ABSTRACT

The Risks Analysis consists of the systematic exam of an industrial installation (project or existent) to identify the present risks in the system and to form opinion about potentially dangerous occurrences and its possible consequences. There are two types of risks analysis: the qualitative analysis and the quantitative. The qualitative analysis studies all the possible existent risks of the place, and it relates these risks in agreement with the probability of such accidents happen and with the coming consequences of such accidents. The risks that present high probability of happening and that cause great damages to the structure or the people are analyzed, then, in a quantitative way.

Two sceneries were specified for the use of quantitative techniques. The studied sceneries are related with the existent risks in the storage of gasoline in drums stored in the Laboratory of Analysis of Fuels of UFPR / ANP. The models associated to the sceneries in studies were obtained of the literature. The studied sceneries were Fire on pools and Unconfined Explosion. For each studied scenery it was possible to evaluate the consequences of material, humans and environmental damages associated to the accidents. The results show that in case of the fire in pool, for a distance of 61.35 m and 42.8 m starting from the center of the flame, burns happen in third degree and first degree, respectively, in people that are not protected and, for the unconfined explosion the results show that for a distance of 15.43 m of the center of the explosion a person has 90% of chance of having tympanum rupture, and for a distance of 9.5 m of the center of the explosion a person has 99% of chance of dying.

WORD-KEY: Analysis of Risks, Safety, Fuel
MATERIALS AND METHODS

1 Fire on pool

In this scenery it is admitted that all the gasoline contained in a drum leaks for the ground and form a pool. This pool then catches fire, as shown in Fig. 2.

A bibliographical study was made in order to determine the properties of the gasoline. Some data are pertinent for the calculations that will be accomplished, and they are in Table 1.

Table 1. Some properties of the gasoline and of the air

<table>
<thead>
<tr>
<th>Volume of the drum</th>
<th>0.159</th>
<th>m³</th>
</tr>
</thead>
<tbody>
<tr>
<td>density of the gasoline</td>
<td>750</td>
<td>kg/m³</td>
</tr>
<tr>
<td>density of the air</td>
<td>1.1614</td>
<td>kg/m³</td>
</tr>
</tbody>
</table>

The first thing to be done is to esteem the area of the formed pool when all the fuel leaked out the drum. It was assumed that the land is plane and impermeable, and that the formed pool is circular. In agreement with the software of analysis of risks "ARCHIE", the area of the puddle is given for:

\[
\log(A) = 0.492 \log(m_p) + 1.617
\]  

where \(A\) is the pool area in ft² and \(m_p\) is the pool mass in lbs. Then the liquid surface burn speed of the pool (\(m\)) is calculated. In agreement with Lee (1980), we have:

\[
m = m_\infty [1 - \exp(-k_3 \cdot d)]
\]

where \(d\) is the pool diameter in ft, \(m\) is the liquid surface burn speed of the pool in in/min, \(m_\infty\) is the liquid surface burn speed of a very big diameter pool in in/min (= 0.6), \(k_3\) is a constant in ft⁻¹ (= 0.2). Done that, the relationship \(L/D\) is calculated, that relates the flame height with the pool diameter. In agreement with Lee (1980), we have:

\[
\frac{L}{D} = k_4 \cdot \left(\frac{m_T}{\rho_a(gD)^{1/2}}\right)^{0.6}
\]

where \(D\) is the pool diameter in m, \(L\) is the flame length in m, \(m_T\) is the mass burn rate of fuel in kg/m²s, \(g\) is the gravity acceleration in m/s², \(\rho_a\) is the air density in kg/m³, and \(k_4\) is a constant (= 42). The next step is to calculate the emission coefficient of the pool surface. In agreement with Lee (1980), the emission coefficient of the pool surface for a fuel that produces smoke is given below:

\[
E_s = 140 \exp(-0.12D) + 20[1-\exp(-0.12D)]
\]

where \(E_s\) is the pool emission coefficient in kW/m² and \(D\) it is the pool diameter in meters. Finally, the distances are calculated for the heat fluxes of 5 and 10 KW/m². An exposed person to a heat flux of 5kW/m² will have burns of to 1st degree and an exposed person to a heat flux of 10kW/m² will have burns of up to 3rd degree, with probability of death of 1%.

\[
X_{10} = 0.3 \frac{R_p \cdot Ep}{0.3048}^{0.57}
\]

where \(X_{10}\) is the distance for a heat flux of 5kW/m² in meters, \(X_5\) is the distance for a heat flux of 10kW/m² in meters, \(R_p\) is the radius pool in meters and \(Ep\) is the pool emission coefficient in kW/m².
2 Unconfined Explosion

Explosions that happen outdoors are said unconfined, as shown in Fig. 3.

Figure 3. Unconfined explosion

The accidental leak of gases or inflammable liquids in the atmosphere can result in the formation of a cloud of a mixture explosive vapour/air. The ignition of the cloud will originate a flame front that will spread through the explosive area of the cloud. Depending on the flame front speed, a pressure wave can be created. This is a danger related to the transport, storage, handles and production of gases and inflammable liquids.

The consequences of a UVCE (Unconfined Vapor Cloud Explosion) are, in general, catastrophic, because the pressure wave travels a great area, desolating everything and everybody, causing a lot of deaths /injured people and material damages.

2.1 Models for estimating the effects of a UVCE

For the scenery unconfined explosion some considerations were made, located in Table 2:

Table 2. Some Physical e Chemical properties of gasoline and air

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gasolin LEL in ar</td>
<td>1.4 (%v/v)</td>
</tr>
<tr>
<td>Gasoline lower calorific power</td>
<td>43961 kJ/kg</td>
</tr>
<tr>
<td>Curitiba atmospheric pressure</td>
<td>90.68 kPa</td>
</tr>
<tr>
<td>Laboratory volum</td>
<td>614.22 m³</td>
</tr>
<tr>
<td>Ambient temperature</td>
<td>25 °C</td>
</tr>
<tr>
<td>Gasolin molecular weight</td>
<td>98 kg/kmol</td>
</tr>
<tr>
<td>Air molecular weight</td>
<td>29 kg/kmol</td>
</tr>
</tbody>
</table>

Several models have been proposed, even so the simplest model and more known is it called "equivalent TNT".

2.1.1 The Equivalent Model TNT

This model consists of transforming a UVCE in an explosion of a certain mass of TNT (trinitrotoluene) with the same effects. Once known the "equivalent mass of TNT", starting from quite simple graphic, we can know the developed overpressure at a distance given by the explosion. The use of the concept of “equivalent mass of TNT” was been worth of the detailed knowledge of the effects of the explosion of this explosive, acquired along the years by the mining industries and by the army.

\[
M_{\text{equivalent}} = \frac{a \cdot M \cdot Q}{4690}
\]

(7)

The parameter a is the relationship between the energy of combustion of the equivalent mass of TNT and the potentially combustion energy available released in the explosion, M is the mass of the product (kg) and Q is the combustion heat of the product (kJ/kg). In the case of hidrocarbons leaks, a is generally equal to 10%.

We can try to explain the physicist meaning of the decomposing it in two components:
- nor the whole cloud participates in the explosion, that is, just the part understood among the inflamability limits
- nor all the energy of the combustion is transformed in pressure wave

The next step is to find the reduced distance Z. The figure 4 shows a graph of the overpressure of an explosion of TNT versus the reduced distance. Previous studies demonstrated that the death probabilities equal to 99% and probabilities of tympanum rupture equal to 90% are given for picks of pressure of 2 and 0.84 bar, respectively. Entering with these values in the graph of Fig. 4, we can find the reduced distance Z in meters. For we find, finally, the distances for the death probabilities and rupture of tympanum of 99% and 90%, respectively, the following equation is used:

\[
Z = \left(\frac{D_{\text{desired}}}{M_{\text{equivalent}}^3}\right)\text{TNT}
\]

(8)

where Z is the reduced distance in meters and D_{\text{desired}} it is the desired distance in m.

Figure 4. Overpressure of an explosion at the level of the soil
2.1.2 The model of M.J. Tang and Q.A. Baker

The method developed by M.J. Tang (2000) is based on experimental data, and it presents more precise results in comparison to the method of equivalent TNT for small distances of the center of the explosion.

Known the low limit of inflammability of the fuel (LEL), we want to know the percentage in volume of fuel that will vaporize. Thus it becomes necessary to determine the volume of the place where this fuel is present. Using the equation of the ideal gases, the mass of fuel can be determined in vapor form.

The next step is to determine the "scaled overpressure". It is given by the reason of the pressure pick by the absolute atmospheric pressure. Done that we’ll calculate the dissipated energy by the vapor cloud in the explosion.

\[ E = \text{PCI}_G \text{m}_G \]  \hspace{1cm} (9)

where \( E \) is the energy dissipated by the vapor cloud in kJ, \( \text{PCI}_G \) is the gasoline low caloric power in kJ/kg and \( \text{m}_G \) is the mass of suspended gasoline in the air in kg. Now the parameter \( R \) is calculated, because the scaled overpressure is already known. The parameter \( R \) is obtained from the equation:

\[ \bar{R} = \frac{0.34}{R^{4/3}} + \frac{0.062}{R^2} + \frac{0.033}{R^{2/3}} \] \hspace{1cm} (10)

Finally, we find "stand-off distance " (R). It is obtained below from the equation:

\[ R = \frac{\bar{R}}{\left(\frac{E}{p_0}\right)^{1/3}} \] \hspace{1cm} (11)

where \( p_0 \) are the atmospheric pressure.

RESULTS

The results obtained for the fire sceneries in pool and unconfined explosion are demonstrated in the Tables 3 and 4, respectively.

Table 3. Fire on pool

<table>
<thead>
<tr>
<th>Pool height (m)</th>
<th>Pool radius (m)</th>
<th>Flame height (m)</th>
<th>Heat flux of 5 kW/m² distance (m)</th>
<th>Heat flux of 10 kW/m² distance (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.003</td>
<td>3.99</td>
<td>30.53</td>
<td>61.35</td>
<td>4280</td>
</tr>
</tbody>
</table>

Table 4. Unconfined Explosion

<table>
<thead>
<tr>
<th>Fatality probability</th>
<th>Tymanum rupture probability</th>
<th>Pressure pick (kPa)</th>
<th>Distance for probability of 99% of fatality (m)</th>
<th>Distance for probability of 90% of tympanum rupture (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>99%</td>
<td>90%</td>
<td>200</td>
<td>9.5</td>
<td>84</td>
</tr>
<tr>
<td>99%</td>
<td>90%</td>
<td>200</td>
<td>11.65</td>
<td>84</td>
</tr>
</tbody>
</table>

For the fire scenery in pool, the height of the puddle was varied from 0.001 meter up to 0.01 m. The approximate calculated value was of 0.003 m. For this height of calculated pool, we met the distances for a heat flux of 5 kW/m² and 10 kW/m². In case a person is exposed to a heat flux of 5 kW/m² without the protections owed for more than one minute, he will have burns of 1st degree. In case this same person is exposed to a flux of 10 kW/m² for more than one minute, this person will have serious burns of 3rd degree. For a height of pool of 0.003 m, the theoretical height of the formed flame would be of 30.53 m.

For the scenery of unconfined explosion, it was used two different mathematical models. Both models obtained approximate results, however the model of Tang and Baker are more precise for small distance of the center of the explosion than the model of equivalent TNT. With both models it was possible to find the distances of the center of the explosion where a located person would have probability of tympanum rupture of 90% and death probability of 99%, for example.

CONCLUSION

Through the obtained results, it was possible to conclude that for the fire scenery in pool, a person located at 61.35 m of the center of the fire and without the appropriate protections would have burns of 1st degree if he was exposed to a heat flux for more than 1 minute. In case this person was to 42.80 m of distance of the center of the fire, and he stayed there without the due protections for more than 1 minute, he would have serious burns of 3rd degree, with great fatality probability.

For the scenery of Unconfined explosion we conclude that a person located at 15.43 m of the center of the explosion has probability of tympanum rupture of...
90%, and a person located at 9.5 m of the center of the explosion has fatality probability of 99%.

ACKNOWLEDGEMENTS

Acknowledgements to the National Oil Agency for the opportunity of developing this work and for the financial support.

NOMENCLATURE

- $a$: is the relationship between the energy of combustion of the equivalent mass of TNT and the potentially combustible energy available liberated in the explosion.
- $A$: pool area ($\text{ft}^2$);
- $d$: pool radius ($\text{ft}$);
- $D$: pool radius ($\text{m}$);
- $D_{\text{desired}}$: desired distance ($\text{m}$);
- $E$: cloud energy dissipated ($\text{kJ}$);
- $E_p$: pool emission coefficient ($\text{kW/m}^2$);
- $E_s$: pool emission coefficient ($\text{kW/m}^2$);
- $g$: gravity acceleration ($\text{m/s}^2$);
- $k_3$: constant ($\text{ft}^{-1}$) (= 0.2);
- $k_4$: constant (= 42);
- $L$: flame height ($\text{m}$);
- $m$: liquid surface burn speed of the pool (in/min);
- $m_p$: pool mass (lbs);
- $m_f$: mass burn rate of fuel ($\text{kg/m}^2\text{s}$);
- $m_o$: mass of suspended gasoline in the air (kg);
- $m_\infty$: liquid surface burn speed of a very big diameter pool, in in/min (= 0.6)
- $M_{\text{equivalent TNT}}$: TNT equivalent mass (kg);
- $M$: product mass (kg);
- $p_0$: absolut atmospheric pressure (kPa);
- $\bar{P}$: pressão escalar (dimensioless);
- $PCI_G$: gasoline low calorific power ($\text{kJ/kg}$);
- $Q$: combustion heat of the product, ($\text{kJ/kg}$);
- $R$: “stand-off distance” ($\text{m}$);
- $R_p$: pool radius ($\text{m}$);
- $\bar{R}$: parameter (dimensioless);
- $X_5$: distance for a heat flux of $5\text{kW/m}^2$ ($\text{m}$);
- $X_{10}$: distance for a heat flux of $10\text{kW/m}^2$ in meters ($\text{m}$);
- $Z$: reduced distance ($\text{m}$) and;
- $\rho_a$: ambient air density ($\text{kg/m}^3$).

REFERENCES
