DEVELOPMENT OF A COMPUTATIONAL SOFTWARE FOR
HAZARDOUS AREA CLASSIFICATION STUDIES

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Abstract: Due to the processing of flammable products in chemical plants,
petrochemical and oil refineries, explosion risks can occur due to leaks of
flammable material, through flanges, process valves or equipments connections
and electric instruments putting at risk the industrial safety. The Area
Classification is therefore, an important step for the specification of instruments
and industrial equipments. The Brazilian standard ABNT/NBR/IEC 60079-
10:2009, which guides the Area Classification, requires in its equations the leak
rate of flammable product to determine the required area around the source of
risk. The aim of this work was develop a methodology to determine the leak rate
of flammable products in an industrial environment, limited to liquid, gases and
vapors and not including combustible dust (dust explosion), in accordance with
previously established sources.

Keywords: Leak rate, Flammable, Area classification.

1. Introduction

The need of explosion protection date of the late XIX century in underground coal
mining where the danger is concentrated in the presence of methane gas and coal dust.
The first efforts to minimize the risk was to promote small explosions with the aid of a
long rod in which burning fuel. In 1815, the English Humphrey Davy invented the safety lamp and yet in the XIX century, it was developed the first machine for the coal mine ventilation. Later, in 1897 it was published the first National Electrical Code, NEC, and in 1906 is founded the IEC, the International Electrotechnical Commission (Source-IEC 2012).

Currently there are many standards, such as international IEC-60079-10, the North American National Fire Protection Association (NFPA 497), the National Electrical Code (NEC), the American Petroleum Institute (API RP 505), the Brazilian ABNT/NBR/IEC 60079-10, among others, establishing methodologies and recommendations for area classification study. The Fig. 1, show the timeline in the development of IEC and NEC.

In the present paper we present a software which allows calculation of the release rate of flammable material in vents, leaks in pipes and evaporation and allows too assess
the risk volume for the area classification. The software was developed in Visual Basic Net, version 2010 for Windows 7 systems, Vista and XP.

2. Fundamentals Concepts

For the determination of risk volume, the main concepts that must be taken into account involve the type of risk source, the gases and vapor properties, rate of release, safety factors and the degree ventilation.

To initiate a combustion, which is an oxidation reaction, three elements must be presents simultaneously: air (oxygen), ignition source and the flammable substance as show in the Fig. 2 (Bega, 2003).

![Figure 2. Explosion triangle (Silva, 2009).](image)

2.1. Gases and Vapors Properties

Fuel form explosives mixtures with air within an upper and lower specific range. For the area classification the knowledge about the lower flammable limit (LEL) of the component is important (Dácio, 2006). Table 1 shows some gases flammable limits.

<table>
<thead>
<tr>
<th>Gas</th>
<th>Lower limit</th>
<th>Upper limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrogen</td>
<td>4 %</td>
<td>75.6 %</td>
</tr>
<tr>
<td>Methane</td>
<td>5 %</td>
<td>15 %</td>
</tr>
<tr>
<td>Propane</td>
<td>2.1 %</td>
<td>9.5 %</td>
</tr>
</tbody>
</table>

Fig. 3 graphically shows flammable limits behavior in function of concentration and temperature.
2.2. Ventilation

It consists of one of the most important factors to reduce the concentration of explosive gases in a process area below the lower explosive limit (LEL). Ventilation can be natural or forced and, depending on its degree, the area can be disqualified (Dácio, 2006). The types of ventilation here considered are as follows:

**Proper ventilation.** Natural or artificial ventilation considered to be sufficient to prevent the accumulation of significant amounts of flammable mixture in concentrations above 25% of its lower explosive limit (LEL).

**Inappropriate ventilation.** This kind of ventilation is applied to rooms, buildings or spaces without natural or mechanical ventilation systems able to provide an adequate air circulation as defined above.

**Limited ventilation.** Natural or artificial ventilation sufficient to assure, in a reasonable way, that there will be no accumulation of hydrocarbons flammable mixture in a concentration above 25% of its lower explosive limit for significant periods of time. This concept applies to releases that are relatively small in quantity and short in duration.

2.3 Groups and hazardous areas

Gases are classified in two explosion groups, depending on the workplace, if on surface or underground. Therefore, there is the Group I, comprising electric materials intended for mines having methane, and Group II, designed to open spaces in the presence of flammable industrial gases (Sánchez, 2006).

![Fig. 3. Flammable limits (Sache, 2003).](image-url)
Depending on the residence time of an explosive substance, risk zones are classified as Zones 0, 1 and 2 for gases, as shown in Figure 4, and as Zones 20, 21 and 22 for dust (Source IEC-2012).

Fig. 5 presents an example of area classification for vents and relief valves, based on typical figures, in accordance with API 505 standard. Typical leaks areas are 0.25 mm$^2$, 2.5 mm$^2$ and 5 mm$^2$ and the two smaller hole sizes (0.25 and 2.5 mm$^2$) are often used for area classification (Ivings and Gant, 2005).
2.4 Equations

In accordance with ABNT/NBR/IEC 60079-10 (2009) standard, the Eq. (1) determines the minimum air flow theoretically required to dilute a mixture of flammable material until the minimum concentration reaches the lower flammability limit.

\[
\left( \frac{dV}{dt} \right)_{\text{min}} = \frac{(dG/dt)_{\text{max}}}{k \cdot \text{LEL}} \cdot \frac{T}{293} \tag{1}
\]

where:

\( (dG/dT)_{\text{max}} \) = maximum rate of release at source (kg/m\(^2\).s).
\( T \) = the ambient temperature (K);
LEL = lower explosive limit, mass per volume (kg/m\(^3\));
\( k \) = safety factor applied to the LEL;
\( (dV/dT)_{\text{min}} \) = minimum volumetric flowrate of fresh air (volume per time, m\(^3\)/s).

Calculation of the mass rate of gas release with restricted velocity is given by Eq. (2).

\[
\frac{dG}{dt} = S \cdot p \sqrt{\frac{\gamma M}{R \cdot T}} \left( \frac{2}{\gamma + 1} \right)^{\frac{\gamma + 1}{2(\gamma - 1)}} \tag{2}
\]

where:

\( T \) = gas temperature (K);
\( S \) = opening area (mm\(^2\));
\( R \) = universal gas constant (J/kmol.K);
\( \gamma \) = polytropic index;
\( p \) = pressure inside de vessel (Pa);
\( M \) = molar mass of the gas (kg/kmol);
\( dG/dt \) = mass rate of gas release (kg/s).
The volume of risk is calculated by Eq. (3).

\[ V_z = \frac{\int f \left( \frac{dV}{dt} \right)_{\text{min}} dt}{C} \]  

(3)

where:

\( V_z = \) risk volume (m\(^3\));
\( C = \) the number of fresh air changes per unit time (s\(^{-1}\));
\( f = \) efficiency of the ventilation;
\( (dV/dT)_{\text{min}} = \) minimum volumetric flowrate of fresh air (volume per time, m\(^3\)/s).

In order to compare the results provided by the ABNT/NBR/IEC 60079-10 (2009) standard for specific cases, such as vents (vessels, reactors), leakages and evaporation, the following equations obtained from literature were applied.

**Vents for vessels and reactors.** The mass velocity is calculated by Eq. (4) (Lees, 1996).

\[ G = \frac{h_{fg}}{v_{fg}} \left( \frac{1}{T.C} \right)^{\frac{1}{2}} \]  

(4)

where:

\( T = \) gas temperature (K);
\( C = \) specific heat of liquid (J/kg.K);
\( h_{fg} = \) latent heat (J/kg);
\( v_{fg} = \) specific volume (m\(^3\)/kg);
\( G = \) mass velocity (kg/m\(^2\).s).
Fig. 6 presents the software interface for area classification, where the rate of gas release and the volume of risk are calculated. The substance is chosen from a database, and temperature, pressure, ventilation data and estimated leak area to be provided.

![Software interface for calculation of leak in vents.](image)

**Fig. 6.** Software interface for calculation of leak in vents.

**Gas leak in equipment and pipes.** The specific mass rate of gas leak in equipment or piping is calculated by Eq. (5), according to Raman and Cameron (2005).

\[
W = C_d \left[ \frac{P_1}{V_1} k \left( \frac{2}{k+1} \right)^{\frac{k}{k-1}} \right]^{\frac{1}{2}}
\]  

(5)

where:

- \( C_d \) = discharge coefficient;
- \( k \) = specific heat ratio (Cp/Cv);
- \( P_1 \) = upstream absolute pressure (Pa);
- \( V_1 \) = specific Volume (m\(^3\)/Kg);
- \( W \) = specific mass flowrate (Kg/m\(^2\).s).
The Fig. 7 demonstrates the interface of the software for the classification area, where the gas release rate and the risk volume are calculated. The substance is chosen from a data base and the temperature, pressure, ventilation data and leakage area must be estimated.

![Software interface for calculation of leak in equipment.](Fig. 7)

**Liquid Evaporation.** According to Less (1996), the Eq. (6) used to calculate the mass vaporization rate of a volatile liquid is:

\[
E_v = 3.6 \times 10^{-10} \left( \frac{M \cdot p^0}{T} \right) u^{0.78} r^{1.89}
\]

where:

- \( E_v \) = mass evaporation rate (kg/s);
- \( T \) = liquid temperature (K);
- \( u \) = mean wind speed (cm/s);
- \( r \) = radius of pool (m);
- \( M \) = molecular weight of liquid (kg/kgmole);
- \( p^0 \) = vapour pressure of the liquid (dyn/cm²).
The vaporization rate of a cold liquid, including most liquefied gas, is normally governed for the rate of heat transferred by conduction from the ground.

The Fig. 8 shows interface of software classification area, where the evaporation rate of liquid and volume risk are calculated. The substance chosen from a database, must be provided the temperature, puddle radius, data of ventilation and wind speed.

![Software interface for calculation of evaporation liquids.](image)

**Fig. 8.** Software interface for calculation of evaporation liquids.

### 4. Case Study

Consider case of propane leak in vent and the operation conditions in Table 2. Using the standard ABNT/NBR/IEC 60079-10 (2009), with the largest area of leak, the software provided classification radius of 1,97 m (Zone 1). The equation Lees (1996), resulted in classification radius of 1,48 m, approaching of 1,5 m as shown in typical figure.

<table>
<thead>
<tr>
<th>Temperature, °C</th>
<th>30,0</th>
<th>30,0</th>
<th>30,0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressure, bar abs</td>
<td>6</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>Ventilation average, f</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Safety factor, k</td>
<td>0,25</td>
<td>0,25</td>
<td>0,25</td>
</tr>
<tr>
<td>Air changes per time, C</td>
<td>12</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>Leak area, mm²</td>
<td>5,0</td>
<td>2,5</td>
<td>0,25</td>
</tr>
<tr>
<td>Typical figure, m</td>
<td>1,5</td>
<td>1,5</td>
<td>1,5</td>
</tr>
<tr>
<td>Classification radius - NBR/IEC 60079-10, m</td>
<td>1,97</td>
<td>1,57</td>
<td>0,73</td>
</tr>
<tr>
<td>Classification radius - Lees, m</td>
<td>1,48</td>
<td>1,18</td>
<td>0,54</td>
</tr>
</tbody>
</table>
It is observed that for leakage areas smaller than 5,0 mm\(^2\) using the typical figure serves classification area for the need of service. The results using the standard ABNT/NBR/IEC 60079-10 (2009) with leakage area of 5,0 mm\(^2\) features relative deviation of 30%. The Table 3 as shown the results modifying the temperature with pressure and leakage area equal to 30 °C and 5 mm\(^2\) (worst case).

**Table 3. Classification area with different pressure operations.**

<table>
<thead>
<tr>
<th>Pressure, bar</th>
<th>3</th>
<th>6</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Typical figure, m</td>
<td>1.5</td>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td>Classification radius - NBR/IEC 60079-10, m</td>
<td>1.56</td>
<td>1.97</td>
<td>2.51</td>
</tr>
<tr>
<td>Classification radius - Lees, m</td>
<td>1.18</td>
<td>1.48</td>
<td>1.76</td>
</tr>
</tbody>
</table>

The standard indicates that areas classification should not be less than 1.5 m in any case, however the results show the progressive increase of modifies pressure the extent of areas classification requiring further attention by the designer.

**5. Conclusions**

As the presented calculation methodology, the computer application can be applied in three specific industrial situations: a) Vents; b) Leaks in equipment; c) Liquid evaporation. For each of these cases, information such as the type of substance, physical state, temperature and pressure are required. The result obtained for leak vents was compared with area classification studies published in the literature.

Considering the example of leakage in vent, typical figure of classification area as shown a radius risk of 1,5 m not quantified leakage area. The standard NBR/IEC 60079-10 for area values equal to 2,5 mm\(^2\) approach the typical default value classification of 1,5 m.

However, the reduction of area to 0.25 mm\(^2\) showed a relative deviation than 50% less of value shown by the typical figure. The result with equation of Lees (1996) showed to be conservative to worst case (5,0 mm\(^2\)) equaling to the typical figure values found. Another point considered is strong influence of the process operating pressure on classification radius. The typical figure showed that uncertainty of growing to higher pressures compare with mathematical methods. The results obtained are not conclusive since the leakage rate is quite dependent on estimates of the leakage area in process.
equipaments. Applied studies in industrial cases should be conducted in order to validate the calculation methodology.

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References


