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Estimating Firewater Runoff in Process Plants: An analysis of available models for retention pond sizing

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The environmental impact of polluted firewater is a critical point to the current efforts to improve the sustainability of industrial plant. In case of a fire accidents in process plants, the firefighting water can cause considerable damages if it enters surface water, infiltrates the ground, or contaminates groundwater. By properly designing waste-water retention and treatment systems, these issues can be addressed taking into consideration the amount of contaminated firewater that needs to be collected and treated.

This paper is a contribution to the estimation of amount of firewater runoff to be discharged in the drainage systems and the sizing of retention pond presenting the results of the application of different models and their convergence to a design value.

Three models, based on object surface or the largest fire compartment area and selected from the European Safety guideline (UNECE, 2019), have been investigated. The analysis is, further, enhanced with two alternative calculation models that consider the contribution of the discharged firefighting foam extinguishing system.

* 1. Introduction

Fires are adverse events that harm the environment. The volume of firewater to be discharged in the retention basins is a challenging undertaking since the prediction of the duration of a fire and the amount of water needed to extinguish it depends on many variables. Some guidelines for predicting the duration of a fire can be established by making assumptions about the amount of flammable or combustible materials in a process unit and considering factors such as the rate at which the liquid burns, the effects of evaporation, the design of fire-fighting systems, and the use of process isolation devices.

* + 1. Aromatic Plant Case Study

The analyzed case study considers an aromatic complex designed by Maire Tecnimont in the southern Europe, where a possible accidental scenario is the release of flammable hydrocarbons in liquid and gas phase that can produce a fire that could escalate. An active fire protection system, which includes water and foam-based systems, is adopted to control and/or extinguish the fires that may occur in the facility, limiting its escalation and minimizing the effects to facilities when exposed to the resulting radiation.

* + 1. Fire scenario

The scenario is a fire in the process area where the discharged FW is calculated to provide simultaneous firefighting, fire intensity control and exposure protection of process equipment of the fire area made by a single fire-scenario envelope. Firefighting is provided by two monitors from opposite directions and by the water spray systems activated by Fire Detection system. Furthermore, two hydrants and two hose reel stations are assumed to be in service inside the process area.

All the models for FW runoff estimation are applied considering the biggest fire area, in terms of FW demand and surface extension of an Isomerization and Fractionation Unit (FA-7) and for fire area in the Refrigeration Unit (FA-15) of an Aromatics plant. In case of an accidental fire, the fire water runoff and discharged foam solution are collected in the retention basin 374-UT-002. The basin for the collection of potentially polluted rainwater/firewater basin is part of wastewater treatment plant. To determine the retention volume required for FW runoff for the area with the highest fire contingency, the UNECE guidelines have been taken as reference (UNECE, 2019).

* 1. Models

In the present study three different models extracted from the UNECE guidelines have been considered:

* The Verband Der Schadenversicherer e.v. (association of non-life insurers) - VDS model;
* The joint expert group on water and industrial accidents model - JEG advanced model;
* The German federal state of Hessen model;

All models are based on “object surface or largest fire compartment area”. The analysis is then integrated with two alternative calculation models not connected to “object surface or largest fire compartment area” and developed considering the contribution of discharged firefighting foam extinguishing system present in the study case and the time to deliver the water/foam solution to the retention basin. The two models are:

* The burning rate method (Rigolio, 2010);
* The “Four Phases Intervention Model”.
	+ 1. VDS Model

The model is developed by the German insurance industry and published as Guideline VDS 2257 (UNECE, 2019). This model takes into consideration the type and quantity of combustible materials, the presence of fire detection systems, the size of the largest fire compartment, the type of fire brigade and the fire protection technical infrastructure”. Formula is reported below.

|  |  |
| --- | --- |
|  | (1) |

VDS model requires as input the “object surface or largest fire compartment”. Due to complexity of a process area, the calculations are made considering as parameter A two different values. The results of VDS model are reported in Table 1:

Table 1: VDS Model applied to curbed area surface and equipment surface

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Area  | A(m2) | SWL(m2) | BAF | BBF | M(m3) | BSF | FW Retention volume (m3) |
| FA-7 curbed area surface | 7150 | 0.24 | 0.75 | 3.64 | 3722 | 3.64 | 2310 |
| Equipment surface in FA-7 | 4355 | 0.24 | 0.90 | 3.64 | 3722 | 3.64 | 1963 |

* + 1. Advanced JEG Model

This model, proposed by the Joint Expert Group on Water and Industrial Accidents (JEG model) estimates 1 m3 of the retention basin per square meter of the protected object surface or its biggest fire compartment, following the formula:

|  |  |
| --- | --- |
|  | (2) |

The calculated volume can be reduced to 10 per cent by providing a constantly operating factory fire service (advanced JEG model) since considers the presence of advanced fire protection strategies (e.g. deluge systems).

|  |  |
| --- | --- |
|  | (3) |

Considering that a comparison of the advanced JEG model with the other models has shown that with lower fire densities, the JEG model provides results within the mid-range of the other models, while in the event of higher fire densities, the model achieves lower values (UNECE, 2019) a reduction to 25 per cent instead to10 per cent is considered for the presence of the operational factory fire service:

|  |  |
| --- | --- |
|  | (4) |

Table 2: Advanced JEG Model applied to curbed area surface and equipment surface

|  |  |  |
| --- | --- | --- |
| Area  | A (m2) | FW Retention volume (m3) |
| No operational factory fire service | Operational factory fire service - 0.1 | Operational factory fire service - 0.25 |
| FA-7 curbed area surface | 7,150 | 7,150 | 715 | 1,788 |
| Equipment surface in FA-7 | 4,355 | 4,355 | 436 | 1,089 |

* + 1. Province of Hessen Model

The model developed for industrial sites by the German Federal State of Hessen in 2011 for industrial sites is based on empirical data or assessment of the fire load (UNECE, 2019). For objects or fire compartments larger than 600 m2, the dimensioning of firefighting water retention basins can be calculated as follows:

|  |  |
| --- | --- |
|  | (5) |

The calculated retention volumes are shown in Table 3.

Table 3 : Province of Hessen model - FW runoff retention Volume R (m3)

|  |  |  |
| --- | --- | --- |
| Area  | A (m2) | FW Retention volume (m3) |
| FA-7 curbed area surface | 7,150 | 1,287 |
| Equipment surface in FA-7 | 4,355 | 784 |

* + 1. Burning rate model

This model is based on the burning velocity of discharged substance that is contributing to the fire. The estimation of actual contaminated firewater volume is determined by the following equation, generally applicable to all the considered fire scenarios (Rigolio, 2010).

|  |  |
| --- | --- |
|  | (6) |

The "burning rate formula" considers a single release at time from a single equipment. Due to the nature of a large fire that can impact more equipment resulting in release from various equipment the overall liquid hold-up present in the FA-7 has been conservatively considered. Because of the non-linearity of the formula used for calculation of height of liquid pool (h), it was chosen to calculate the duration of fire scenario for the equipment with the largest liquid hold-up on FA-7 (C-202).

Table 4: Burning rate model input data

|  |  |  |  |
| --- | --- | --- | --- |
| Liquid hold-up Volume of C-202(m3) | Vb Burning Rate(m/s) | h - height of liquid pool (m) | tf - Duration of fire scenario (h) |
| 250 | 6.49E-05 | 0.012 | 0.05 |

The retention volume for a fire in FA-7 is then calculated considering a linear ratio between the tf calculated with the liquid hold-up of column C-202 and all liquid hold-ups present in FA-7 and contained in other equipment:

|  |  |
| --- | --- |
|  | (7) |
|  | (8) |

Table 5: Burning rate - FW runoff retention Volume R (m3)

|  |  |  |  |
| --- | --- | --- | --- |
| Liquid hold-up FA-7(m3) | Vb Burning Rate(m/s) | tf - Duration of fire scenario (h) | FW runoffretention Volume R (m3) |
| 3,722 | 6.49E-05 | 0.79 | 1,465 |

* + 1. Four Phases Intervention Model

The “Four Phases Intervention Model” is a test method that evaluates the contribution of discharged foam and the time to deliver the water/foam solution to the retention basin. This method considers the sequence of intervention of automatic/semiautomatic systems with their typical flowrate and the contribution given by fire brigades that will discharge fire water from the truck and foam solution for 65 minutes, plus the contribution given by the FW discharge to cool the equipment during the time needed till the released foam flows from farthest point to reach the retention basin.

Four phases of intervention are considered as follows:

**Phase 1** - Activation of all the automatic system (automatic deluges) upon intervention of fire detectors. Duration of this first phase is considered 10 minutes.

**Phase 2** - Intervention of Plant operators activating after ten minutes from automatic fire alarm (operators intervention time) the semi-automatic deluge systems, FW monitors, hydrants and hose reels of the area. Duration of the second phase is considered 5 minutes.

**Phase 3** - Intervention of Plant fire brigades that will discharge after 15 minutes from automatic fire alarm (Fire brigades intervention time) water and foam for a duration of 65 minutes.

**Phase 4** - The phase 4 is defined as the time that it takes for the water drop, once fallen on the ground, to reach the retention basin. This time is given by below equation:

|  |  |
| --- | --- |
|  | (9) |
|  | (10) |

Sizing of open channels or of gravity pipes assumes that a uniform flow can occur (parallel-walled channels, cross sectional area being constant). The sizing criteria used for the uniform movement, present in the pipes, is the Hazen and Williams formula:

|  |  |
| --- | --- |
|  | (11) |
|  | (12) |

while the flowrate Qopen ch (m3/s) is calculated with the following expression:

|  |  |
| --- | --- |
|  | (13) |

The Hazen and Williams roughness coefficient for pipes carrying foam solution depends on type and condition of pipe sewer surface material in contact with flow (NFPA 11, 2024). For all water collecting pipes a typical circular cross section has been considered and pipes shall be at levels and gradients that ensure liquids are not retained in any part of drain system. The calculated travel time is 10 minutes for FA-7 under analysis. For fire area FA-15, it is considered the progressive intervention of all deluge systems in the area (automatic and semi-automatic) + 2 fire monitors + 2 hydrants and 2 hose reels + the intervention of fire brigades after 15 minutes from the fire detection alarm that will discharge water and foam solution.

Table 6: Four Phases water run-off contribution

| Phase | Phase 1 | Phase 2 | Phase 3 | Phase 4 |
| --- | --- | --- | --- | --- |
| **Time duration****(min)** | 10 | 5 | 65 | 10 |
| **Contribution** | Automatic deluge discharge till operator intervention | Activation of semi-automatic deluge by operator + FW monitors and hydrants discharge | FW monitors and hydrants discharge + automatic/semi-automatic deluge systems + fire brigade intervention (foam and water discharge) | Deluge discharge for cooling of equipment |

The following assumptions have been made:

* FW monitors flowrate considered for design purposes is 170 m³/h at a pressure of 8.5 kg/cm²g, for hydrants and hose reels the flowrate is 239 m³/h at a pressure of 8.5 kg/cm²g, for fire water truck of fire-brigades is 330 m³/h.
* In FA-7 under analysis, three semi-automatic deluge system are foreseen. Their contribution in terms of FW is 847 m3/h. In FA-15 three automatic deluge system are foreseen. Their contribution in terms of FW is 684 m3/h. The activation of FA-15 also determines the activation of semi-automatic system in the nearby area with further contribution in terms of FW of 446 m3/h.
* The discharged foam solution by fire truck is calculated considering the application density of 6.5 l/min m2 for 65 minutes (NFPA 11, 2024) on the pool surface of 232 m² (API 521, 2022).
* 30 % of discharged fire water will evaporate or dispersed by wind in the surrounding areas and does not reach the retention basin (evaporation phenomena + wind effect).

Table 7: Four Phases - FW runoff retention Volume R (m3)

|  |  |
| --- | --- |
| Area  | FW Retention volume (m3) |
| FA-7  | 1,889 |
| FA-15 | 1,956 |
|  |  |

* 1. Analysis of model results

The Table 8 below shows the results of different methods where it is highlighted that the obtained values can have substantial difference. In particular, the VDS model that considers the plan surface of fire area 7 is the most conservative approach, on the other hand, the outcomes of Advanced JEG model return the smallest FW runoff retention volume considering the calculation based on equipment surface. A limitation on maximum fire area surface on process plant results in an optimization of FW runoff retention volume, considering that the application of models on plan surface of fire area results in bigger FW retention volumes. Furthermore, the reduction factor of advanced JEG model of 0.1 gives as result lower values of FW runoff retention volume, while for large fire area the application of a more conservative value of 0.25 produces results within the same range of other models.

Table 8: Results of FW runoff retention volume for different models

| Model | Actual fire compartment area or Object area | FW Runoff Retention VolumeR (m3) |
| --- | --- | --- |
| VDS Model | Plan Surface of FA-7 curbed area surface | 2,310 |
| Equipment geometrical surface up to 15 m height | 1,963 |
| Advanced JEG Model | Plan Surface FA-7 curbed area surface. Operational factory fire service 0.1 | 715 |
| Equipment geometrical surface up to 15 m height Operational factory fire service 0.1 | 436 |
| Plan Surface FA-7 curbed area surface Operational factory fire service 0.25 | 1,788 |
| Equipment geometrical surface up to 15 m height. Operational factory fire service 0.25 | 1,089 |
| Province of Hessen Model | Plan Surface FA-7 curbed area surface | 1,287 |
| Equipment geometrical surface up to 15 m height | 784 |
| Burning rate model | n/a | 1,465 |
| 4 Phases intervention Model | Based on FA-7 FW demand | 1,889 |
| Based on FA-15 FW demand | 1,956 |

* 1. Conclusions

This paper analysed the estimation of amount of firewater runoff to be discharged in the drainage systems and the sizing of retention pond presenting the results of the application of different models and their convergence to a design value. The retention volumes calculated using the different methods differ significantly on the definition of fire area surface and reduction parameters. A limitation on maximum fire area surface on process plant results in an optimization of FW runoff retention volume, considering that the application of all analysed models based on plan surface of fire area results in bigger FW retention volumes compared to the application on equipment geometrical surface. The VDS model shows the most conservative results while the Advanced JEG model turns out to give lower Firewater runoff retention volumes. The adoption of a test method defined as “Four Phases intervention model”, that evaluates the contribution of discharged foam and the time to deliver it to the retention basin considering the sequence of intervention of automatic/semiautomatic systems and the contribution given by fire brigades, can validate the results of selected models and the selection of parameters for the estimation of FW runoff retention volume.

Nomenclature

A – object surface or largest fire compartment, m2

Af – object surface or largest fire compartment surface area, m2

Aw – wetted cross-sectional area of water in the drainage waterway, m2

BAF – fire section area factor, -

BBF – fire load factor, -

BSF – fire protection factor, -

C – Hazen and Williams Roughness coefficient, -

FW – Fire Water, -

h – height of liquid pool, m

K – reduction factor for effects like evaporation of water, -

in contact with fire

M – volume of all stored materials, m3

r – hydraulic radius, m

Pw – wetted cross-sectional perimeter of water in the drainage waterway, m

Qopen ch – open channel flowrate, m3/s

QFW – firewater flowrate, m3/s

R – FW runoff retention Volume, m3

S – hydraulic gradient – slope, m/m

SWL – specific water input, m3/m2

t – phase 4 duration, s

te – time of entry into the system equal to 60 s

tf – fire scenario duration, s

tt – time of travel inside the pipes, s

V – velocity of flow, m/s

Vb – burning rate, m/s

References

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