PETROLEUM, SAFETY AND ENVIROMENT

F. R. Chote
and G. N. Kaskantzis

Universidade Federal do Paraná
Setor de Tecnologia
Curso de Engenharia Mecânica
lipao@demec.ufpr.br

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

INTRODUCTION

The safety and personnel's qualification are constant factors of any industrial philosophy that has as primordial objective the improvement of the quality and productivity. However, these parameters have been neglected and they become, in many cases, the main ones responsible for the failure in the attempts of implementation of new managerial and operational philosophies in companies. (Duart, 2002)

The chemical processes plants, due to the intrinsic nature of the substances and of the products that they handle, are subject to a range of risks that can, not rarely, produce irreparable damages to the equipments, as well as to cause serious lesions, or even deaths, to the workers and the surrounding communities, out of the limits of its facilities. The increase of risks of industrial accidents of great danger, coming of the use of more advanced and complex technologies, creation of new processes and products, great storage capacities and transport of dangerous products, increased the pressure on the companies in the sense of reducing its risks, clarifying the people about the risks and adopting emergency measures and contention of efficient risks. Besides, with the evolution of the social sector, themes linked to ecological areas and work accidents started to worry the public about the industries and, consequently, the government authorities. Consequently, the industries were forced to examine with more sharpness the effects of its operations intra and extra-walls. (Beneditti, 19994, Metropolo, 1999)

In this sense, the risks manager appeared as a mitigation instrument and administration of present risks in the industrial way, offering philosophies and technical tools that seek optimize the use of the technology, which suffers accelerated progress and, not rarely, inconsistent with the minimums patterns of safety that should be present inside of industrial activities. The risks manager inside of a company represents the possibility to attribute safety and reliability to the processes and procedures, constituent of its operational atmosphere, allowing the integration of two poles that, until then, linked indirectly: the work safety and the patrimonial safety. This work search to contribute for the operational improvement of the Laboratory of analysis of fuels of ANP, through the study of some fire sceneries and explosion of drums of gasoline. Figure 1 shows the Laboratory of Analysis of Fuels of UFPR/ANP.

Figure 1. Laboratory of Analysis of Fuels

The Laboratory of analysis of fuels of UFPR / ANP began its activities in May of 2000. It is located in Pilot Factories A and B of UFPR. Now there are analyzed, approximately, 200 samples of fuels / month. About 2500 gas stations of Paraná are visited, 500 each month. The laboratory assists the Fiscalization of ANP and PROCON, too.

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.

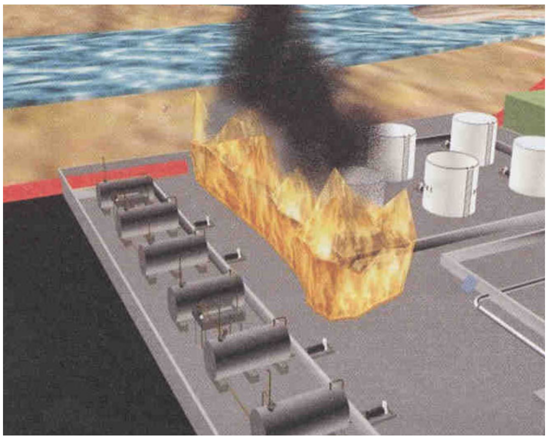

Figure 2. Fire on pool

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

Volume of the drum	0.159	m^3
density of the gasoline	750	kg/m^3
density of the air	1.1614	kg/m^3

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:

$$\log(A) = 0.492 \log(m_p) + 1.617 \qquad (1)$$

where A is the pool area in ft^2 and m_P it 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:

$$m = m_\infty [1 - \exp(-k_3 d)] \qquad (2)$$

where d is the pool diameter in ft, m is the liquid surface burn speed of the pool in in/min, m_∞ 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 Lees (1980), we have:

$$\frac{L}{D} = k_4 \cdot \left(\frac{m_T}{\rho_a (gD)^{1/2}} \right)^{0.6} \qquad (3)$$

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/m^2s, g is the gravity acceleration in m/s^2, ρ_a is the air density in kg/m^3 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:

$$E_s=140\exp(-0.12D)+20[1-\exp(-0.12D)] \qquad (4)$$

where E_s is the pool emission coefficient in kW/m^2 and D it is the pool diameter in meters. Finally, the distances are calculated for the heat fluxes of 5 and 10 KW/m^2. An exposed person to a heat flux of $5kW/m^2$ will have burns of to 1st degree and an exposed person to a heat flux of $10kW/m^2$ will have burns of up to 3rd degree, with probability of death of 1%.

$$X_{10} = 0.3 \frac{Rp}{0.3048} Ep^{0.57} \qquad (5)$$

$$X_5 = 0.43 \frac{Rp}{0.3048} Ep^{0.57} \qquad (6)$$

where X_5 is the distance for a heat flux of $5kW/m^2$ in meters, X_{10} is the distance for a heat flux of $10kW/m^2$ in meters, Rp is the radius pool in meters and Ep is the pool emission coefficient in kW/m^2.

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 gasolin and air

Gasolin LEL in ar	1.4	(%v/v)
Gasoline lower calorific power	43961	kJ/kg
Curitiba atmospheric pressure	90.68	kPa
Laboratory volum	614.22	m^3
Ambient temperature	25	ºC
Gasolin molecular weight	98	kg/kmol
Air molecular weight	29	kg/kmol

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 (trinitrotolueno) 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.

$$M_{\text{equivalente}}\,\text{TNT} = \frac{a \cdot M \cdot Q}{4690} \qquad (7)$$

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:

$$Z = \frac{D_{\text{desired}}}{(M_{\text{equivalent}}\,\text{TNT})^3} \qquad (8)$$

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

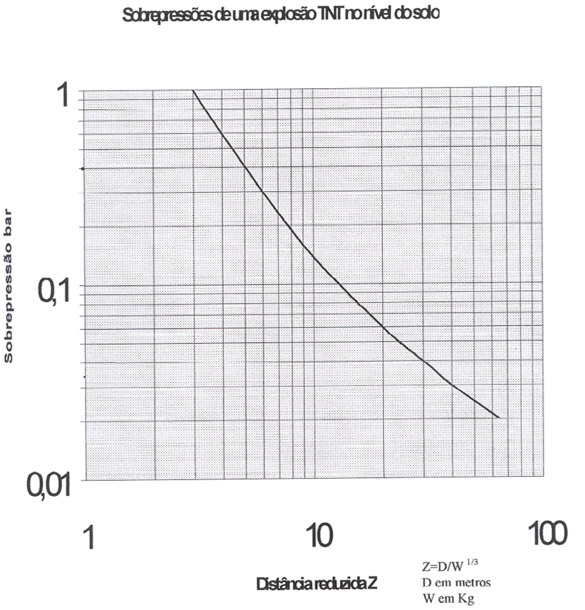

Figure 4. Overpressure of an explosion at the level of the soil

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 inflamability 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.

$$E=PCI_G\ m_G \qquad (9)$$

where E is the energy dissipated by the vapor cloud in kJ, PCI_G is the gasoline low calorific power in kJ/kg and m_G is the mass of suspended gasoline in the air in kg. Now the parameter $\overline{R}$ is calculated, because the scaled overpressure is already known. The parameter $\overline{R}$ is obtained from the equation:

$$\overline{P} = \frac{0,34}{\overline{R}^{4/3}} + \frac{0,062}{\overline{R}^{2}} + \frac{0,033}{\overline{R}^{3}} \qquad (10)$$

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

$$\overline{\mathrm{R}} = \frac{\mathrm{R}}{(\mathrm{E}/\mathrm{p}_0)^{1/3}} \qquad (11)$$

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

Pool height (m)	Pool radius (m)	Flame height (m)	Heat flux of 5 kW/m^2 distance (m)	Heat flux of 10 kW/m^2 distance (m)
0.003	**3.99**	**30.53**	**61.35**	**4280**

Table 4. Unconfined Explosion

M.J. Tang and Q.A. Baker model (2000)

Fatality probability= 99%		**Tympanum rupture probability = 90 %**	
pressure pick (kPa)	for probability of 99% of fatality (m)	pressure pick (kPa)	Distance for probability of 90% of tympanum rupture (m)
200	9.5	84	15.43

Model equivalent TNT

Fatality probability= 99%		**Tympanum rupture probability = 90 %**	
pressure pick (kPa)	for probability of 99% of fatality (m)	pressure pick (kPa)	Distance for probability of 90% of tympanum rupture (m)
200	11.65	84	17.36

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/m^2 and 10 kW/m^2. In case a person is exposed to a heat flux of 5 kW/m^2 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/m^2 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 combustion energy available liberated in the explosion.
A = pool area (ft^2);
d = pool radius (ft);
D = pool radius (m);
$D_{desired =}$ desired distance (m)
E = cloud energy dissipated (kJ);
E_p = pool emission coefficient (kW/m^2);
E_s= pool emission coefficient (kW/m^2);
g = gravity aceleration (m/s^2);
k_3 = constant (ft^{-1}) (= 0,2);
k_4 = constant (= 42);
L = flame height (m);
m = liquid surface burn speed of the pool (in/min);
m_P = pool mass (lbs);
m_T = mass burn rate of fuel (kg/m^2s);
m_G = mass of suspended gasoline in the air (kg);
m_∞= liquid surface burn speed of a very big diameter pool, in in/min (= 0.6)
$M_{equivalente}TNT$ = TNT equivalent mass (kg);
M = product mass (kg);
p_0 = absolut atmospheric pressure (kPa);
$\overline{P}$ = pressão escalar (dimensioless);
PCI_G = gasoline low calorific power (kJ/kg);
Q = combustion heat of the product, (kJ/kg);
R = “stand-off distance” (m);
Rp = pool radius (m);
$\overline{R}$ = parameter (dimensioless);
X_5 = distance for a heat flux of $5kW/m^2$ (m);
X_{10} = distance for a heat flux of $10kW/m^2$ in meters (m);
Z = reduced distance (m) and;
ρ_a = ambient air density (kg/m^3).

REFERENCES

Benedetti, R. P., 1994, “Flamable and Combustible Liquids Code Handbook”**,** 5º edition, National Fire Protection Association, Massachusetts, USA .

Duarte, M., 2002, **“**Riscos Industriais – Etapas para a Investigação e a Prevenção de Acidentes”**,** Petrobrás, Rio de Janeiro, Brasil

Lee, F. P., 1980, **“**Loss prevention in the process industries”, Vol. 1, Loughborough University of Technology, Great Britain.

Metropolo, P. L., 1999, “Análise de Conseqüências”**,** CPDEC, Universidade de Campinas (UNICAMP), Campinas, Brasil

Tang, M. J. , 2000, “Comparison of blast curves from vapor cloud explosions”, Wilfred Baker Engin,nering Inc., San Antonio, US.