CHEMICAL ENGINEERING TRANSACTIONS
VOL. 90, 2022
A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.cetjournal.it
Guest Editors: Aleš Bernatík, Bruno Fabiano

ISBN 978-88-95608-88-4; **ISSN** 2283-9216
DOI: 10.3303/CET2290042

Asset Integrity in the Case of Wildfires at Wildland-Industrial Interfaces

Federica Ricci[a,*], Giordano Emrys Scarponi[a], Elsa Pastor[b], Eulàlia Planas[b], Valerio Cozzani[a]

[a] LISES – Department of Civil, Chemical, Environmental, and Materials Engineering- Alma Mater Studiorum – Università di Bologna, via Terracini 28, 40131 Bologna (Italy)
[b] Department of Chemical Engineering, Centre for Technological Risk Studies - Universitat Politècnica de Catalunya BarcelonaTech, Eduard Maristany 16, E-08019 Barcelona, Catalonia, Spain
federica.ricci18@unibo.it

Wildfires are uncontrolled fires involving the combustion of wild vegetation. When a wildfire front approaches the Wildland-Industrial Interface there can be a serious threat for process and storage equipment items located at the plant boundary. Ensuring the integrity of such equipment prevents the fire from spreading inside the plant site and causing major accidents such as fire, explosion, and toxic gas dispersion. The provision of adequate clearance areas is paramount since the early stages of the plant design. Once the facility is built, the implementation of safety measures can protect industrial items and ensure tank integrity. A tailored methodology for the calculation of safety distances between wild vegetation and tanks accounting for the safety system was developed and applied to a case study. The outcomes provide useful information on the effectiveness of safety measures for the protection of industrial items exposed to wildfire.

1. Introduction

Natural events impacting industrial sites can lead to technological scenarios resulting in high losses. These accidents are termed Natech accidents, and their frequency is increasing in the last decades (Ricci et al., 2021a). Among other natural disasters, wildfires are raising concern due to the high number of events that have occurred in recent years. Possible causes of the growing trend can be attributed to the effects of climate change and global warming (Flannigan et al., 2016). These events represent a serious threat for the population living at the Wildland-Urban Interface (WUI) as well as for industrial facilities and infrastructures built in the proximity of wildland areas, usually referred to as Wildland-Industrial Interface (WII) areas. Moreover, the increasing extension of WUI and WII due to the rapid urbanization and industrialization of rural areas is raising concerns about the wildfire issue (Wigtil et al., 2016). Ensuring the integrity of equipment items is paramount to avoid wildfire spread inside the plant site and potential escalation to major accidents such as fire, explosion, and toxic gas dispersion. In the current industrial practice, asset integrity is often pursued by the provision of a clearance area surrounding the facility.
Ricci et al. (2021b) developed a methodology for the assessment of safety distances between storage tanks and wild vegetation to ensure the integrity of tanks exposed to wildfire. This is based on a technically sound approach that accounts for both the features of the wildfire and those of the equipment. An application of the methodology to a case study inspired by a real refinery tank farm demonstrated that the actual distances between tank and vegetation do not guarantee tank integrity (Ricci et al., 2021c). The ability of the methodology to provide a vulnerability ranking of the equipment was also shown. The ranking allows to prioritize the intervention of emergency response teams towards more vulnerable tanks and to identify tanks requiring the application of further safety measures. Changes in the layout of existing plants are very difficult. In these cases, it is necessary to introduce protective measures other than safety distances to protect the equipment exposed to wildfire. Protection measures can aim at reducing the time required for the actuation of the emergency response procedures and/or at increasing the time to failure of tanks.

Paper Received: 10 January 2022; Revised: 17 March 2022; Accepted: 3 May 2022
Please cite this article as: Ricci F., Scarponi G.E., Pastor E., Planas E., Cozzani V., 2022, Asset integrity in the case of Wildfires at Wildland-Industrial Interfaces, Chemical Engineering Transactions, 90, 247-252 DOI:10.3303/CET2290042

In the present study, an improved version of the methodology is presented, which allows accounting for the application of two types of safety measures: firewalls and spray systems. Firewalls are passive protective measures built between wild vegetation and tanks (Sutton, 2017a). Industrial sites can have boundary walls to protect the site from intrusions by malicious people and attacks from the outside. When industrial sites are located at the wildland-industrial interface, the boundary wall can provide a shielding effect to the tanks and protect them against external fires. Spray systems are active protective measures that can be used to keep tanks cool and avoid collapse due to fire exposure, reducing the heating effect of the incident radiation on the tank surface. The use of spray water is more effective because water drops evaporate quickly ensuring fast heat removal (Sutton, 2017b). The modified methodology is applied to a case study. Safety distances resulting from the application of different barriers are calculated and compared to assess their effectiveness.

2. Methodology

The methodology proposed in the present study aims at evaluating the effect of protective measures on the safety distance, extending the procedure proposed by Ricci et al. (2021b) considering firewalls and spray systems. The assessment considers the characterization of the wildfire in terms of flame geometry, emissive power, and residence time, and makes use of specific vulnerability models for the assessment of the tank response to fire exposure. In the following, the four steps for the calculation of safety distances are illustrated.

2.1 Wildfire characterization

Wildfire front can affect industrial sites through thermal radiation. The direct contact between flames and equipment items is unlikely thanks to a clearance area that typically surrounds the plant (Zárate et al., 2008). Thus, the heat transfer between fire and tanks is calculated through the solid flame model (Eisenberg et al., 1975). In this approach, the flame is modelled as a solid body with a defined shape, dimensions, and emissive power. The fire is conservatively modelled as a black body (i.e., $\varepsilon_F = 1$) with a flame temperature of 1200 K (Billaud et al., 2011) and the emissive power is calculated using the Stefan-Boltzmann law (Eq. 1):

$$E = \varepsilon_F \cdot \sigma \cdot {T_F}^4 \quad (1)$$

where E is the emissive power (W/m^2), ε_F is the emissivity of the flames, T_F is the flame temperature (K) and σ is the Stefan-Boltzmann constant (5.67 10^{-8} W·m^{-2}·K^{-4}).

As for the shape and dimension, wildfire can be schematized as a flat plane of dimensions L_F (flame length) and W_F (fire front width), inclined by a tilt angle θ with respect to the ground. The fire front width and the tilt angle are difficult to estimate, and they are extremely site-specific. Thus, the following conservative choices are maid: infinite fire front width inclined by the tilt angle that maximizes the view factor. The flame length is defined on the base of the type of burning vegetation (grasslands, shrublands or woodlands/forests), according to Eq. 2 (Ricci et al., 2021b):

$$L_F = \begin{cases} 7.5\ m & Grassland\ (GF) \\ 13\ m & Shrubland\ \ (SF) \\ 3.5 \cdot H_V & Woodland/forest(CF) \end{cases} \quad (2)$$

where H_V is the vegetation height (m). Woodland/forest fires in which the tree crown burns actively are referred to as crown fires. Figure 1 shows an illustration of the three different types of fire considered.

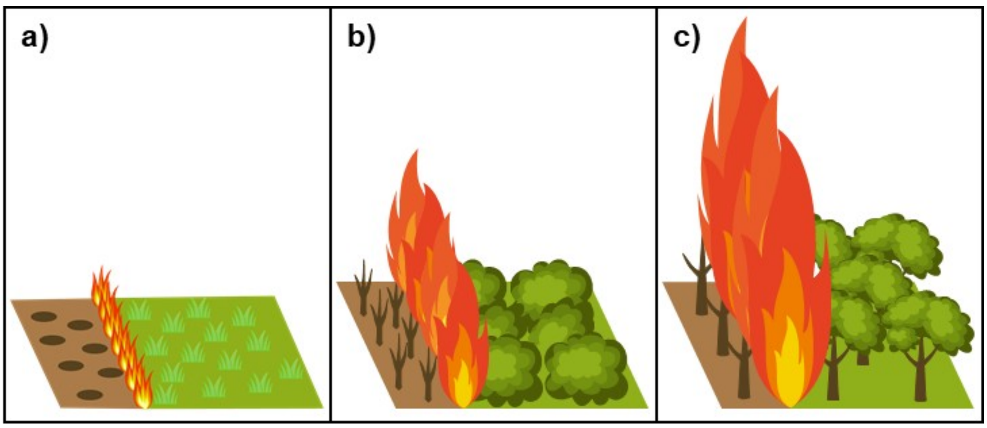

Figure 1: Representation of the fire resulting from: a) grassland; b) shrubland; c) woodland/forest (crown fire).

2.2 Calculation of the incident radiation

The incident radiation that reaches the tank surface due to the wildfire can be calculated using Eq. 3:

$$I = E \cdot F \cdot \tau_a \quad (3)$$

where I is the incident radiation (W/m^2), τ_a is the atmospheric transmissivity (assumed 1) and F is the view factor between the tank and the flame, calculated following the method proposed by Mudan (1987).
The incident radiation in the case of firewall can be calculated through Eq. 3 modifying the view factor. Figure 2 shows the schematization of the wildfire and the firewall.

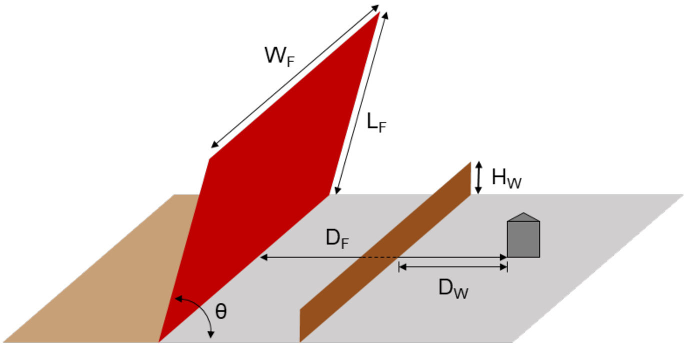

Figure 2: Flame shape and geometrical parameter used to model the fire scenario and the firewall.

For the spray system, the reduction is quantified through the attenuation parameter φ, and the mitigated incident radiation can be calculated according to Eq. 4:

$$I_m = \varphi \cdot I \quad (4)$$

where I_m is the mitigated incident radiation (W/m^2), φ is the attenuation parameter and I is the incident radiation from the wildfire calculated according to Eq. 3.

2.3 Evaluation of the time to failure of tanks

The time to failure TTF of tanks can be evaluated through correlations present in the literature (Landucci et al., 2009). Correlations distinguish between atmospheric tanks (Eq. 5) and pressurized vessels (Eq. 6). The time to failure TTF (s) is given as a function of the incident radiation on the tank surface I (kW/m^2) and the volume of the tank V (m^3).

$$\mathrm{Ln}\, TTF_{atm} = -1.13 \cdot \ln I - 2.67 \cdot 10^{-5} \cdot V + 9.9 \quad (5)$$

$$\ln TTF_{press} = -0.95 \cdot \ln I - 8.845 \cdot V^{0.032} \quad (6)$$

2.4 Definition of safety distances

The safety distances are then calculated through the comparison of the time to failure with a reference time RT. The reference time is defined as the minimum between the exposure time to the wildfire front t_e and the response time of plant emergency teams t_r. A credible and conservative value of the exposure time is 15 minutes for a target located at the edge of the forest. Then, the safety distance is calculated as the minimum value of the distance at which the time to failure is lower than the response time.

3. Case study

To demonstrate the effectiveness of firewalls and spray systems in protecting industrial items from wildfires a case study was defined, considering four conditions:

- Case 1 (wildfire): no safety measures are considered.
- Case 2 (firewall): the firewall is considered, with a height (H_W) of 3 m and located at the plant boundary, thus having a distance from tanks (D_W) of 30 m, and a target distance to the fire front (D_F) of 60 m.
- Case 3 (spray system).: the spray system is considered, with an average value of 0.5 for the attenuation parameter (Landucci et al., 2017).
- Case 4 (firewall and spay system): both the firewall and the spray system as previously defined are considered.

For all cases, the layout reported in Figure 3 is considered: a tank farm featuring 2 atmospheric tanks and 2 pressurized ones. The atmospheric tanks (T1 and T2) have a diameter of 40 m and a height of 10 m. The pressurized vessels (P1 and P2) have a diameter of 5 m and a length of 8 m. All the tanks are placed at 30 m from the plant boundary, while the distance from the wild vegetation is 60 m.

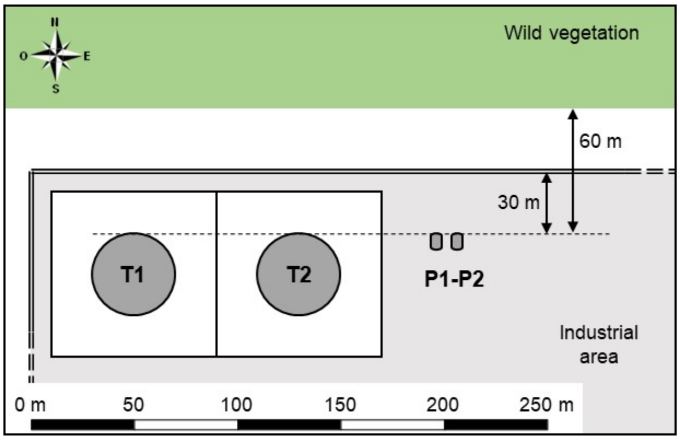

Figure 3: Layout of the tank farm considered as a case study

Four types of wild vegetation are considered for each case, the features of which are reported in Table 1. A reference time equal to the maximum exposure time t_e (i.e., 15 min) is considered for demonstration purposes. It is worth mentioning that the case of grassland fire is not considered in the present work as the clearance area in the layout is enough to ensure tanks integrity in this case (Ricci et al., 2021b).

Table 1: Main features of the wild vegetations considered in the case study

Vegetation ID	Type of vegetation	Height of vegetation, H_V [m]	Length of flames, L_F [m]
SF	Shrubland	-	13
CF5	Forest	5	17.5
CF15	Forest	15	52.5
CF25	Forest	25	87.5

4. Results and Discussion

Figure 4 shows the incident radiation on the target surface as a function of the fire-target distance (D_F) and the safety measures applied to the case study for shrubland fire (panel a) and crown fire with tree height of 25 m (panel b).

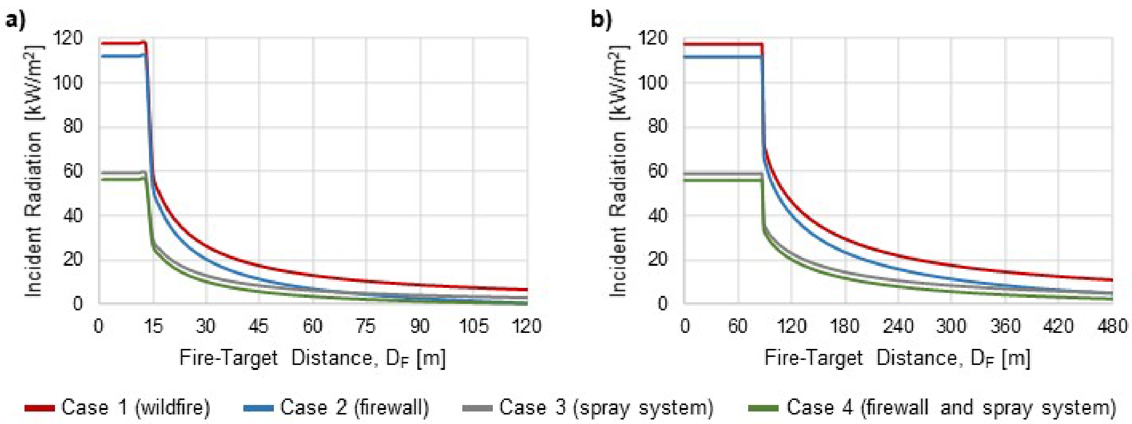

Figure 4: Incident radiation as a function of the distance and the safety measure considered in the case study for (a) shrubland fire and (b) crown fire with tree height of 25 m.

It is worth mentioning that the view factor has a constant value for fire-target distances shorter than the flame length, thus leading to a discontinuity in the incident radiation.
Case 2 (firewall) shows an increasing reduction of the incident radiation on the target surface as the distance increase. Moreover, firewalls are more effective when used with shrubland fires rather than crown fires. For instance, the incident radiation reduction moves from of around 47% to 5% when considering a fire-target distance of 60 m. The heat load reduction provided by spray systems (Case 3) results to be more effective than firewall for short distances while there is an inversion in the trend considering long distances. The distance at which the firewall becomes more effective than the spray system increases as the flame length increases, following the results obtained for firewalls. Clearly enough, the implementation of both safety measures (Case 4) guarantees a larger reduction of incident radiation than applying each measure individually.
Figure 5 shows the safety distances in the case of atmospheric tanks for different wildfire conditions and safety measures.

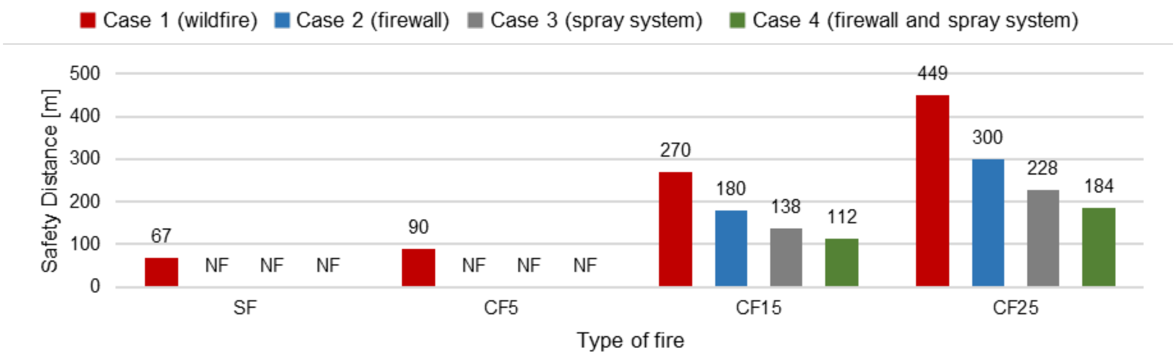

Figure 5: Safety distances as a function of vegetation type and safety measures for atmospheric tanks. NF: No failure of the target due to the wildfire according to the clearance area present in the layout (60 m) and the reference time considered (15 min).

Given the 60 m clearance distance present in the layout, all the types of fire considered can affect atmospheric tanks if no safety measure is applied. Focusing on shrubland fire (SF) and crown fire with tree height of 5 m (CF5), firewalls and spray systems can protect the tanks even used individually. In both cases, the safety distances after their implementation are less than the clearance distance (60 m) in the layout. On the contrary, for crown fire deriving from forests with 15 m and 25 m trees, the implementation of safety measures does not guarantee the integrity of the tanks. However, firewall and spray system reduce the safety distance by around 33 % and 50 % if applied separately, 60 % if applied simultaneously.
The clearance distance present in the layout is higher than the safety distance required for pressurized vessels considering shrubland and forest with a vegetation height of 5 m. Thus, only crown fires resulting from trees of 15 m and 25 m are considered, and the related safety distances are reported in Figure 6.

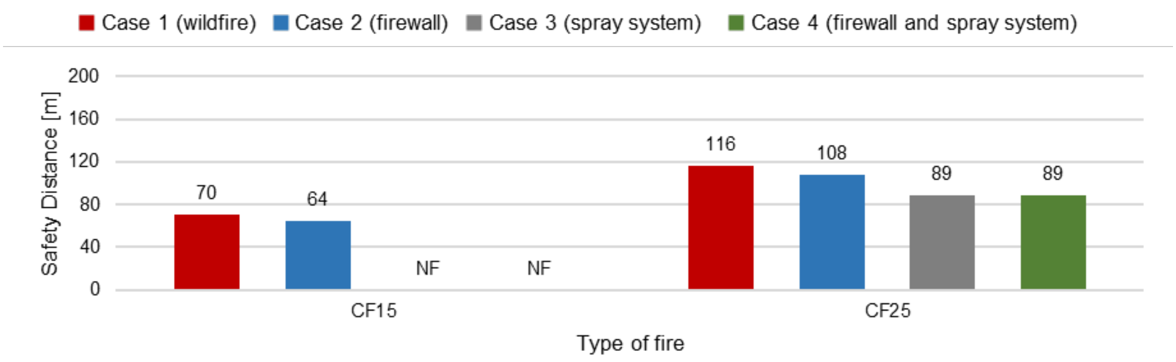

Figure 6: Safety distances as a function of vegetation type and safety measures for pressurized vessels. NF: No failure of the target due to the wildfire according to the clearance area present in the layout (60 m) and the reference time considered (15 min).

The implementation of firewall alone results to be ineffective for both the cases considered. Instead, the spray system can ensure the integrity of the tank considering the first case (CF15). In the latter case (CF25), both firewall and spray system, even when used together, do not reduce the safety distance sufficiently to make the tanks safe. In the case of pressurized tanks, the reduction of the safety distance obtained is less than for atmospheric tanks. However, the spray system is effective in protecting tanks in the case of worst scenarios, such as crown fire from a vegetation height of 15 m.
Even if safety measures introduced in the layout do not ensure tank integrity, they increase the time to failure of tanks. This means that the emergency teams have more time to effectively protect the tanks, increasing the probability of a successful intervention. In the case of implementation of both firewall and spray system, the time to failure more than doubles with respect to the case where no safety measures are considered.

5. Conclusions

Wildfires may represent a serious threat to industrial items located at the plant boundary. The protection of such items is paramount to avoid the spreading of fire inside the industrial site and prevent major accidents. In the present work, a methodology for the calculation of safety distances that accounts for the implementation of safety measures was provided. The application of the methodology to a case study highlighted that firewalls and spray systems ensure tank integrity in the case of shrubland fires and crown fire with a limited height of the vegetation. The effectiveness of the safety systems decreases with the increase of the wildfire flame length. In our case study, even if safety measures do not ensure tank integrity in all cases, they increase the time available for emergency teams, enhancing the probability of a successful intervention.

Acknowledgments

The study was carried out within the research project “Assessment of Cascading Events triggered by the Interaction of Natural Hazards and Technological Scenarios involving the release of Hazardous Substances” funded by Italian Ministry for Scientific Research (MIUR) under the “PRIN 2017” program (grant 2017CEYPS8) and project PID2020-114766RB-100 funded by MCIN/ AEI /10.13039/501100011033.

References

Billaud Y., Kaiss A., Consalvi J.-L., Porterie B., 2011, Monte Carlo estimation of thermal radiation from wildland fires. International Journal of Thermal Sciences, 50, 2–11.
Eisenberg N., Lynch C., Breeding R., 1975, Vulnerability model. A simulation system for assessing damage resulting from marine spills, Report No. CG-D-137-75.
Flannigan M.D., Wotton B.M., Marshall G.A., de Groot W.J., Johnston J., Jurko N., Cantin A.S., 2016, Fuel moisture sensitivity to temperature and precipitation: climate change implications. Climate Change, 134, 59–71.
Landucci G., Gubinelli G., Antonioni G., Cozzani V., 2009, The assessment of the damage probability of storage tanks in domino events triggered by fire. Accident Analysis and Prevention, 41, 1206–1215.
Landucci G., Necci A., Antonioni G., Argenti F., Cozzani V., 2017, Risk assessment of mitigated domino scenarios in process facilities. Reliability Engineering and System Safety, 160, 37-53.
Mudan K.S., 1987, Geometric view factors for thermal radiation hazard assessment. Fire Safety Journal, 12, 89-96.
Ricci F., Casson Moreno V., Cozzani V., 2021a, A comprehensive analysis of the occurrence of Natech events in the process industry. Process Safety and Environmental Protection, 147, 703-713.
Ricci F., Scarponi G.E., Pastor E, Planas E., Cozzani V., 2021b, Safety distances for storage tanks to prevent fire damage in Wildland-Industrial Interface. Process Safety and Environmental Protection, 147, 693–702.
Ricci F., Scarponi G.E., Pastor E., Munoz J.A., Planas E., Cozzani V., 2021c, Vulnerability of Industrial Storage Tanks to Wildfire: a Case Study, Chemical Engineering Transaction, 86, 235-240.
Sutton I., 2017a, Chapter 1 – Safety in Design, in Plant Design and Operations (Second Edition), Gulf Professional Publishing, Pages 1-34.
Sutton I., 2017b, Chapter 12 - Firefighting, in Plant Design and Operations (Second Edition), Gulf Professional Publishing, Pages 353-379.
Wigtil G., Hammer R.B., Kline J.D., Mockrin M.H., Stewart S.I., Roper D., Radeloff V.C., 2016, Places where wildfire potential and social vulnerability coincide in the coterminous United States. International Journal of Wildland Fire 25, 896–908.
Zárate L., Arnaldos J., Casal J., 2008, Establishing safety distances for wildland fires. Fire Safety Journal, 43, 565–575.