Fire Fighting in Process Plants

Analysis of actual firewater consumption

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Guidelines for firewater design and estimation of maximum firewater demand in process plants are defined in various international and company standards.
The amount of firewater to be discharged in the drainage systems and basins is however more complex to evaluate, because the modelling and standardization of the effective duration of a fire and the related consumption of water necessary to fight and extinguish the fire depends on a lot of factors.
Notwithstanding this, criteria for modelling the duration of a fire scenario can be established, starting from assumptions on the amount of flammable/combustible liquids or solids contained in a process unit and taking into account factors like the liquid burning rate, evaporational effects, properly designed fire fighting systems and process isolation devices.
The estimation of fire scenario duration leads to evaluate the amount of actual consumed firewater and the results of the analysis may be applied as guidelines for a correct estimation/validation of the size of waste firewater drainage systems and of the capacity of wastewater basins designed to contain firewater.

1. Introduction

In the analysis of fire accidents in process plants, the main attention is usually given to the damages caused by fire to personnel, equipment and structures, while the environmental issues due to contamination by means of polluted firewater are often underestimated, even though they can also lead to severe consequences.
A proper design of waste water retention and treatment systems can cope with these issues and the key factor to be evaluated in the design of such system is the actual amount of contaminated firewater to be collected, contained and treated.

Fires involving flammable gas/liquids and combustible liquids/solids are fought by means of water. The analysis and modelling of the potential fire scenario taking into account a proper installation of process safety and fire fighting devices leads to estimate the relevant duration and maximum amount of firewater required to fight the fire.
In hydrocarbons and dust fire scenarios water is usually not considered as an extinguishing medium but it is used mainly for cooling purposes.

The fire is assumed to go out when all the combustible subjected to fire is burned.
The scenarios analyzed herein below are mainly considering process plants units and apply only to outdoor undiked process areas where the use of other extinguishing media like foaming agents, water mist or total flooding systems is not applicable.
The following scenarios are analyzed as examples of potential fires that may occur in outdoor undiked process areas:

- Scenario 1: Flammable liquid fire
- Scenario 2: Combustible liquid fire
- Scenario 3: LPG fire
- Scenario 4: Combustible powder fire

Only liquid pool fire and dust fire scenario have been analyzed here, jet fire scenarios due to flammable gas release have been considered not significant in the context of evaluation of actually consumed firewater due to:

- Low duration of jet fires experimented in case histories
- Low solubility of flammable gases in water which leads to have usually a consumed firewater not contaminated from pollutants

The estimation of actual contaminated firewater volume is based on the following equation, generally applicable to all the considered fire scenarios.

$V_{FW} = Q_{FW} * t_f * K$ *Equation 1.1*

where:

V_{FW} = Actual contaminated firewater volume
Q_{FW} = Firewater flow rate. It is assumed for each scenario that the same amount of required firewater flow rate, that may be given by a combination of manual and automatic fire fighting systems, is continuously used to fight the fire from the beginning till fire is completely stopped.
t_f = Fire scenario duration
K = Reduction factor, which takes into account effects like evaporation of water in contact with fire and high temperature surfaces, as well as dispersion of water onto unpaved areas, especially by wind effect.

This reduction factor should be evaluated case by case as a function of factors like the layout and the paving of the area and the type of fire fighting systems.
For example the evaporation of water in contact with high temperature is higher if fixed systems like water spray are used due to higher contact surfaces while the dispersion rate is generally higher for hydrants and monitors compared to water spray and deluge systems.
As a minimum value the reduction factor should be estimated as 10% (K = 0,9)

The volume VFW of contaminated firewater represents the contribution of firewater that shall be considered in dimensioning the waste water retention basins in process areas. The below analysis describes for each scenario methods and assumptions that have been adopted to estimate the factors t_f.

2. Fire Scenario Identification and Calculation

2.1 Scenario 1: Flammable liquid fire

Flammable liquid fire scenarios may occur in process units handling liquid hydrocarbons and they are mainly due to loss of containment of flammable liquid generating a pool onto the ground which may be ignited creating a pool fire.
The fire duration modelling is based on the following assumptions:

- The process unit subjected to pool fire is completely isolated by means of remote operated shut-off valves (ROSOV), therefore the complete volume V of flammable liquid subjected to fire can be identified and intercepted by activating an emergency button in control room.
- The worst case in which the loss of containment and fire involves all the intercepted volume when fire starts is considered.
- No flashing effects are considered, all the volume V of liquid subjected to loss of containment is burned.

In case some of the above assumptions are considered not applicable to the specific case under study, further coefficient of reduction factors shall be applied.
The duration of fire scenario can be estimated by the following:

$t_f = h / v_b$ <u>*Equation 2.1*</u>

where
v_b = burning rate. The burning rate is the velocity at which the fuel is burned.
Burning rate data for typical flammable liquids are presented in the following Table 2.1 (see [1]) where v_b = m" (mass burning rate) * r (density):

Table 2.1: Flammable Liquids Burning Rate

Substance	*Mass Burning Rate* $m'' [kg / m^2 * sec]$	*Density* $\rho [kg / m^3]$	*Burning Rate* $v_b [mm / sec]$
Benzene	0.085	874	$9,73 * 10^{-2}$
Hexane	0.074	650	$11,38 * 10^{-2}$
Heptane	0.101	675	$14,96 * 10^{-2}$
Xylene	0.09	870	$10,34 * 10^{-2}$
Benzine	0.048	740	$6,49 * 10^{-2}$
Gasoline	0.055	740	$7,43 * 10^{-2}$
Kerosene	0.039	820	$4,76 * 10^{-2}$

h = height of liquid pool. In case of outdoor uncurbed areas an average constant pool fire height can be estimated by means of the following simplified experimental model in function of the Volume of liquid and the fuel burning rate (see [2])

$h = 4V / [\pi (\sqrt{3}/2 + 1)(V^3 g / v_b^2)^{1/4}]$ <u>*Equation 2.2*</u>

where V and v_b are fluid volume and burning rate and "g" is the acceleration due to gravity.

The Equation 2.2 derives from the modelling of pool fire maximum diameter in case of instantaneous release, on which a corrective factor is applied in order to consider an average pool diameter and the assumption of circular pool so that the average height can be calculated applying the formula of the volume of a cylinder.

For the estimation of firewater flow rate, it is assumed that water spray and deluge systems are usually installed in process units handling flammable fluids. The required firewater demand for cooling the equipment subjected to fire may be typically defined as follows:
The deluge system of the equipment subjected to fire + two adjacent deluge systems + an amount of water given by fire network equipment (hydrant / monitors) located around the fire area + an amount of water given by the use of mobile fire equipment.
The volume of firewater actually consumed can be estimated applying the Equation 1.1.

2.2 Scenario 2: Combustible liquid fire

Combustible liquid fire scenarios may occur in process units handling oils or other kind of combustible liquids and they are mainly due to loss of containment of process units or systems that can be completely isolated or to loss of containment of oil stored in closed systems located in a small defined area which may be curbed like in case of lubricating or diathermic oil skids.

In both cases the volume of liquid subjected to fire can be easily estimated and the same assumptions done for scenario 1 are considered.
The fire duration time shall be calculated with the Equation 2.1 considering the burning rate data of typical combustible liquid provided in the following Table 2.2 (see [1]):

Table 2.2: Combustible Liquids Burning Rate

Substance	*Mass Burning Rate* $m'' \ [kg / m^2 * sec]$	*Density* $\rho \ [kg / m^3]$	*Burning Rate* $v_b \ [mm / sec]$
Diesel	0.045	918	$4{,}90 * 10^{-2}$
Transformer Oil	0.039	760	$5{,}13 * 10^{-2}$
Fuel Oil	0.035	970	$3{,}61 * 10^{-2}$
Crude Oil	0.034	855	$3{,}92 * 10^{-2}$
Lube Oil	0.039	760	$5{,}13 * 10^{-2}$

The pool fire height may be estimated with Equation 2.2 but the systems handling combustible liquids are often located in curbed area, therefore, the height of liquid pool is easily estimated as V / A, where A is the area inside the curb.
The required firewater flow rate for systems handling combustible liquids may be estimated with the same approach described in scenario 1, considering that water spray and deluge system with special mulsyfire nozzles are installed mainly when the combustible fluid is handled above its flash point. In other systems only the contribution of firewater hydrants and monitors and mobile fire equipment shall be evaluated.
The volume of firewater actually consumed can be estimated applying the Equation 1.1.

2.3 Scenario 3: LPG fire

LPG fire scenario is due loss of containment of LPG and, due to nature of this kind of fluid, the liquid pool is affected by significant flashing effects.

LPG Plant units are usually equipped with ROSOV and the LPG volume subjected to loss of containment can be easily intercepted.
Equation 2.1 and 2.2 are still applicable to determine the fire duration taking into account the following:

- LPG burning rate v_b = 0,14 mm/sec (see [1]).
- Volume subjected to fire Vf = V * K_V, where Kv is a reduction factor due to the fact that not all the volume of LPG subjected to loss of containment will be involved in the pool fire, but a significant part of liquid volume will flash once the LPG is released to atmosphere. This reduction factor should be calculated case by case based on process and release conditions.

The firewater flow rate can be estimated as in scenario 1, assuming that water spray and deluge systems are always installed in LPG units, but the main purpose is cooling adjacent equipment, because there is no dilution effects, since LPG is a gas practically not soluble in water.
This means that the required volume of firewater estimated by applying the Equation 1.1 has to be considered as not contaminated.
Solubility of LPG in water (see [3]) varies from 60 mg/l (Butane, Propylene) to 70 mg/l (Propane), which is generally in the same range of environmental limit for discharging hydrocarbons in water sewer of process plants, which is the range between 10 mg/l (EPA) and 100 mg/l (EN 858, see [4])

In case of process units containing LPG, therefore, the contribution of firewater volume V_{FW} in the sizing of contaminated waste water basins shall be checked in function of the applicable environmental limits.

2.4 Scenario 4: Combustible powder fire

Combustible powder fire scenario described here in below applies specifically to organic powder plants, but once available the burning rate data, can be extended to all powders scenario.

Fire duration t_f can be still evaluated with the Equation 2.1, in which
h = height of the dust layer. This value depends on the quantity of powder subjected to loss of containment but also on a lot of factors like wind, height and layout of the area which may help disperding the powder and operating procedure like proper housekeeping. Generally it may be estimated as maximum 10 mm.
v_b = powder burning rate, typical data provided in the following Table 2.3 (see [5][3])

Table 2.3: Organic Powders Burning Rate

Substance	*Mass Burning Rate* $m'' [kg / m^2 * sec]$	*Specific Gravity* $\rho [kg / m^3]$	*Burning Rate* $v_b [mm / sec]$
Nylon	0.021	1090	$1,89 * 10^{-2}$
LD Polyethylene	0.020	910	$2,20 * 10^{-2}$
HD Polyethylene	0.020	940	$2,13 * 10^{-2}$
Polypropylene	0.017	900	$1,93 * 10^{-2}$

In fire scenario generated by loss of containment of powder, firewater is not only a cooling medium, but it may have an effective contribution also in extinguishing the fire, because the heat removal due to wetting of powder decreases the efficiency of combustion, therefore the application of Equation 2.1 should be considered a conservative approach for this scenario. Effective duration of the fire can be determined by fire tests on contained dust layer with application of a fixed firewater flow rate.

Powder units are generally equipped with fixed firewater sprinkler systems and the required firewater demand may be calculated as in scenario 1.

The volume of firewater actually consumed can be estimated applying the Equation 1.1.

3. Conclusions

The practical application of the modeling described in this paper is to employ the calculated volume of contaminated V_{FW} to determine the firewater contribution in sizing of waste water collection, retention and treatment units.

The major loss of containment scenario among the process units which are collected to the sized retention system shall be selected, without considering contemporarity between two different scenarios.

The volume of V_{FW} should be estimated for each of the significant scenario identified and the highest value should be considered and compared with V_R maximum volume of containment rainwater which is calculated as a function of the rain flow rate data and the surface area that is collected in the waste water basin to be designed.

The major value between V_{FW} & V_R shall be the waste water basin volume V_{WWB}.

In plants where an external or centralized waste water treatment system is foreseen the volume of the basin may be reduced, provided that the excess water can be delivered to the centralized system by gravity or via pumps sized to handle the flow rate of contaminated water.

References

[1] AA.VV., SFPE Handbook of Fire Protection Engineering, 2002 Edition, National Fire Protection Association

[2] AA. VV., Handbook for fire calculation and Fire Risk Assessment in Process Industry, Scandpower AS

[3] Material Safety Data Sheet Database, 2005, Sigma Aldrich

[4] J. N. Veenstra, K. S. Mohr, 2000, An Overview of US and International Regulations Regarding Hydrocarbons in Water Effluents, I.P.E.C. Albuquerque

[5] Hopkins D., September 1995, Predicting the Ignition Time and Burning Rate of Thermoplastics in the Cone Calorimeter, NIST GCR 95-677.