9

Illustrative Examples, Calculations, and Guidelines for DDA Selection

9.1. Introduction

This chapter presents a number of examples and calculations that illustrate the selection, application, and sizing of DDAs and other protective measures (discussed in Chapter 3) for the prevention of flame propagation. Also included is a list showing the factors that should be considered for the selection of an appropriate DDA.

9.2. Example 1—Protective Measures for a Vent Manifold System

This example illustrates several protective measures that were provided for a vent manifold system in an actual aromatics chemical plant.

Figure 9-1 is a schematic drawing of the major equipment and protective measures that comprise the vent manifold system. In the system shown, the vent vapors (offgas) from the condensers of two vacuum columns are collected in a manifold which goes to the vacuum pump system. From the vacuum pump system, the vapors go to a seal drum (hydraulic flame arrester), and then to the firebox of a process heater, where they are incinerated.

The offgases from the two vacuum columns, at the vacuum pump discharge, normally contain 1.3 mole percent organic vapor (C₆ to C₈ aromatics) in air, which slightly exceeds the lower flammable limit of the
FIGURE 9-1. Vent manifold system protective measures.
mixture (about 1.0 mole percent organic in air). This stream, therefore, requires constant inerting with nitrogen for safe injection into the process heater firebox flame zone.

The following safety measures were provided:

- A constant nitrogen addition into the discharge line from the vacuum pump to the vacuum pump discharge drum/seal drum system.
- A vacuum pump seal drum design which provides a liquid seal (hydraulic flame arrester) to mitigate flame propagation backward into the vacuum system. The seal liquid is an organic stream (mostly C₈ aromatics) that comes from the vacuum pump discharge drum overflow.
- A detonation flame arrester with an integral thermocouple at the inlet to the process heater firebox to prevent backflash into the vacuum system.
- An interlock system (sensors and valves) which isolates offgas flow to the process heater firebox and routes the offgas to atmosphere on detection of low nitrogen flow or high temperature at the detonation flame arrester outlet.

This example illustrates the use of several protective measures to minimize the possibility of flame propagation.

### 9.3. Example 2—Sizing of an End-of-Line Deflagration Flame Arrester

This example shows the calculations necessary to size an end-of-line deflagration flame arrester.

Size an end-of-line deflagration flame arrester for the normal vent nozzle of a 126,000 gallon API-type atmospheric pressure storage tank for the following conditions:

- Liquid stored: methyl alcohol (flash point = 52°F)
- Liquid pump-in rate: 250 gpm
- Liquid pump-out rate: 200 gpm
- Tank design pressure: 6 inches WC positive and 2 inches WC negative
- Liquid storage temperature: ambient

Venting capacity for liquid movement and thermal breathing are based on API Std. 2000 (1998).
Calculations

1. Calculate the outbreathing rate (for a combination of liquid pump-in and thermal breathing).
   Provide 1 SCFH of air per every 3.5 gph of maximum filling rate for liquids with flash points of less than 100°F.

   \[
   \text{SCFH air} = \frac{\text{gpm} \times 60}{3.5} + T_v
   \]

   where \( T_v \) is the thermal venting capacity (see Table 9-1)

   \[
   \text{SCFH air} = 250 \times \frac{60}{3.5} + 3000 = 4285.7 + 3000 = 7285.7
   \]
2. Calculate the inbreathing rate (for a combination of liquid pump-out and thermal breathing).

Provide 1 SCFH of air per every 7.5 gph of maximum emptying rate for liquids of all flashpoints.

\[
\text{SCFH air} = \text{gpm} \times \frac{60}{7.5} + T_v
\]

SCFH air = 200 \times \frac{60}{7.5} + 3000 = 1600.0 + 3000 = 4600.0

3. Select the flame arrester size from a vendor’s flow curve for the largest flow rate.

Figure 9-2 is a flow curve (tank pressure vs. air flow), from one flame arrester manufacturer, that indicates pressure drop for flow in either direction. This figure illustrates that a 3-inch flame arrester would be adequate.
9.4. Example 3—Calculation of Limiting Oxidant Concentration (LOC)

This example shows how to calculate the limiting oxidant concentration of a vapor if an experimentally determined value is not available.

From Eq. (4-2) (page 57), the LOC of a vapor, when nitrogen is the diluent, can be calculated as follows:

\[ \text{LOC} = \text{LFL (moles oxygen/moles fuel)} \]

**Calculation**

Calculate the LOC of n-butane, as follows:

1. The LFL of n-butane is 1.6 volume percent in air (Crowl and Louvar 1990).
2. The amount of oxygen needed to completely react with butane is:
   \[ C_4H_{10} + 6.5 \text{ O}_2 \rightarrow 4 \text{ CO}_2 + 5 \text{ H}_2\text{O} \]
3. \( \text{LOC} = 1.6(6.5 \text{ moles O}_2/\text{mole n-butane}) = 10.4 \) volume percent oxygen.
4. The actual LOC, as reported in NFPA 69, is 12 volume percent oxygen when using nitrogen as an inerting gas. This calculation, in general, gives a value that is on the conservative (safer) side.

9.5  Example 4—Calculation of the LFL and UFL of Mixtures

This example shows how to calculate the LFL and UFL of gas–vapor mixtures, using the Le Chatelier rule (Crowl and Louvar 1990).

The LFL and UFL of a mixture can be calculated by the following equations:

\[
\begin{align*}
\text{LFI}_{\text{mix}} &= \frac{1}{\Sigma(y_i/LFL_i)} \\
\text{UFI}_{\text{mix}} &= \frac{1}{\Sigma(y_i/UFL_i)}
\end{align*}
\]

where \( \text{LFL}_i \) is the lower flammable limit for component \( i \) in volume percent of component \( i \) in fuel and air; \( \text{UFL}_i \) is the upper flammable limit for component \( i \) in volume percent of component \( i \) in fuel and air; and \( y_i \) is the mole fraction of component \( i \) on a combustibles only basis.
9.6. Example 5—Calculation of the MESG of Mixtures

**Calculation**

Calculate the LFL and UFL of a gas mixture composed of 0.8% hexane, 2.0% methane, and 0.5% ethylene by volume in air.

The data for this calculation are listed below.

<table>
<thead>
<tr>
<th>Component</th>
<th>Volume percent</th>
<th>Mole fraction on combustible basis</th>
<th>LFL (vol. %)</th>
<th>UFL (vol. %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hexane</td>
<td>0.8</td>
<td>0.24</td>
<td>1.1</td>
<td>7.5</td>
</tr>
<tr>
<td>Methane</td>
<td>2.0</td>
<td>0.61</td>
<td>5.0</td>
<td>15.0</td>
</tr>
<tr>
<td>Ethylene</td>
<td>0.5</td>
<td>0.15</td>
<td>2.7</td>
<td>36.0</td>
</tr>
<tr>
<td>Total combustibles</td>
<td>3.3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Air</td>
<td>96.7</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\[
\text{LFL}_{\text{mix}} = \frac{1}{0.24/1.1 + 0.61/5.0 + 0.15/2.7} = \frac{1}{0.396} = 2.53\%
\]

by volume total combustibles

\[
\text{UFL}_{\text{mix}} = \frac{1}{0.24/7.5 + 0.61/15.0 + 0.15/36.0} = \frac{1}{0.0769} = 13.0\%
\]

by volume total combustibles

Since this mixture contains 3.3% by volume total combustibles, it is above the \(\text{LFL}_{\text{mix}}\), and below the \(\text{UFL}_{\text{mix}}\), thus is within the flammable range.

9.6. Example 5—Calculation of the MESG of Mixtures

This example illustrates how to calculate the MESG for a gas–vapor mixture using the original Le Chatelier rule, which includes only the MESG values of the combustible components, and the modified Le Chatelier rule (proposed in NFPA 497), which includes inert gases as well.

The equation for the MESG of a gas/vapor mixture is as follows:

\[
\text{MESG}_{\text{mix}} = \frac{1}{\Sigma(y_i / \text{MESG}_{\text{mix}})}
\]

where \(y_i\) is the mole fraction of component \(i\) in the mixture, and \(\text{MESG}_i\) is the MESG of component \(i\).
**Calculation**

Calculate the MESG of the following mixture using both the original and the modified Le Chatelier rule:

<table>
<thead>
<tr>
<th>Component</th>
<th>Volume Percent</th>
<th>MESG, mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ethylene</td>
<td>45</td>
<td>0.65</td>
</tr>
<tr>
<td>Propane</td>
<td>12</td>
<td>0.97</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>20</td>
<td>∞</td>
</tr>
<tr>
<td>Methane</td>
<td>3</td>
<td>1.12</td>
</tr>
<tr>
<td>Isopropyl ether</td>
<td>17.5</td>
<td>0.94</td>
</tr>
<tr>
<td>Diethyl ether</td>
<td>2.5</td>
<td>0.83</td>
</tr>
</tbody>
</table>

Using the original Le Chatelier rule the mixture MESG will be calculated using only the combustible gases (i.e., ignoring the nitrogen).

The composition of the gas mixture then is as follows:

<table>
<thead>
<tr>
<th>Component</th>
<th>Volume Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ethylene</td>
<td>56.25</td>
</tr>
<tr>
<td>Propane</td>
<td>15.00</td>
</tr>
<tr>
<td>Methane</td>
<td>3.75</td>
</tr>
<tr>
<td>Isopropyl ether</td>
<td>21.88</td>
</tr>
<tr>
<td>Diethyl ether</td>
<td>3.12</td>
</tr>
</tbody>
</table>

The mixture MESG is then equal to:

\[
\left( \frac{0.5625}{0.65} + \frac{0.15}{0.97} + \frac{0.0375}{1.12} + \frac{0.2188}{0.94} + \frac{0.0312}{0.83} \right)^{-1} = \frac{1}{1.3239} = 0.755 \text{ mm}
\]

Since this MESG value is close to the upper value for Group C (greater than 0.45 mm and less than or equal to 0.75 mm), it might be prudent to classify the mixture as Group C, or consider testing the mixture for a more accurate determination.

Using the modified Le Chatelier rule, the mixture MESG is equal to:

\[
\left( \frac{0.45}{0.65} + \frac{0.12}{0.97} + \frac{0.20}{\infty} + \frac{0.03}{1.12} + \frac{0.175}{0.94} + \frac{0.025}{0.83} \right)^{-1} = 0.944 \text{ mm}
\]
9.7. Determination If a DDT Can Occur

It is not always easy to determine when a DDT may occur in a piping system, and when to specify either a deflagration or detonation flame arrester. Chatrathi et al. (2001) state that, based on their experimental work, when the $L/D$ ratio in a straight pipe reaches a value of 60 to 70, a DDT will occur.

9.8. Typical Locations in Process Systems

It is very important to install deflagration and detonation flame arresters in the correct location. This is discussed in detail in Chapter 6, but some considerations and recommendations are presented below.

*End-of-line Deflagration Flame Arresters*

Figure 3-1 (page 19) shows where an end-of-line deflagration flame arrester should be located. It preferably should be installed on a nozzle that is near the outer edge of the tank/vessel roof for ease of accessibility for maintenance and removal.

*In-line Deflagration Flame Arresters*

Figure 3-2 (page 20) shows the installation of an in-line deflagration flame arrester. It also preferably should be located on a nozzle that is near the outer edge of the tank/vessel roof. The length of the vent discharge piping should be kept as short as possible to avoid the possibility of a DDT occurring. Recommendations for the maximum length of the vent discharge piping should be obtained from flame arrester manufacturers. This length may vary depending on the design of the flame arrester and the vapor or gas being handled (e.g., Group B, C, or D).

*In-line Detonation Flame Arresters*

Figure 3-3 (page 21) shows where detonation flame arresters should be located in a vent manifold (vapor collection) system and upstream of a
vapor control unit. The detonation flame arresters should be installed on nozzles near the outer edge of the tank/vessel roof, similarly to the deflagration flame arresters discussed above. If a detonation flame arrester is located upstream of an item of equipment with an open flame in it, such as a thermal oxidizer, it should be located at a distance far enough from the inlet nozzle to avoid impingement on the arrester element from the open flame or radiant heat. Flame arrester manufacturers should be consulted for their recommendations on how far away from the flame source (e.g., thermal oxidizer) to locate the detonation flame arrester.

9.9. List of Steps in the Selection of a DDA or Other Flame Propagation Control Method

In the selection of an appropriate DDA or other flame propagation control method consideration must be given to a number of factors which affect the choice. Presented below is a list of items to be considered in a logical sequence.

1. Is a flammable mixture possible in a vessel and/or piping system?
2. If it is, does ignition in one part of the system need to be contained/isolated from other parts of the system?
3. If it does, what is the most appropriate way of doing this, i.e., deflagration venting, oxidant concentration reduction (inerting or gas enrichment), combustible concentration reduction (dilution), deflagration suppression, deflagration pressure containment, equipment and piping isolation, or installation of a DDA?
4. If a DDA is chosen, the following factors should be considered and data obtained:
   (a) normal and upset conditions of flow, pressure, temperature, and composition
   (b) type of DDA (dry type, hydraulic, packed bed, etc.)
   (c) gas/vapor MESG and/or NEC Group
   (d) physical location of the DDA and whether it should be a deflagration of detonation flame arrester
   (e) allowable pressure drop (using a 20% fouling allowance)
   (f) should the DDA be unidirectional or bidirectional?
   (g) can a stabilized flame (continuous burn) be established on the DDA?
   (h) materials of construction/corrosion effects of the gas or vapor
   (i) is a thermocouple integral with the DDA required?
   (j) are pressure drop taps required?
are nozzles needed for injection of cleaning media?
(l) is piping upstream of the DDA larger than the DDA?
(m) is certification (USCG, UL, FM, CEN, etc.) required?
(n) what other vendor options are available or required?

9.10. References

9.10.1. Regulations, Codes of Practice, and Industry Standards


9.10.2 Specific References
