SAFE INCINERATION OF EXPLOSIVE AIR MIXTURES

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ABSTRACT
An explosive gas incinerator system comprises a fume source inlet for receiving a process exhaust with a volatile material that is explosive when its concentration exceeds a lower explosive limit (LEL). A source flowmeter measures the volume of process exhaust being input. A temperature sensor measures the temperature of the process exhaust. A motorized damper is used for diluting the process exhaust with an ambient air input to produce a damper outflow with an explosive concentration less than the LEL. A damper flowmeter measures the total mixture volume of the process exhaust and ambient air input in the damper outflow. Another temperature sensor measures the temperature of the damper outflow. A gas monitor measures the concentration of volatile material in the damper outflow. An oxidizer burns the damper outflow in a flame to produce a cleaner exhaust, and a fan forces gas flows through the oxidizer. A system controller is connected to receive measurement data from the flowmeters, gas monitor, and temperature sensors, and is connected to control the motorized damper to maintain the damper outflow into the oxidizer below the corresponding LEL of the volatile material. Operator errors and attempts at sabotage can be detected and controlled.
Fig. 1
SAFE INCINERATION OF EXPLOSIVE AIR MIXTURES

FIELD OF THE INVENTION

[0001] The present invention relates to exhaust gas incinerators, and more particularly to the safe incineration of explosive air mixtures.

DESCRIPTION OF THE PRIOR ART

[0002] Industrial processes exhaust various gases and particles into the air. Modern regulations require that the emissions be controlled and limited, and one way to scrub the exhaust is to incinerate it before it leaves the smoke stack. But some exhausts can be explosive if they have mixtures with the right percentages of air-to-fuel. The lower explosive limit (LEL) is a value that represents the minimum percent of an explosive-fume mixed in air which will explode. The source of ignition can either be an open flame or the auto-ignition temperature.

[0003] Some exhausts must be licensed, certified, and monitored. The exhausts can either be permitted to be flow variable, or the more restrictive constant flow type. Thus in the manufacturing of fluorescent paint which generates formaldehyde, the flow of air through the system is provided simply to remove the fumes. The United States Food and Drug Administration (FDA) is sometimes involved in exhaust operating permits, and this can specify a particular flow rate.

[0004] The types of conventional systems for processing explosive-fumes are numerous. One such system uses an LEL-monitor set to a minimum lower explosive limit. If the LEL monitor senses an ignition, it activates an alarm to safely shut down the industrial process. Such type of emergency shut-down monitoring can result in lost production time and costly cleanups and restarts.

[0005] Another strategy used in conventional systems processes is to inject so much excess air into the exhaust that the percentage of explosive-fumes can never be more than a small fraction of the LEL. Although this practice will work to prevent explosions, the fuel costs to incinerate the much higher flowrates resulting can be enormous. In general, the higher an LEL a system can be safely operated at, the higher will be the efficiency of the incineration fuels consumed. In other words, substantial operational costs savings can be realized.

[0006] Green Oasis Environmental, Inc. (Charleston, S.C.), has a website (www.greenoasis.com) that describes its thermal oxidizer as comprising a burn chamber, blowers, burner, heat exchanger and associated controls. Light end hydrocarbons in gaseous form can be injected into the burn chamber and mixed with outside air supplied by blowers. The mixture is burned at 1700-2000°F. The exhaust is directed to the shell of a heat exchanger to heat used oil to the desired temperature. Dampers control the amount of heat supplied to the heat exchanger. In the oxidation process, hydrocarbons are converted to water and carbon dioxide with a destruction/removal efficiency that will meet or exceed all local or federal regulations. The thermal oxidation process is so effective in eliminating emissions that it is principally sold as an emissions control device. Such thermal oxidizer used in the EnviroEconomics™ process has anti-flashback protection, and operates below the lower explosive limit (LEL), qualifying the system for operation in hazardous areas. The thermal oxidizer’s microprocessor-based control function is incorporated into the overall system’s controls, permitting fully automatic operation.

SUMMARY OF THE INVENTION

[0007] Briefly, a fume incinerator system embodiment of the present invention operates at any explosive level of the input flows below or above their LEL. Monitors and controllers are used to inject just enough air into the input mixture to prevent the flow from exceeding the LEL as it enters the incinerator flames. The incinerator system comprises a fume source inlet for receiving a process exhaust with a volatile material that is explosive when its concentration exceeds a lower explosive limit (LEL). A source flowmeter measures the volume of process exhaust being input. A temperature sensor measures the temperature of the process exhaust. A motorized damper is used for diluting the process exhaust with an ambient air input to produce a damper outflow with an explosive concentration less than the LEL. A damper flowmeter measures the total mixture volume of the process exhaust and ambient air input in the damper outflow. Another temperature sensor measures the temperature of the damper outflow. A gas monitor measures the concentration of volatile material in the damper outflow. An oxidizer burns the damper outflow in a flame to produce a cleaner exhaust, and a fan forces gas flows through the oxidizer. A system controller is connected to receive measurement data from the flowmeters, gas monitor, and temperature sensors, and is connected to control the motorized damper to maintain the damper outflow into the oxidizer below the corresponding LEL of the volatile material.

[0008] An advantage of the present invention is that a system and method is provided to guard against accidental operator error and deliberate sabotage.

[0009] Another advantage of the present invention is that a system and method are provided for significant fuel savings over prior art systems.

[0010] A further advantage of the present invention is that a system and method are provided to control explosive-fume/air mixtures with a built-in safety factor through the use of the variable speed fan plus the warning message to the operator. Such gives the operator time either to correct the out of tolerance condition or to execute an orderly shut-down. Such also provides further cost savings.

[0011] These and other objects and advantages of the present invention will no doubt become obvious to those of ordinary skill in the art after having read the following detailed description of the preferred embodiments which are illustrated in the various drawing figures.

IN THE DRAWINGS

[0012] FIG. 1 is a functional block diagram of a first fume incineration system embodiment of the present invention that operates with a standard flow from the source;

[0013] FIG. 2 is a functional block diagram of a second fume incineration system embodiment of the present invention that operates with a variable flow from the source; and

[0014] FIG. 3 is a perspective diagram of a gas train used in embodiments of the present invention.
DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

[0015] FIG. 1 illustrates a constant-source-flow fume incineration system embodiment of the present invention, and referred to by the general reference numeral 100. The system 100 is connected to receive a fume source 102 of gases for incineration before discharging them into the atmosphere. A standard flow is received from fume source 102 according to the nature of the source or government operating permits dictating such. A source flowmeter 104 monitors the volume of gases entering and reports its measurements to a system controller 106. A first temperature sensor 108 allows the controller 106 to convert to Standard Conditions for its calculations. A motorized damper 110 is adjusted by the controller 106 to admit more or less ambient air 112 in order to dilute the incoming gases enough to keep their mixture below the lower explosive limit (LEL). Such LEL is the lowest percentage of volatile gases in the air mixture that will explode if exposed to open flames or sparks, or that will auto-ignite at a particular temperature.

[0016] A principle object of the present invention is to economize on the incineration fuels used by keeping the volume of fumes mixed with air to be incinerated to a minimum. But such mixture needs to be below the particular LEL, so the optimum mixture will be just short of the LEL as it passes a damper flowmeter 114.

[0017] A second temperature sensor 116 and redundant gas monitors 118 and 120 provide measurements for the controller 106 to help it keep the motorized damper 110 set for the optimum exhaust mixture. Too little input air will be dangerous, and too much will waste operating fuel. The gas monitors can be LEL-Monitors that use gas chromatograph technology.

[0018] A detonation flame arrestor 122 prevents flames from backing down a flume 123. A third temperature sensor 124 is located at an oxidizer 126. For straight thermal incineration, the temperature sensor 124 is placed at the outlet of oxidizer 126 to control the oxidizer incineration temperature. In catalytic systems, the temperature sensor 124 is inside and is used to control the temperature of the catalyst bed. Such oxidizer 126 has a natural gas or propane fuel input 127 and is operated as a fume incinerator that may include catalysts. An extraction fan 128 pushes a clean exhaust 130 into the atmosphere. Such fume incinerators are commercially marketed by Conversion Products (Hayward, Calif.), HiTemp Technology Corporation (Flemington, N.J.), Green Oasis Environmental, Inc. (Charleston, S.C.), etc. A watchdog timer 132 periodically makes sure the controller 106 is awake and functioning. If not, the process is shut down and an alarm is sounded.

[0019] Many explosive-fumes are toxic. Therefore, these systems are always run negative so that if there is a leak in the ducting, ambient air is drawn into the duct rather than having toxic/explosive-fumes escape into the room or the atmosphere.

[0020] Embodiments of the present invention permit the incineration of any fume stream regardless of the initial LEL percentage. Such includes conditions where the explosive-fume leaving the source 102 is at or above the LEL. Such systems control the explosive-fume/air mixture so that just enough air is added to prevent the mixture from exceeding the specified LEL percentage. Therefore, safety and fuel economy are both improved compared to conventional systems.

[0021] These systems can also guard against accidents, operator error, and deliberate sabotage. Since many explosive-fumes are toxic, these systems are run with negative internal pressures so that if there is a leak in the ducting, ambient air will be drawn in. The toxic/explosive-fumes are thus prevented from freely escaping into the room or the atmosphere.

[0022] The source 102 is shown in FIG. 1 as a single item, in reality, there may be multiple sources. Source 102 includes processes that generate explosive substances in their exhaust fumes.

[0023] Source flowmeter 104 measures the actual flow of the effluent stream from the source 102. First temperature sensor 108 measures the temperature of the effluent stream as it arrives, so all calculations can be made at standard conditions. The controller 106 calculates the speed needed by extraction fan 128 that will keep the effluent stream flowing at its specified rate.

[0024] The measurement data from gas monitors 118 and 120 are used by the controller 106 to calculate the amount of air necessary to keep the fume/air mixture at a specified setpoint value. The amount of ambient air added is controlled by a combination of the position of the motorized damper 110 and the fan speed. The ambient air admitted into the system is used to keep the flow entering the oxidizer 126 at an acceptable LEL percentage.

[0025] Damper flowmeter 114 measures the effluent and ambient air mixture flow. The amount of ambient air introduced via the motorized damper 110 is the difference between the total flow measured at damper flowmeter 114 minus the effluent air measured by source flowmeter 104. Such measurement data is sent to the controller 106 to convert the values to standard conditions.

[0026] The first gas monitor 118 determines the percent of the explosive-fume in the stream. Such value is sent to the controller 106 which uses the measurement data to calculate the amount of ambient air that will be needed to maintain the explosive-fume at a safe level.

[0027] The second gas monitor 120 samples the fume stream and calculates the percent of the explosive-fume in the effluent stream. Any time the mixture exceeds a predetermined safety percentage, an alarm circuit is activated. Such function is a redundant safety device. It will only be activated if the system fails to maintain the prescribed level of the explosive mixture in air. It can also be used to verify the operating accuracy of the first gas monitor 118.

[0028] The alarm circuit can be used to turn off the burner in the oxidizer 126, or if local codes require it, the alarm circuit can be used to shut down both source 102 and the oxidizer 126.

[0029] The detonation flame arrestor 122 is optional. It should be used where there is a possibility that the velocity of the effluent passing through the oxidizer could fall below normal flame propagation speed. The detonation flame arrestor 122 can prevent a flame from traveling back to the source 102 which may be operating above the LEL.
The oxidizer 126 may be a straight thermal unit or a catalytic unit. The oxidizer 126 is designed so that the incineration temperature and residence time at incineration temperature will reduce the percent of explosive-fumes in the effluent to the specified level.

For straight thermal incineration, the third temperature sensor 124 measures the temperature of the effluent stream as it leaves the main body of the oxidizer. For a catalyst based oxidizer, the third temperature sensor 124 measures the temperature of the effluent stream entering the catalyst bed. The temperature measurement data is used by the controller 106 and a burner fuel flow valve to maintain a specified incineration temperature.

The extraction fan 128 is a variable speed type that allows the amount of air pulled through the system to be varied over a wide range. Such fan is used to maintain a negative system pressure upstream to prevent explosive and/or toxic fumes from leaking out. Fan 128 can also be located upstream of oxidizer 128.

The controller 106 is a computer capable of mathematical and statistical quality control calculations according to data inputs, and input/output control. The source 102 may include more than one product, so the controller 106 preferably permits an operator to select which product is being processed. A display screen can be used to post system progress and graphically display the operating parameters. The target average and the upper and lower tolerance limits of each of the control parameters would be useful in the display.

It necessary to include a number of safety devices in system 100. For example, a zero-speed switch and a backup air-pressure switch connected to the extraction fan 128 to detect blade stalling and flow malfunctions. If at any time the fan slows down below a set minimum extraction speed, and the zero speed switch has not activated a shut-down procedure, the air pressure switch can override it and shut the system down. Air pressure switch on the combustion blower is used to detect if the combustion blower motor fails. If a failure is detected, the oxidizer flame is extinguished. A gas pressure switch in the fuel supply 127 feeding the oxidizer burner is used as a shut-off if the actual gas pressure exceeds or falls below safe values.

A detonation flame arrestor 122 is placed between inlet to the oxidizer 126 and the source 102 of the fumes. The effluent velocity through the oxidizer is set well above the flame propagation speed. However, if the extraction fan 128 fails, the velocity through the oxidizer 126 may fall below the flame propagation speed. Since the conditions in the system interior could be above the auto-ignition point, the flame front could move upstream all the way to the source 102 if the detonation flame arrestor 122 were not included.

An alarm circuit is included in the first gas monitor 118 that is activated anytime the LEL percentage exceeds a design maximum.

The watchdog timer 132 is constantly reset electrically during normal operation. If the resets fail to come, at a minimum, it will shut down the oxidizer 126. The maximum amount of time that can elapse without danger is pre-determined. A time period less than this calculated value is placed in the control program and the watch dog timer is set for that time.

Each time, the control program elapsed time equals the allowable time, the watch dog timer is re-set. If anything happens to the program and it fails to execute the re-set, the watch dog timer times out and all the outputs are turned off so that the oxidizer flame is extinguished and the flow of explosive-fumes is stopped.

An alarm circuit is included in the first gas monitor 118 that will be activated any time the stream mixture exceeds a safe value. An alarm circuit in the second gas monitor 120 is included as a back-up safety in case the alarm associated with the first gas monitor 118 has malfunctioned.

As a further safety check, both gas meters are used to sample the effluent stream. Both readings are sent to the controller 106 where they are processed. Although the accuracy of the gas meters is excellent, statistical equations can be used to determine the true reading of each gas meter output and the natural tolerances of the system.

True average values can be calculated to a predetermined level of accuracy, e.g., 0.5%. One procedure takes the sum of "n" readings and divide by "n" for the first average. Save each individual value in a matrix for use in determining the natural tolerance of each device. Take five additional readings and add to the conventional sum. Then divide the new sum by the total number of readings taken. Save each individual value in a matrix for use in determining the natural tolerance of each device. Take the difference between the two averages and divide by the first average. If the error is 0.5% or less this is the average value (x) that will be used. If the error is greater than 0.5%, the steps are repeated.

After the true average percentage values have been determined, the next step is to determine the natural tolerance of each of the devices. All processes that can be measured have a variance above and below their average value which are termed the normal control limits of the process.

To calculate the natural upper control limit (UCL) and natural lower control limit (LCL) the following formulas can be used:

\[ UCL = X + 3s \sqrt{\frac{1}{N}} \sum_{i=1}^{N} (X_i - \mu)^2 \]

\[ LCL = X - 3s \sqrt{\frac{1}{N}} \sum_{i=1}^{N} (X_i - \mu)^2 \]

Where:

- UCL = natural upper control limit;
- LCL = natural lower control limit;
- X = process average;
- \( Y_i \) = individual reading of the process value;
- N = total number of samples.

A large percentage of the program code of controller 106 will be devoted to safety functions. So in case of an accidental or malicious change in the process functions, the program code can detect a change from standard conditions and shut the system down before there can be an explosion.
The readings taken by source flowmeter 104, first temperature sensor 108, damper flowmeter 114, first gas monitor 118 and second gas meter 116 are sent to the controller 106. From measurement data stored internally, the controller 106 determines if the LEL percentage downstream from the motorized damper 110 is at a specified level.

If the fume percentage is above the upper control limit, the controller 106 opens the motorized damper 110 and the extraction fan 128 increases the amount of air to bring the percentage back to within limits for safety. If the fume percentage is below the specified level, the controller 106 decreases the motorized damper 110 and the extraction fan 128 settings to reduce the air flow. Such brings the fume percentage back to within limits to save fuel.

The upper natural tolerance limit and the lower natural tolerance limit are set to include 90.73% of all readings. The control program is capable of determining the difference between an out-of-tolerance condition versus a random incident which can occur and still have the process in control.

During factory calibration, controller 106 builds a series of tables including, (1) motorized damper 110 settings and the corresponding ambient flow, (2) fan speed (percent of maximum setting) and the corresponding total flow, (3) user’s actual LEL percentage from the process, and (4) target percentage of the LEL. The measurement data is saved in the controller’s 106 permanent memory and is used for a starting point when the system is re-calibrated at the user’s site. At the user’s site, the measurement data is updated if necessary to match local conditions.

The amount of ambient air needed to keep the explosive mixture percentage at a specified level is calculated. APLEL is the actual LEL percentage of the effluent stream leaving the source 102. TPLEL is the target percentage of the LEL when entering the oxidizer 126. AVC is the actual explosive-fume content of the effluent stream in cubic feet per minute. TSCFM is the total air flow in cfm needed to achieve TPLEL, the target LEL percentage TSCFM=AVC/(LEL/100×TPLEL/100). ACFM is the amount of ambient air in cfm needed to reach TSCFM. ACFM=2SCFM−ESCFM.

As an example, consider the following:

ESCFM=1,000 SCFM: effluent stream

APLEL=90%: published LEL value

TPLEL=50%: target LEL percentage which will enter the oxidizer 126.

AFCM=1,800−1000=800 SCFM

Therefore, if the process were generating 1,000 SCFM with an explosive-fume content of 90% of the published LEL. It would be necessary to add 800 SCFM of ambient air to bring the mixture down to 50% of the published LEL.

The extraction fan 128 has a variable speed motor. It is sized so that it can remove air from the system based on the projected worst percentage of the explosive-fume and the highest temperature expected from the oxidizer. If the exhaust air from the oxidizer is 1,800 SCFM at 600°F, the extraction fan 128 must be capable of moving 3,600 cfm plus a safety factor. The extraction fan 128 speed is calibrated using damper flowmeter 114 and second temperature sensor 116 with the motorized damper 110 completely open.

Starting at the fan’s minimum setting, the flowmeter reports the amount of air flowing at a series of defined steps. A typical table would be,

<table>
<thead>
<tr>
<th>Percent of maximum speed</th>
<th>cubic feet delivered</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>1,120</td>
</tr>
<tr>
<td>15</td>
<td>2,240</td>
</tr>
<tr>
<td>20</td>
<td>3,360</td>
</tr>
<tr>
<td>25</td>
<td>4,480</td>
</tr>
<tr>
<td>30</td>
<td>5,600</td>
</tr>
<tr>
<td>35</td>
<td>6,720</td>
</tr>
<tr>
<td>40</td>
<td>7,840</td>
</tr>
<tr>
<td>45</td>
<td>8,960</td>
</tr>
<tr>
<td>50</td>
<td>10,080</td>
</tr>
<tr>
<td>55</td>
<td>11,200</td>
</tr>
<tr>
<td>60</td>
<td>12,320</td>
</tr>
<tr>
<td>65</td>
<td>13,440</td>
</tr>
<tr>
<td>70</td>
<td>14,560</td>
</tr>
<tr>
<td>75</td>
<td>15,680</td>
</tr>
<tr>
<td>80</td>
<td>16,800</td>
</tr>
<tr>
<td>85</td>
<td>17,920</td>
</tr>
<tr>
<td>90</td>
<td>19,040</td>
</tr>
<tr>
<td>95</td>
<td>20,160</td>
</tr>
<tr>
<td>100</td>
<td>21,280</td>
</tr>
</tbody>
</table>

Since the system is essentially linear, it is possible to determine any percent setting by the following,

\[ Cp=\frac{(ESCFM−Vstep)}{fstep}+Clfa \]

Where:

\[ CP=\text{calculated percent}; \]
\[ TSCFM=\text{calculated flow}; \]
\[ Clva=\text{closest lower value of flow from the table}; \]
\[ Clfa=\text{equivalent percent for clva}; \]
\[ Vstep=\text{difference between successive volumes of air flow steps}; \]
\[ Fstep=\text{difference between successive percentages}. \]

As an example, to move 7,000 cfm, from the above definition and table,

\[ TSCFM=7000 \]
\[ Clva=6720 \]
\[ Clfa=35 \]
\[ Vstep=1120 \]
\[ Fstep=5 \]

Cp=((7000−6720)/1120)×35=36.25%.

The damper 110 is calibrated at the factory by using the difference between damper flowmeter 114 and source flowmeter 104 to calculate the amount air entering the duct over the range of damper settings while maintaining the standard flow from the source 102. For example, using
settings of 5-90 degrees, a typical ambient damper setting air flow in degrees open in SCFM,

<table>
<thead>
<tr>
<th>damper setting degrees open</th>
<th>air flow CFM</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>500</td>
</tr>
<tr>
<td>10</td>
<td>1,500</td>
</tr>
<tr>
<td>15</td>
<td>2,500</td>
</tr>
<tr>
<td>20</td>
<td>4,000</td>
</tr>
<tr>
<td>25</td>
<td>5,000</td>
</tr>
<tr>
<td>30</td>
<td>5,900</td>
</tr>
<tr>
<td>35</td>
<td>6,500</td>
</tr>
<tr>
<td>40</td>
<td>7,000</td>
</tr>
<tr>
<td>45</td>
<td>7,500</td>
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<tr>
<td>50</td>
<td>8,000</td>
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<tr>
<td>55</td>
<td>9,200</td>
</tr>
<tr>
<td>60</td>
<td>10,200</td>
</tr>
<tr>
<td>65</td>
<td>10,900</td>
</tr>
<tr>
<td>70</td>
<td>11,600</td>
</tr>
<tr>
<td>75</td>
<td>12,300</td>
</tr>
<tr>
<td>80</td>
<td>12,900</td>
</tr>
<tr>
<td>85</td>
<td>13,400</td>
</tr>
<tr>
<td>90</td>
<td>13,600</td>
</tr>
</tbody>
</table>

[0078] There is an equivalent fan speed which moves such calculated ambient air and the effluent flow from the source 102 at its specified rate. Therefore, for each entry in the motorized damper 110 table, there is a corresponding fan speed,

<table>
<thead>
<tr>
<th>damper setting in degrees open</th>
<th>ambient air flow SCFM</th>
<th>fan speed percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>500</td>
<td>10</td>
</tr>
<tr>
<td>10</td>
<td>1,500</td>
<td>15</td>
</tr>
<tr>
<td>15</td>
<td>2,500</td>
<td>20</td>
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<tr>
<td>20</td>
<td>4,000</td>
<td>25</td>
</tr>
<tr>
<td>25</td>
<td>5,000</td>
<td>30</td>
</tr>
<tr>
<td>30</td>
<td>5,900</td>
<td>35</td>
</tr>
<tr>
<td>35</td>
<td>6,600</td>
<td>40</td>
</tr>
<tr>
<td>40</td>
<td>7,000</td>
<td>45</td>
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<tr>
<td>45</td>
<td>7,500</td>
<td>50</td>
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<tr>
<td>50</td>
<td>8,000</td>
<td>55</td>
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<tr>
<td>55</td>
<td>9,200</td>
<td>60</td>
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<tr>
<td>60</td>
<td>10,200</td>
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<td>65</td>
<td>10,900</td>
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<td>70</td>
<td>11,600</td>
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<tr>
<td>75</td>
<td>12,300</td>
<td>80</td>
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<tr>
<td>80</td>
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<tr>
<td>85</td>
<td>13,400</td>
<td>90</td>
</tr>
<tr>
<td>90</td>
<td>13,600</td>
<td>100</td>
</tr>
</tbody>
</table>

[0079] Although the change in air flow between damper settings is not linear, the error in treating the change as linear is minor. So the flow rates between table values can be calculated,

\[ C_{do} = (C_d - C_{lf}) \times \frac{\text{Vstep}}{\text{Fstep} + \text{Ed}} \]

Where:

- \( C_{do} \) = calculated degree open;
- \( C_d \) = the calculated total flow needed;
- \( C_{lf} \) = the closest lower value of flow from the table;
- \( \text{Ed} \) = equivalent degree open for \( \text{clf} \);
- \( \text{Vstep} \) = difference between successive volume air flow steps;
- \( \text{Fstep} \) = difference between successive damper positions.

[0080] As an example, suppose, the damper should be open far enough to bring in 7,200 cfm of ambient air. From the above definition and table,

- \( Tf = 7200 \);
- \( Clf = 7000 \);
- \( Ed = 40 \);
- \( Vstep = 500 \);
- \( Fstep = 5 \);

\[ C_{do} = ((7200 - 7000) / 500) \times 40 = 42.0 \text{ degrees open.} \]

[0081] The same extrapolation equation is used to match the fan speed to the motorized damper 110 setting.

[0082] Because there can be small variations in the actual values, a further correction is used to achieve the most accurate flow rates possible. For a calculated 12-degrees open, an actual flow rate is 5,100 SCFM. The conditions required for 5,350 SCFM,

\[ \text{Degrees} = \frac{\text{current degrees required flow}}{\text{current flow}} \times 12.6 \text{ degrees.} \]

[0083] For safe operation, the calibration of the system is done in two parts. A first calibration is done at the factory, while the second calibration is done at start-up under actual running conditions each time the system is started up. The system is initially calibrated so that settings for the motorized damper 110, extraction fan 128 and the oxidizer burner control have been determined under controlled test conditions.

[0084] The settings for the motorized damper 110 are determined by using a signal generator and the two flowmeters. The signal generator is used to send to the calibration program the percent of explosive-fume that the user has specified will be released at the source 102. The oxidizer 126 is raised to incineration temperature so that true fan speed under operating conditions can be recorded in memory. Source flowmeter 104 measures the amount of effluent air coming from the source 102. Damper flowmeter 114 measures the amount of effluent air plus ambient air in the system downstream from the motorized damper 110.

[0085] The controller 106, using the simulated fume percent and the effluent flow rate, calculates the amount of ambient air needed to bring the air/effluent mixture to the specified percentage of the published LEL. The controller 106 opens the motorized damper 110 to a position where the second flowmeter measures the total amount of effluent plus ambient air to achieve the correct explosive percentage while maintaining the correct effluent flow from the source 102.

[0086] The test setting of the motorized damper 110 and extraction fan 128 speed are put into permanent memory when the system parameters are all correct.

[0087] To comply with air quality management district requirements, on each start-up, the oxidizer should be brought up to temperature before the process is started. E.g., with motorized damper 110 and extraction fan 128 at their operating settings. The controller 106 then reads the two flowmeters and compares the two flow rates with the flow rates in memory. If these flow rates are within the established natural tolerances, the start-up can proceed.
The system 100 should be brought up to its operating conditions with the thermal or catalytic oxidizer below the auto-ignition point. However, due to air quality management district requirements, the thermal abatement device should be at incineration temperature before the process is started.

Under these conditions, if there were an operator error or an act of sabotage, operating conditions must be verified as being correct before the fume/air mixture reaches the LEL.

Operator error is more easily identified than specific acts of sabotage where the objective is to cause an explosion. One way to cause an explosion is to change the product formulation in such a manner that the explosive-fume that is generated by the process would be above the LEL. Such form of sabotage is detected. Both gas meters have an alarm circuit set for shut-down if the explosive-fume meets the specified shut down level.

If the gas meters were re-calibrated so that the LEL emergency shut-down percentage value was above the true LEL of the fume, then the system could explode before the LEL shut-down percentage was reached. Protecting against this event is more complex. One procedure begins with a series of test start-ups when it is known that all the system variables are at their specified values. The start-up procedure is defined in such a manner that the conditions at the point of product introduction are constant with respect to time at every start-up.

Air quality district permits allow some deviation from standards during commissioning. So it is possible to perform the following procedure without being in violation of permit conditions. When each test start-up begins, a dedicated timer is set to zero. Then at specified time intervals, as the start-up process proceeds, conditions for the following devices are recorded: motorized damper 110, extraction fan 128, first gas monitor 118, second gas monitor 120, source flowmeter 104, first temperature sensor 108, damper flowmeter 114, second temperature sensor 116, and oxidizer 126 burner firing rate.

From the incoming data, variable are calculated and recorded in memory for the time interval for the motorized damper setting, the extraction fan speed, source flowmeter, damper flowmeter, first gas monitor, second gas monitor, and oxidizer burner firing rate. E.g., average value, upper natural tolerance limit, lower natural tolerance limit, and rate of change of each device value with respect to time.

During regular start-up if one or more of the process variables have been changed, then the values of the above eight devices will be out of the range of either the upper or lower natural tolerance limits. In addition, since the rate of change is also recorded, the current rate of change is compared to the established values in the table.

If any deviations occur, the controller 106 could shut the system down before the process reaches the point where it is generating explosive-fumes at a rate which exceeds the LEL.

If the extraction fan 128 were sabotaged so that the amount of air flow was decreased, there are several ways to detect this fault. The obvious detection would be the decreased flow reported by the flowmeters. Also, the concentration of the explosive-fume would be increased. Such would be caught by comparing start-up values with the table established. It would be immediately detected that the air flow was below the established quantity and the rate of increase of fume concentration would also be out of tolerance. Finally, the rate of temperature increase in the oxidizer 126 would be above standard conditions because of the lowered air flow.

Fig. 2 illustrates a variable-source-flow system embodiment of the present invention, and referred to by the general reference numeral 200. An ambient air input 202 is drawn into a fume source 204. A flow of gases for incineration 206 is input to flowmeter 208 which monitors the volume of gases entering. It reports its measurements to a system controller 210. A second temperature sensor 212 allows the controller 210 to convert to Standard Conditions for its calculations. A pair of redundant gas monitors 214 and 216 provide measurements for the controller 210. A detonation flame arrestor 218 prevents flames from backing down a flume 219.

A third temperature sensor 220 is used to control the oxidizer temperatures. A natural gas or propane fuel input 223 supports the incineration flames inside. An extraction fan 224 forces out a clean exhaust 226 into the atmosphere.

System 200 could function without source flowmeter 208. However, the source flowmeter will be needed to check for operator errors and sabotage. The readings taken by the flowmeter 208, first temperature sensor 214, first gas meter 216, and second gas meter 216 are sent to controller 210.

If the fume percentage is above an upper control limit, the speed of the extraction fan 128 is increased to bring the percentage back to within safety limits. If the fume percentage is below the specified level, the speed of extraction fan 128 is reduced. Such brings the fume percentage to within limits to save fuel.

The upper natural tolerance limit and the lower natural tolerance limit are set to include 99.73% of all readings. The control program determines the difference between an out-of-tolerance condition versus a random incident which can occur and still have the process in control.

During factory calibration, the controller 210 builds a series of tables, e.g., (1) fan speed (percent of maximum setting) and the corresponding total flow, (2) user’s actual LEL percentage from the process, and (3) target percentage of the LEL. The measurement data is saved in the controller’s 210 permanent memory and is used for a starting point when the system is re-calibrated at the user’s site and in the safety routines. At the user’s site, the measurement data is updated if necessary to match local conditions.

The extraction fan 224 is driven by a variable speed motor. Such type of a drive gives the fan a wide range of capacities. The extraction fan 224 is sized so that it will remove air from the system 200 based on the projected worst percentage of the explosive-fume and the highest temperature expected from the oxidizer.

For example if the exiting air from the oxidizer is 1,800 SCFM at 600° F, the extraction fan 224 must be capable of 3,600 cfm plus a safety factor. The extraction fan 224 speed is calibrated using the flowmeter 208 and first temperature sensor 214. Starting at the fan’s minimum setting, the flowmeter 208 reports the amount of air flowing at a series of defined steps.
FIG. 3 illustrates a typical gas train 300 useful in systems 100 and 200 of FIGS. 1 and 2. Gas train 300 includes a gas inlet 302, a manual gas cock 304, a pilot gas cock 306, a pilot gas regulator 308, a pilot solenoid valve 310, a gas pressure regulator 312, a low gas pressure switch 314, a pressure test connection 316, a shut off valve 318, a normally open vent valve 320, a vent to atmosphere 322, a second valve 324, a high gas pressure switch 328, a second manual gas cock 330, a gas pressure test connection 332, a pilot gas inlet 334, and a burner 336.

Two important benefits of embodiments of the present invention are the protection against operator error and the for detection of sabotage. They do this by building start-up charts. The oxidizer, the fume source and motorized damper, if used, would be at operating conditions. In a material coating example, prior to when the first bit of the product enters the coating tunnel, the LEL percent is zero. As the product enters and eventually fills the coating tunnel, the percent of LEL would increase until the tunnel is full of product.

During a series of controlled start-ups, LEL readings are recorded, e.g., at five second intervals. For example, the oxidizer temperature, oxidizer firing rate, motorized damper setting, and the LEL values from the gas monitor readings. These samples can be used to generate a curve similar to a hyperbola asymptotic to the upper limit of the LEL percentage. Since the fumes are combustible, they will also release heat. This will result in a gradual reduction in the burner firing rate. These values for each reading point are also stored. With enough points recorded during such controlled start-ups, an upper and lower natural tolerance limit for each point can be calculated.

On subsequent production start-ups with the same starting zero point, the controller compares actual values for each point in the process looking at upper and lower control limits. The controller calculates the rate of change of the observed LEL percentage and the rate of change in the firing rate reduction. These values are compared to a standard rate of change. With such information, any unexpected deviations in the control variables can be used to signal an alarm and/or shut down the process.

Although the present invention has been described in terms of the presently preferred embodiments, it is to be understood that the disclosure is not to be interpreted as limiting. Various alterations and modifications will no doubt become apparent to those skilled in the art after having read the above disclosure. Accordingly, it is intended that the appended claims be interpreted as covering all alterations and modifications as fall within the "true" spirit and scope of the invention.

What is claimed is:

1. An explosive gas incinerator system, comprising:
   a fume source inlet for receiving a process exhaust with a volatile material that is explosive when its concentration exceeds a lower explosive limit (LEL);
   a source flowmeter for measuring the volume of said process exhaust being input;
   a temperature sensor for measuring the temperature of said process exhaust;
   a motorized damper for diluting said process exhaust with an ambient air input to produce a damper outflow with an explosive concentration less than said LEL;
   a damper flowmeter for measuring the total mixture volume of said process exhaust and ambient air input in said damper outflow;
   a temperature sensor for measuring the temperature of said damper outflow;
   a first gas monitor for measuring a concentration of said volatile material in said damper outflow;
   an oxidizer for burning said damper outflow in a flame to produce a cleaner exhaust; and
   a fan for forcing gas flows through the oxidizer; and
   a controller connected to receive measurement data from the flowmeters, gas monitor, and temperature sensors, and connected to control the motorized damper to maintain said damper outflow into the oxidizer below the corresponding LEL of the volatile material.

2. The system of claim 1, wherein the controller uses said temperature, gas monitor, and flow measurement data to dilute said damper outflow to the oxidizer to be just under the LEL concentration.

3. The system of claim 1, further comprising:
   a second gas monitor for measuring said concentration of said volatile material in said damper outflow.

4. The system of claim 2, wherein the controller compares data measurements from both the first and second gas monitors to improve the accuracy of measurement of volatile material concentration.

5. The system of claim 2, wherein the controller uses data measurements from both the first and second gas monitors to provide a redundant measurement of the volatile material concentration.

6. The system of claim 1, further comprising:
   an alarm connected to the first gas monitor that will terminate system operation if the concentration of volatile material in said damper outflow exceeds a predetermined limit.

7. The system of claim 1, further comprising:
   an operator-error and sabotage detection function included in the controller.

8. The system of claim 7, wherein:
   the operator-error and sabotage detection function includes start-up charts that are self-generated during controlled start-ups and that are subsequently compared to in-field operating conditions operating conditions where the excursions of particular variables from their norms are interpreted as operator errors or attempts at sabotage and used to signal an alarm or shut down the process.

9. A method for operator-error and sabotage detection in an exhaust incineration system, comprising:
   building start-up charts of key operating variables in an incineration system during controlled conditions; and
   subsequently comparing in-field operating condition variables such that excursions of particular variables from their norms are interpreted as operator errors or attempts at sabotage and used to signal an alarm or shut down the system.

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