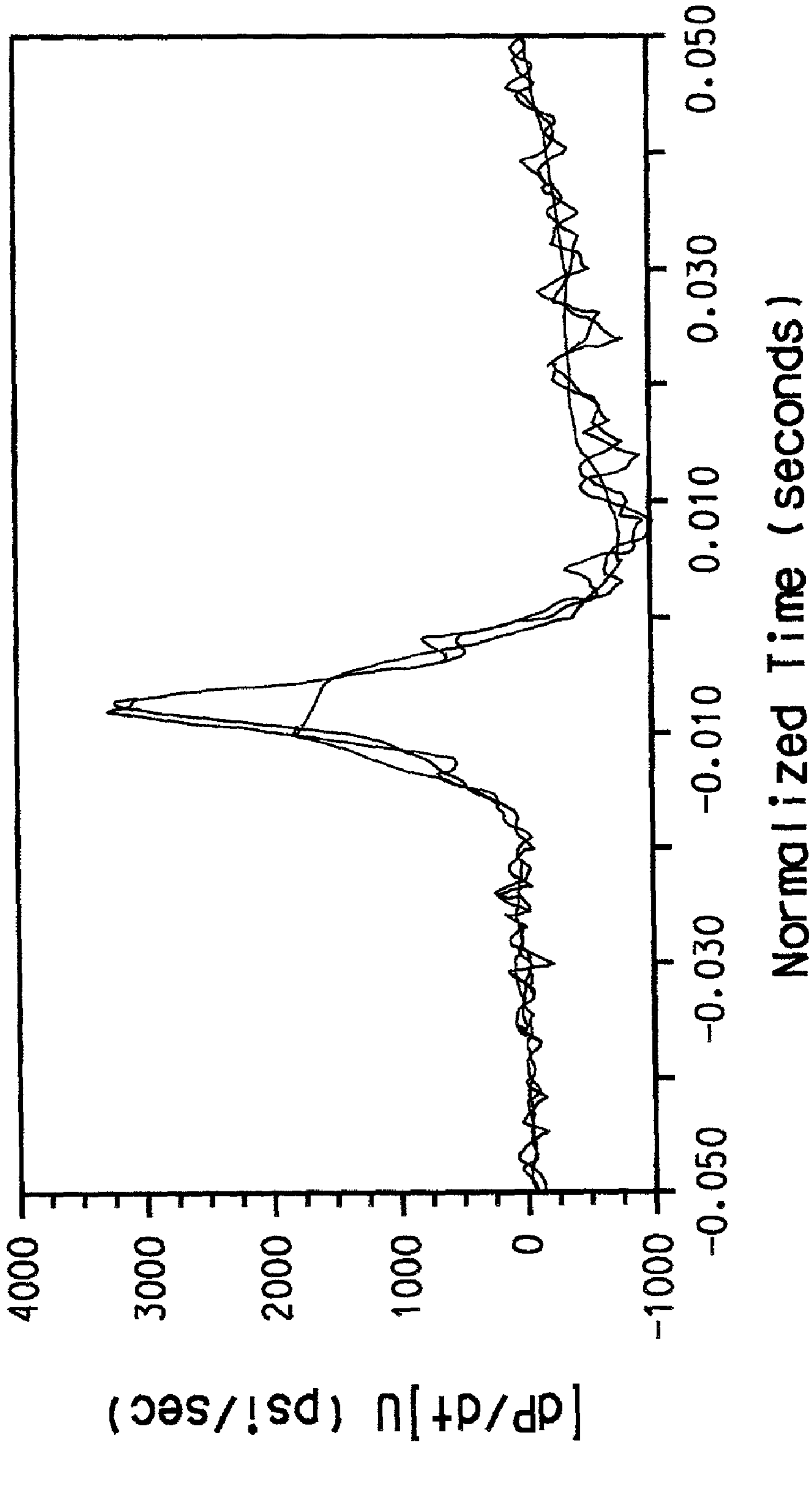

[dP/dt]u (psi/sec)
4000
3000
2000
1000
0
-1000
Normalized Time (seconds)
-0.050
-0.030
-0.010
0.010
0.030
0.050

FIG. 6

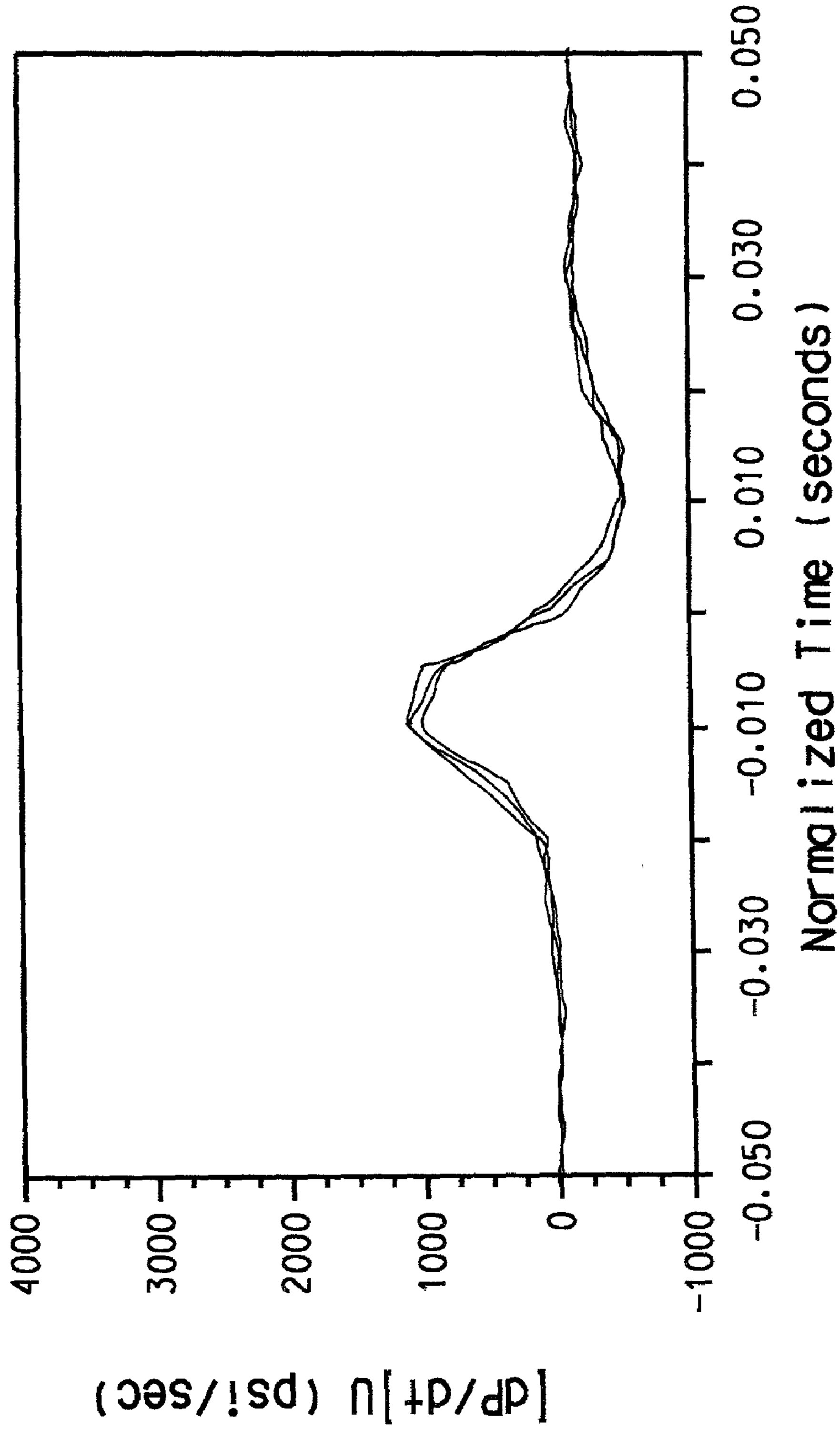

[dP/dt]U (psi/sec)
4000
3000
2000
1000
0
−1000
−0.050
−0.030
−0.010
0.010
0.030
0.050
Normalized Time (seconds)

FIG. 7

METHOD FOR REDUCING THE SEVERITY OF VAPOR CLOUD EXPLOSIONS

FIELD OF THE INVENTION

[0001] The invention is a method of use of protecting chemical process plants or similar facilities that have the potential to release large amounts of flammable vapor suddenly.

BACKGROUND

[0002] The hazards from flammable vapor/air explosions, either internal or external to process equipment, have been addressed in many ways. The elimination of known ignition sources is one of these ways, though typically there is little confidence that all possible ignition sources can be identified and eliminated. Within equipment, the use of an inert atmosphere that is devoid of sufficient oxygen for combustion and the use of operating conditions that avoid the flammability zone between the lower explosive limit and the upper explosive limit are other means.

[0003] It is also known that the severity of internal vapor/air explosions is mitigated by filling the interior of tanks and other vessels containing explosively combustible fuel/air mixtures with reticulated plastic foams as in U.S. Pat. No. 3,561,639 (Allen), or with expanded aluminum foil as in U.S. Pat. No. 3,356,256 (Szego). Other forms of suppression systems may be used to mitigate an internal vapor cloud explosion, such as suppression systems that detect an incipient internal vapor cloud explosion by detection of increased pressure or by detection of fire and subsequently inject water or other inerting agent.

[0004] One of the latest developments in the field of explosion prevention, specifically applicable in the prevention of Boiling Liquid Expanding Vapor Explosions, or "BLEVE's" as defined in U.S. Pat. No. 4,930,651 (Szego), has been the use of heat-resistant, permeable, heat conductive porous material such as the expanded metal foil disclosed in the Szego '256 patent. With the tank filled with such material in a way that there is close thermal contact with the walls of the vessel, when the tank contains a pressurized liquid and is exposed to an external heat source such as a fire, a BLEVE will not occur. Thus the porous metal material is a passive, ever-present, and proactive BLEVE prevention system. Since a BLEVE of a flammable liquid could create a very large external vapor cloud that in turn could be ignited, BLEVE prevention is a means of preventing that subsequent event as well. A suitable material is manufactured by Explosion Prevention Systems, L.L.C. (Fort Worth, Tex.) and has found application commercially in protecting aircraft and military vehicle fuel tanks.

[0005] Since external vapor cloud explosions, flash fires, and fire balls result from the ignition of flammable vapor clouds, a number of systems have been developed to reduce the explosive and flammability potential of such clouds. For example, U.S. Pat. No. 5,495,893 (Roberts and Butz) discloses a system where sensors detect the buildup of flammable vapor, as might develop from a catastrophic leak in a process containing flammable gases and liquids, and suppresses the potential explosion or fire by automatically spraying a fine mist of a non-flammable liquid such as water into the area of the gas buildup. This action reduces or eliminates the size of the vapor cloud available to participate in any potential explosion. It also has the potential to reduce the probability of ignition and/or slow down the acceleration of a flame front.

[0006] Many systems have been patented to deal with suppression of an external fire. These are typified by U.S. Pat. No. 5,609,210 (Galbraith) where a system is provided that is claimed to be an improvement over traditional suppression systems such as carbon dioxide, dry powder extinguishers, and Halons. Suppression systems are thoroughly reviewed in the background section of the Galbraith '210 patent. His invention calls for a gas generation system to provide a means for effective feeding of dry powder suppressants to the source of the flame subsequent to ignition of a flammable cloud.

[0007] All of these systems that have been proposed to alleviate external vapor cloud explosions are active and not passive systems. They require an action of some sort after a flammable cloud is formed to be effective. A more inherently safe system of vapor cloud explosion control would be one that is passive (no moving parts), ever-present, and proactive in its ability to mitigate or eliminate vapor cloud explosion potential at all times.

[0008] It is generally accepted that external vapor cloud explosions occur in process areas that are somewhat congested or confined. Ignition of flammable vapor clouds out in the open with no congestion or confinement result in very large fire balls or flash fires but not in significantly damaging overpressures. Thus, the theory has always been that less congestion and confinement is "good" and anything that increases either or both is "bad." However, while typical operating areas in plants that handle flammable vapors and liquids are not totally enclosed, they have ceilings, floors, walls and process equipment (pumps, pipes, vessels, cable trays, etc.), all of which create congestion and confinement. It is in these areas that a passive, ever-present and proactive vapor cloud explosion mitigation or prevention system would be invaluable.

SUMMARY OF THE INVENTION

[0009] The invention provides a method of reducing the severity of vapor cloud explosions in partially confined operating areas, comprising placing porous, high surface-area-to-volume ratio protective material in the area in sufficient amount to reduce the pressure effects caused by ignition of the flammable vapor clouds. According to a preferred embodiment of the invention, the protective material is a metal mesh or foil material.

[0010] According to another preferred method of the invention, the density of the protective material is between 10 and 100 kg/m^3 and the surface-area-to-volume ratio of the protective material is greater than 100 m^2/m^3.

DESCRIPTION OF THE DRAWINGS

[0011] **FIG. 1** is a schematic of the test apparatus used to test the present invention;

[0012] FIGS. **2-7** are graphical representations illustrating the effect of a protective material as used in the invention on vapor cloud explosion characteristics.

DETAILED DESCRIPTION OF THE INVENTION

[0013] A typical manufacturing process operating area is congested by the equipment therein. Such equipment occupies 2 to 8% of the total volume of the operating area. Many operating areas are partially confined, so that although they may be open on one or more sides, they are semi-confined by the ground, floors, ceilings, and walls. This confinement and congestion suggests strongly that, if the area is inundated with a flammable vapor and this cloud is subsequently ignited, then the intial flame created by ignition will accelerate such that damaging overpressures of 1 to 5 psig or more may result. The congestion and confinement creates turbulence and enhances not only the rate of burning per unit area of flame but also the total flame area. In turn this produces an ever accelerating rate of production of reactants at high temperature and from this an increase in pressure.

[0014] According to the present invention, the protective material used to reduce the overpressures to a tolerable value is a low density, low volume displacement, high surface area per unit volume expanded metal foil or mesh material. The density of the material is preferably in the range of 10 to 100 kg/m^3. The surface area to unit volume ratio is preferably greater than 100 m^2/m^3, more preferably greater than 500 m^2/m^3. One such material, known as Explo-Control, manufactured by Explosion Prevention Systems, LLC, is a candidate for use in this method. It is a specially designed, expanded aluminum alloy foil (20 to 80 micrometers in thickness) of low density (30 to 50 kg/m^3) and low volummetric displacement (1 to 2%). It comes in spherically shaped bodies or cylindrical rolls; other shapes are possible. It is chemically inert with most systems and has mechanical stability, with self compression due to its own weight of 5% for a stack height of 15 m.

[0015] The low density, high surface area, porous protective material employed in the present invention is placed in a portion of the open or available space in the operating area. Since the open space is approximately 98 to 92% of the total, the protective material is judiciously located in blocks, such as batts, layers and cylinders, in portions of that remaining space, leaving room for operators and maintenance personnel and for unimpeded daily operations. The protective material must fill a significant portion, typically 5 TO 20%, of the volume of the operating area. The effectiveness in preventing or mitigating vapor cloud explosions is a function of the orientation and distribution of the protective material as well as the total quantity used. The protective material may be housed in appropriately designed frames to allow for ease of movement to facilitate maintenance on critical equipment and to facilitiate other necessary periodic operations.

[0016] If and when a vapor cloud forms and is ignited, the flame acceleration is reduced or reversed by the batts of the protective material. Overall, the result is the reduction in the rate of formation of combustion products and the rate of release of energy into the area. In turn this reduces the rate of pressure rise and the peak pressures generated by the ignition of the vapor cloud in the semi-confined operating area. It is believed that the use of the protective material suppresses or eliminates deflagrations (flames) because the porosity of the material, characterized by the volume-to-area ratio, is of the same order of magnitude as the critical flame quenching diameter. The critical flame quenching diameter is a characteristic of a gas mixture and is herein defined as the minimum diameter of a tube through which a flame in a stationary gas mixture can propagate indefinitely.

EXAMPLES

[0017] The test apparatus **10** used to simulate an explosion in a partially confined process area and to test the efficacy of using an expanded foil or mesh to reduce the impact of flammable vapor explosions in such a semi-confined area is depicted in **FIG. 1**. The test apparatus included an open-topped 55 gallon metal drum **1** that was 34.5 inches high and 21.7 inches in diameter, with a plywood lid **1***a* covering the top and a weight **1***b* holding the lid in place. For added safety the drum was contained in a 200 cubic foot cylindrical concrete containment barricade **2** open on one end.

[0018] The drum was instrumented with a data acquisition system using Shaevitz™ Sensors (Hampton, Va.) pressure transducers **3***a* and **3***b* with a full range pressure capability of 100" of water. These were located 2.5" from the bottom of the drum and 10.5" from the top. Pressure vs. time traces were recorded at a rate of 0.2 to 0.5 kHz on a digital data acquisition system. The drum **1** also contained an addition port **4** to inject liquid pentane into the drum via an external ⅛" tubing line **5**, a 40 CFM fan **6** at the bottom of the drum to provide air circulation and mixing of the pentane and air, and a nichrome wire ignition source **7** at the bottom of the drum. Pentane concentration within the drum was continuously monitored via an external flow loop **8** passing through a Model 1440 IR gas analyzer **9**, available from Servomex International Ltd., East Sussex, UK.

[0019] For each test, the drum **1** was covered with the weighted plywood lid **1***a* and liquid pentane was added until the concentration reached 2.9% +/−0.05% which is about 110% of the stoichiometric pentane/air concentration. At that point, the lid **1***a* was removed and the pentane air mixture ignited within 10 seconds. The pressure rise and fall as measured by the upper and lower transducers **3***a* and **3***b* were recorded. This enabled determination of both the peak pressure and the rate of pressure rise as a function of time.

[0020] The results of all control tests and demonstrations of the invention are summarized in Table 1.

[0021] Control Example 1 was a baseline test with no obstruction in the drum, i.e., the drum was empty.

[0022] Control Example 2 was a demonstration of the impact of limiting the escape potential of the gases by only partially removing the lid from the drum.

[0023] Control Examples 3-5 were demonstrations of the impact of the piping, machinery, etc., in a process area by the addition of sufficient 1" diameter polyvinyl chloride pipe to the drum to occupy or obstruct 10% of the volume of the drum. Otherwise, the drum was empty. The corresponding pressure vs. time traces are shown in **FIG. 2**, as obtained by recording the output from the pressure transducers on the digital data acquisition system. The corresponding rates of pressure rise vs. time as measured by the lower transducer are shown in **FIG. 4**; the rates of pressure rise vs. time as measured by the upper transducer are shown in **FIG. 6**.

[0024] Examples 6 and 12 include 12.2% by volume of expanded metal foil, available as Explo-Control from Explosion Prevention Systems, L.L.C. (Fort Worth, Tex.) by uniformly distributing 20 small rolls of the material with a density of 1.66 lb/ft^3 and that are 3" in diameter and 11" long in the drum such that 5 rolls were places on each of four parallel planes perpendicular to the axis of the drum at distances from the closed bottom of the drum 25%, 50%, 75% and 100% of the drum height. Each small roll occupied only 0.6% of the total volume. The total volume of the drum occupied by the rolls was 1554 cu inches.

[0025] Test Example 7 incorporates 8.7% by volume expanded metal foil at a mat density of 4 lb/ft^3 and as a 3" thick layer, placed perpendicular to the axis of the test drum and at the midpoint between the bottom and the top of the drum. The foil was placed such that there was a snug fit between the perimeter of the mat and the side wall of the drum.

[0026] Test example 8 incorporates 8.1% by volume expanded metal foil at a mat density of 2.8 lb/ft^3 and as a 3" thick layer, placed perpendicular to the axis of the test drum and at the midpoint between the bottom and the top of the drum. The foil was placed such that there was a ¼"-½" radial gap between the perimeter of the mat and the side wall of the drum.

[0027] Test examples 9, 10, and 13 incorporate the expanded metal foil in a similar manner as Test example 8 except for the use of a lower density mat (1.5 lb/ft^3).

[0028] Test Example 11 incorporates 8.7% by volume expanded metal foil at a mat density of 1.9 lb/ft^3 and as a 3" thick layer, placed perpendicular to the axis of the test drum and at the midpoint between the bottom and the top of the drum. The foil was placed such that there was a snug fit between the perimeter of the mat and the side wall of the drum. Test Example 11 differs from Test Example 7 only in that a lower mat density was used.

[0029] FIGS. 2 and 3 illustrate the relative decrease in explosion pressure in the test apparatus with **(FIG. 3)** and without **(FIG. 2)** the protective material. **FIG. 2** is a graph of the rate of pressure vs. time for Examples 3, 4 and 5. **FIG. 3** is a graph of the rate of pressure vs. time for Examples 9, 10 and 13.

[0030] **FIGS. 4 and 5** illustrate the relative decrease in rate of pressure rise in lower portion of the test equipment apparatus with **(FIG. 5)** and without **(FIG. 4)** the protective material. **FIG. 4** is a graph of the rate of pressure increase vs. time as measured by the lower transducer for Examples 3, 4 and 5. **FIG. 5** is a graph of the rate of pressure increase vs. time as measured by the lower transducer for Examples 9, 10 and 13.

[0031] **FIGS. 6 and 7** illustrate the relative decrease in rate of pressure rise in upper portion of the test equipment apparatus with **(FIG. 7)** and without **(FIG. 6)** the protective material. **FIG. 6** is a graph of the rate of pressure increase vs. time as measured by the upper transducer for Examples 3, 4 and 5. **FIG. 7** is a graph of the rate of pressure increase vs. time as measured by the upper transducer for Examples 9, 10 and 13.

TABLE 1

	Peak Pressure (inches of water)		Maximum Rate of Pressure Rise psi per second	
Example	Lower	Upper	Lower	Upper
Control 1	0.06	0.03		
Control 2	41.5	32.5		
Control 3	19.5	13.0	1350	1800
Control 4	21	13.5	2500	3200
Control 5	22	14.5	2500	3200
Example 6	data lost		data lost	
Example 7	22	5		
Example 8	data lost		data lost	
Example 9	15	5.6	<500	<1100
Example 10	13.5	4.5	<500	<1100
Example 11	18.5	3.5		
Example 12	19.5	13.5		
Example 13	14	5	<500	<1100

[0032] Analysis of the data in Table 1 shows the clear improvement of incorporating as little as 8.1% by volume of the expanded metal foil. As may be seen from FIGS. **2**-**7**, there were major reductions in both peak pressure and maximum rate of pressure rise in Examples 9, 10 and 13 as compared with Control Examples 3, 4 and 5 when the protective material was included in the volume of the test apparatus.

[0033] Comparison of Example 7 with Example 11 indicates that, within the range of values tested, lower density materials appear to work better than higher density materials.

[0034] Comparison of Example 12 (using 20 small rolls of the mesh) with Examples 9, 10, and 13 indicates that the placement and orientation of the mesh, as well as the amount of volume displacement, are important variables affecting the degree of effectiveness of the mesh in reducing the severity of a vapor cloud explosion. Use of the mesh as 20 small, independent and separate rolls did not yield the same degree of pressure and rate of pressure rise reduction as did the use of the mesh as a single contiguous block. This result was observed despite the fact that similar total volume of mesh was used in all of these tests. This result suggests that the flame bypasses the mesh when it is installed in a number of relatively small, multiple discontiguous and independent blocks or rolls, which it can not easily do when the mesh is installed as large, contiguous blocks or mats.

[0035] The results indicate a reduction in the peak pressure in the lower portion of the test equipment of approximately 25% and in the upper portion of the equipment of approximately 60%. The maximum rate of pressure rise was reduced by approximately 80% in the lower portion of the test equipment. The maximum rate of pressure rise was reduced by a factor of approximately 67% in the upper portion of the equipment.

We claim:

1. A method of reducing the severity of vapor cloud explosions in partially confined areas, comprising placing porous, high surface area to volume ratio protective material in the area in sufficient amount to reduce the pressure effects caused by ignition of the flammable vapor clouds.

2. The method of claim 1 wherein the protective material is a metal mesh or foil material.

3. The method of claim 1 wherein the protective material is an expanded aluminum alloy foil.

4. The method of claim 1 wherein the volume of protective material used in the operating area is equal to or greater than 5% of the total available volume of the operating area.

5. The method of claim 1 wherein the density of the protective material is between 10 and 100 kg/m^3 and the surface area to volume ratio of the protective material is greater than 100 m^2/m^3.

6. The method of claim 1 wherein the surface area to volume ratio of the protective material is greater than 500 m^2/m^3.

* * * * *