Fire zoning for PSV sizing and depressurization for process systems

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Fire zoning for PSV sizing and depressurisation during a fire has been briefly explained in API 521. This standard is referring to a height of 7.6m from a sustained pool level which is used as the basis for calculation of wetted area for equipment containing flammable liquid and exposed surface area for equipment containing flammable gas. API 521 states that it is necessary only to size relief devices on the basis of the averaged heat input up to 7.6 m above the base of a pool fire.

Also, this standard for combined relief loads in fire case addresses a fire envelope size of 230m2 to 460m2 which is about 8.5 to 12.5m radius from equipment containing flammable substances which is exposed to fire.

Furthermore for PSV sizing and depressurisation, the standard only focuses on pool fires and disregard jet fires from these calculations due to the impact of an impinging jet fire.

This paper provides overviews for heat radiation envelopes for different types of fires with special focus on jet fires by means of different case studies. This paper explains why fire zoning studies shall be performed for different fire scenarios for PSV sizing and depressurisation system design and it provides reasons for the impact of jet fires heat radiation and its importance in these calculations.

Introduction

API 521 is addressing a generic size for fire zoning around equipment which is exposed to a fire. The size of this fire envelope in API 521 has been specified about 12.5 horizontally and 7.6m vertically from a sustained pool level. This size has an important impact on sizing of PSVs or depressurisation systems in fire scenarios. Process engineers normally use this data for calculation of generated vapour inside systems if the wetted parts of process systems containing liquid hydrocarbons have been located horizontally and vertically in this fire envelope. Identically the same size of fire envelope is applied for systems containing hydrocarbon gas which are leading to hydrocarbons gas expansion.

The purpose of this paper is to high light the back ground information regarding the provided size of fire envelope by API 521 and to explain the limitations of the provided information. This paper also addresses the importance of the following factors in fire zoning and how these need to be considered in a fire zoning assessment.

- Type and size of a fire based on a hydrocarbon content and process conditions
- Distinguishing between pool fire scenarios and jet fire scenarios in fire zoning
- And Importance of jet fires heat radiation in gas production facilities for sizing of PSVs and depressurization systems

This paper has been divided in two sections. Section A focuses on fire zoning for PSV sizing and section B provides methodology for fire zoning for depressurisation.

Section A: Fire zoning for PSV sizing for fire scenarios

According to Section 4.4.13.2.2 of API 521 only those sections of equipment within 7.6m from a sustained pool fire level are used for relief load calculations. This standard explains that hydrocarbon fires can exceed a height of 7.6m but, based on experience, using this height is adequate for calculations.

The rate of the generated vapour in a fire case is calculated by dividing absorbed heat value by the latent heat of a flammable content in a system containing a flammable liquid. This method of calculation in API 521 is named as empirical method.

Absorbed heat equation has been correlated based on some experiments from open pool fires and their impact on the tank surfaces containing liquid contents as listed in Table A.1 of API 521. The maximum heat input for this correlation has been addressed around 96 to 100kW/m2.

In some other cases if vessels or systems are containing only flammable gas, the volume of expanded gas is calculated based on the exposed area within the 7.6m from the sustained pool level.

API 521 is addressing another method for heat adsorption in Section A.3.2 and introduces that as analytical method which is included with radiated and convected heat. This calculated heat is used for depressurization calculations.

The analytical methodology is applicable for pool and jet fires for averaged heat flux for pressure increase calculations in the systems or local heat flux for material strength calculations. If an equipment or surface is just exposed to a heat radiation and it is not engulfed in a fire; the difference between the radiated heat from a fire and reflected heat from equipment surface is used in calculations without any convected heat contribution.

The addressed figures for fire envelope size in API 521 seem very optimistic for high pressure systems containing hydrocarbons and as well as some pool fires. Now there are some fundamental questions that need to be answered:

- Can 7.6m vertically and 12.5 m horizontally be generalised for all type of fires and variety of the flammable substances?
- Is it realistic to ignore jet fire heat radiation from these calculations? (This point is not addressing a direct impinging jet fire. It is addressing an indirect heat radiation from a flame which can impact systems when the heat flux is considerable enough to cause an overpressure inside a system)
- Where are the borders for application of empirical method and analytical method? Which one of those shall be applied in the calculations? Is there any better way to make justification for the heat radiation calculations and its application in vapour generation calculations?

In order to answer all these questions, some realistic industrial cases from gas facilities with high pressure systems have been selected for this purpose. The heat radiation studies for these cases have been performed to indicate what real fire scenarios can be expected due to liquid or gas leaks from the systems and how the associated results can be implemented in PSV sizing and depressurization load calculations. These case studies and their corresponding process conditions have been addressed in Table 1 within this paper.

For these studies, a 25 mm leak scenario as the most credible scenario has been selected. This selection has been done with reference to industrial frequency records for different leak sizes leading to reasonable size consequences.

The fire scenario modelling for these studies were carried out using Phast 7.2.

The listed case studies have been selected from upstream and downstream of hydrocarbon facilities. The modelling has been performed with some simplifications in process streams by means of considering pure or combined components as follows:

1. Case 1; 100% of methane
2. Case 2; 90% propane and 10% butane
3. Case 3; 100% butane
4. Case 4; 100% octane

The same process conditions have been applied for all above cases to compare the results with respect to type of substances in fire modelling.

In gas processing facilities methane is normally in a gas phase and its leakage from systems in the presence of an ignition source will lead to a jet fire. The propane and butane are normally processed or stored in high pressure conditions and can be present in systems in form of gas and liquid. During a leak from a 25mm hole, propane and butane will be discharged to the atmosphere and at atmospheric pressure any liquid will vaporise. These components, during discharge to the atmosphere in presence of an ignition source, will lead to a jet fire. Therefore it is not a realistic approach to design PSVs and depressurization systems based on pool fires in gas facilities where there is no or low possibility of pool fires.

Heavier hydrocarbons, such as normal octane, when it is discharged from a 25 mm hole will remain in liquid phase and it will lead to either a liquid jet fire or a pool fire.

The results of jet fire modelling including discharge rate, discharge phase, and different heat radiation levels have been addressed in Table 1; corresponding heat radiation graphs are provided in Figures 1 through 8.

Table 1: Fire heat radiation modelling results for cases 1 to 4

Case no.	**Composition mole fraction/ weight fraction**	**Pressure bar(g)**	**Scenario**	**Temperature ©**	**Operation or storage phase**	**Release phase 25mm**	**Discharge flow rate (kg/s)**	**Horizontal jet fire**			**Vertical jet fire**		
								Heat radiation kW/m2					
								200-250	**150 -180**	**100**	**200-250**	**150 -180**	**100**
1	100% Methane	16	25mm	45	**Gas**	**Gas**	1.2	NP	NP	15	NP	10	11
2	n-C3 90% n-C4 10%	16	25mm	45	**Liq**	**Gas**	12	51	52	53	NP	30	33
3	n-C4 100%	16	25m m	45	**Liq**	**Gas**	12.8	56	56	57	NP	31	34
4	C8 100%	16	25mm	45	**Liq**	**Liq**	14.83	39	41	43	20	20	21

Note: Liq= Liquid NP: Not provided by the software

Fig 1- Case 1 Horizontal jet fire heat radiation graphs

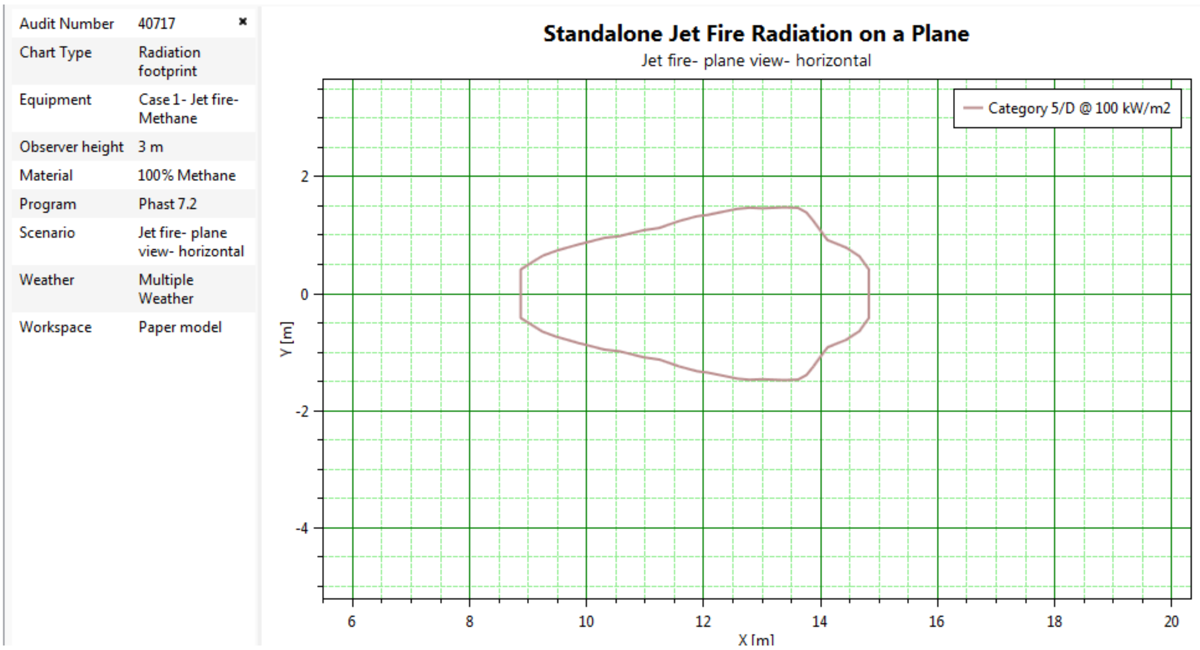


Fig 2- Case 1 Vertical jet fire heat radiation graphs

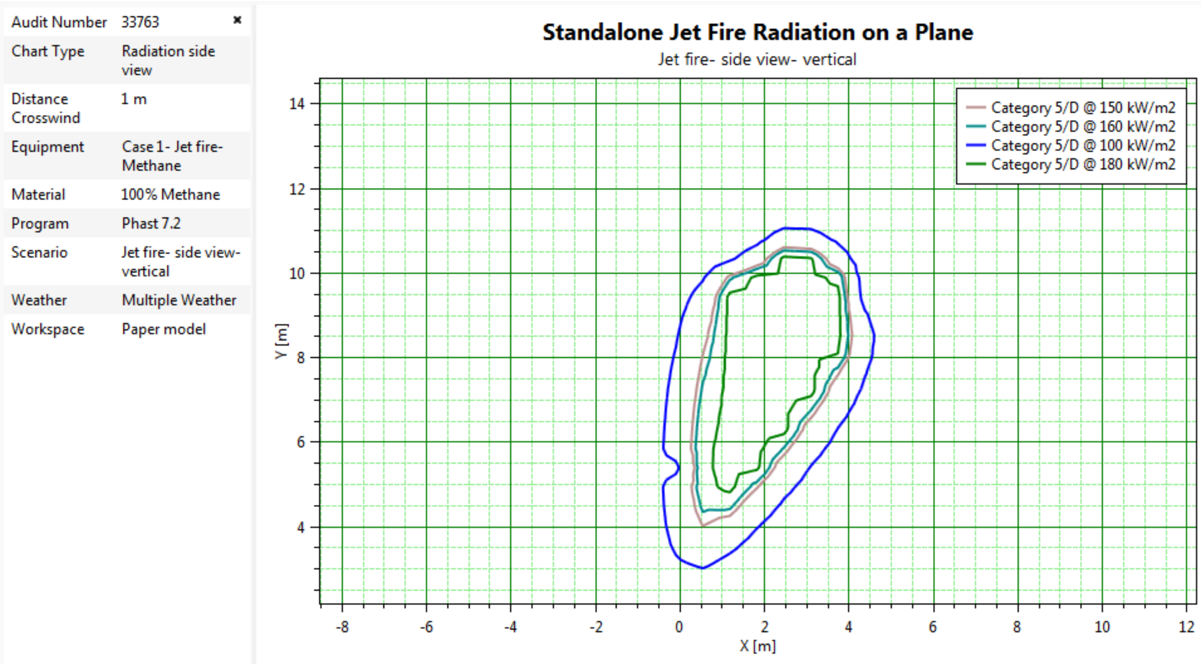


Fig 3- Case 2 Horizontal jet fire heat radiation graphs

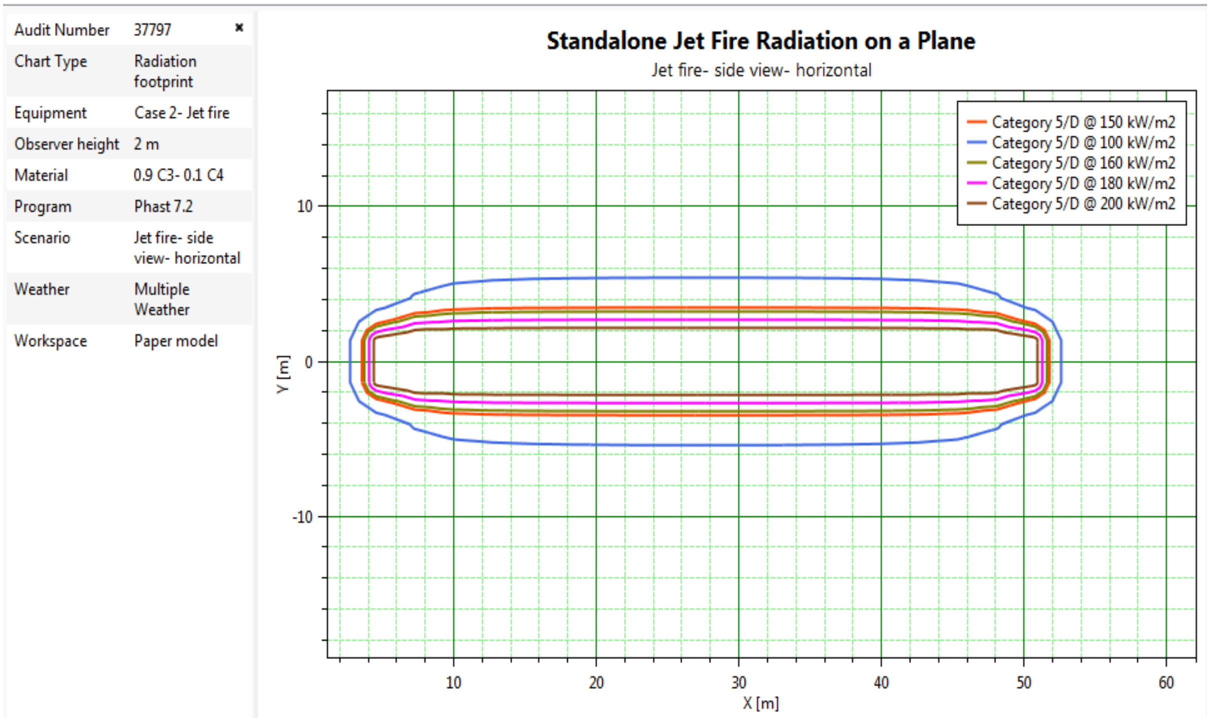


Fig 4- Case 2 Vertical jet fire heat radiation graphs

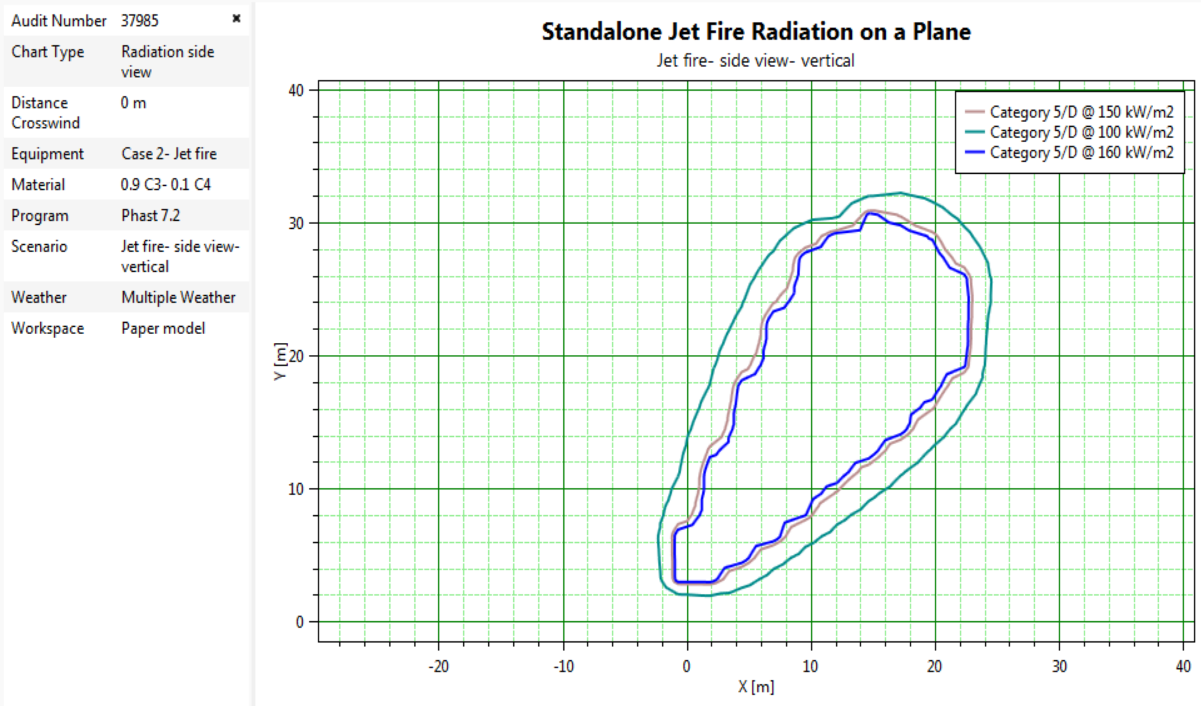


Fig 5- Case 3 Horizontal jet fire heat radiation graphs

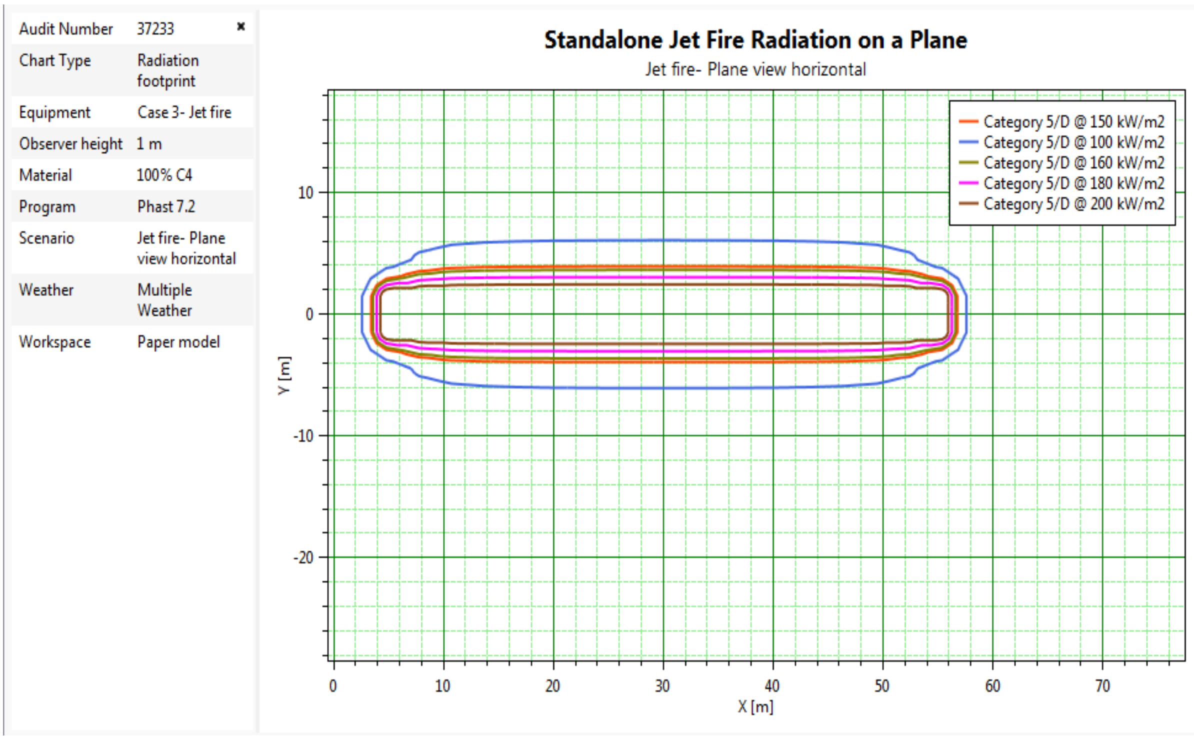


Fig 6- Case 3 Vertical jet fire heat radiation graphs

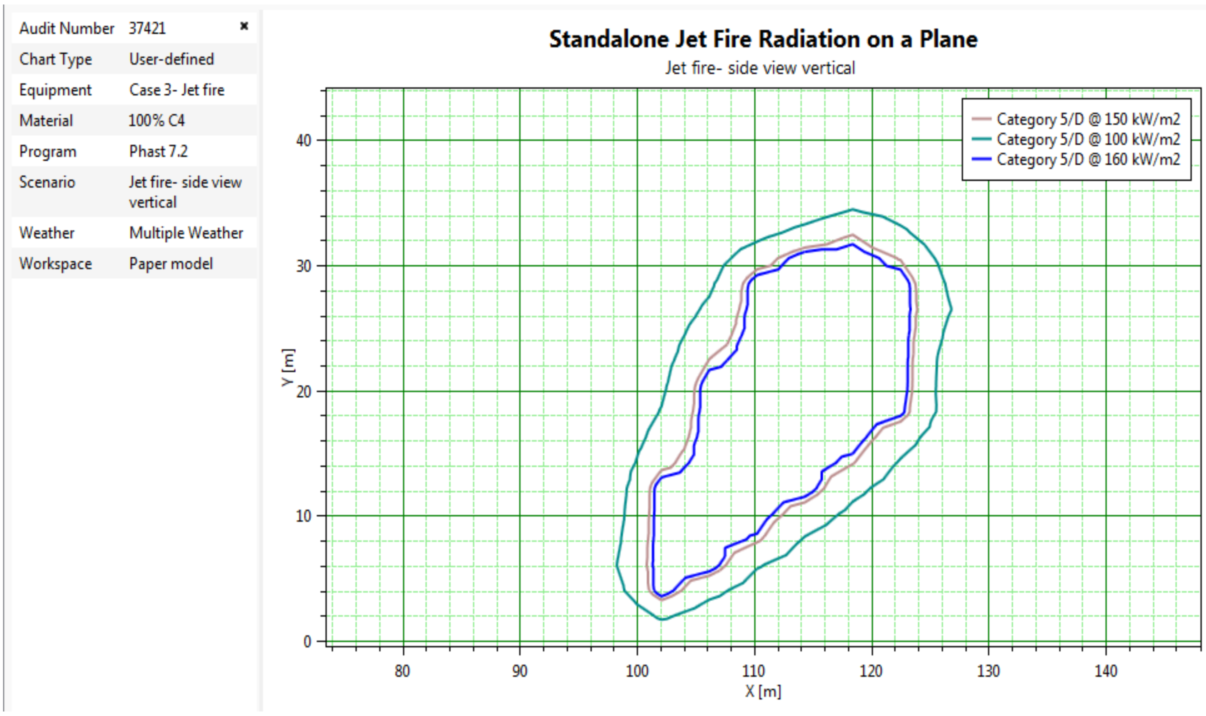


Fig 7- Case 4 Horizontal jet fire heat radiation graphs

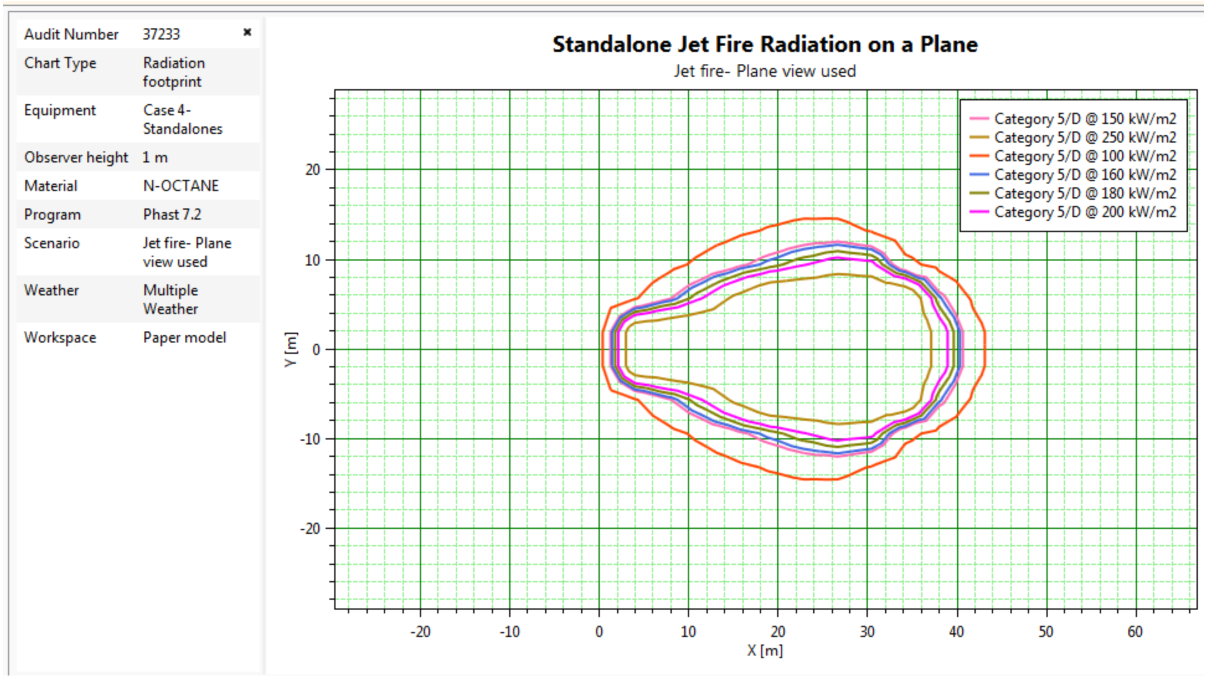
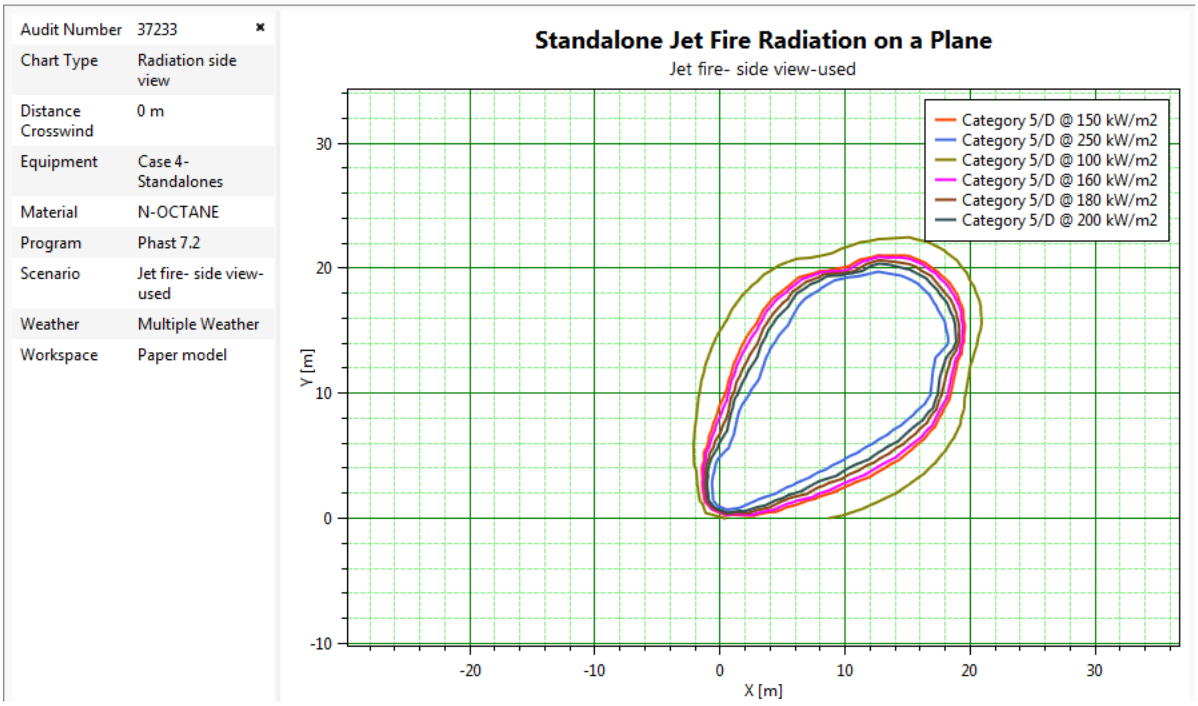


Fig 8- Case 4 Vertical jet fire heat radiation graphs



As it is obvious the direction of a jet fire can vary due to a flange orientation, wind speed and wind direction. The studies were carried out for jet fires horizontally and vertically to show the extent of heat radiation in both directions. The reported results are associated with wind weather condition of 5D in which the heat radiation contours in horizontal and vertical directions are seen in reasonable sizes.

The results of the first case study indicate that the highest heat radiation levels are seen in the range of 100 to 180 kW/m2 with 11m height in vertical direction and 15m radius in horizontal direction. The comparison between API 521 zoning figures (7.6m vertical and 12.5 horizontal) and the modelling results for 100 kW/m2 shows 3.4m and 2.5m difference in fire envelope size in vertical and horizontal directions.

This difference for heavier hydrocarbons than air such as propane, butane and octane is even more. For instance for case 3 with 100% of butane; the heat radiation size for 100 kW/m2 is about 57m and 34m in horizontal and vertical directions respectively.

As it is obvious traditional empirical method for PSV sizing cannot be generically applied for all kinds of fires and all kinds of flammable substances and process conditions. As mentioned before this equation has been correlated for maximum heat radiation level of 100 kW/m2 and normally it is used for fire zone sizes as described in API 521 which is associated with sustained pool level.

Above case studies indicate that the extent of a jet fire heat radiation can be quite big and cannot be neglected or interpreted as a pool fire in the calculations. When equipment is exposed to heat radiation originated from a jet fire, this heat radiation similarly to pool fires needs to be incorporated in PSV sizing calculations if the duration of fire is reasonable.

In order to have a better understanding about amount of absorbed heat in different heat radiation levels and temperatures, some simplified calculations based on analytical method have been performed. The results of these calculations have been presented in Table 2. These calculations have been performed based on constant initial surface temperature.

Table 2- Absorbed heat in a vessel or system in different fire heat radiation levels

Fire heat radiation reaching vessel (kW/m2)	**Associated temperature with fire heat radiation reaching the vessel (Kelvin)**	**Initial external surface temperature of the vessel (Kelvin)**	**Absorbed heat at equipment kW/m2**
350	1576	298	280
300	1517	298	240
250	1449	298	200

Fire heat radiation reaching vessel (kW/m2)	Associated temperature with fire heat radiation reaching the vessel (Kelvin)	Initial external surface temperature of the vessel (Kelvin)	Absorbed heat at equipment kW/m2
200	1370	298	160
170	1316	298	136
150	1275	298	120
140	1254	298	112
130	1231	298	104
120	1206	298	96
100	1152	298	80
80	1090	298	64
60	1014	298	48
45	944	298	36
37	899	298	29
15	717	298	12
9	631	298	7
6.3	577	298	5
4.7	537	298	3

Note: The data presented in table 2 might not be generalised for all type of hydrocarbon fires

As the calculation results indicate, if the heat radiation is about 150kW/m2; the absorbed heat is about 120 kW/m2 when the fire temperature at the equipment surface and initial equipment surface temperature are respectively 1275 K and 298 K.

However, the main focus of this paper is on the jet fires but it is worth mentioning that, not all pool fires will necessarily lead to the same fire envelope size as addressed in API 521. For the design of depressurisation systems and PSV sizing in case of fire; the following items as the starting points shall be investigated:

- Exposed equipment to pool fires
- Exposed equipment to jet fires heat radiation

Process safety engineers need to perform fire modelling by means of a fire hazard scenario assessment in a process facility. If the results of the assessment indicate that equipment is exposed to a pool fire or a jet fire not exceeding 100kW/m2, the same empirical method as before can be applied for the calculations. Also the fire zoning and required assessment shall be carried out in parallel and the results shall be provided to the related process team.

If the results of the assessment indicate higher level of heat radiation than 100 kW/m2, at the equipment surface, then the analytical method shall be applied. Also the size of the heat radiation contour or size of the fire heat radiation envelope shall be assessed and the process team informed.

For the duration of a fire the following aspects need to be evaluated by process safety engineers:

- Adequate numbers, correct types and the best locations of fire detection and related annunciation systems
- Fire detection and annunciation systems reliability and availability,
- Availability of adequate firefighting means
- Human factor aspects that improves operators' capabilities in realisation and decision making for staged depressurization,
- Depressurisation period and remaining inventory inside the system after shutdown and depressurisation time

Section B: Fire zoning for depressurisation

Normally segregation of a process unit to different fire zones for the purpose of depressurisation is complicated. In circumstances that there is a capacity in a depressurisation network, the blow down load is defined for the entire process unit and therefore that takes place in the same sequence. In this case a process unit is defined as one fire zone. Whereas there might be some cases that depressurisation network does not support an entire unit's depressurisation capacity. In this case fire zoning will play a very critical role in the calculations and staged depressurisation strategy.

Fire zoning for a unit depressurisation case is normally carried out for equipment containing flammable substances. Process engineers normally follow the suggested generic fire zoning sizes by API 521 for any type of fire which is according to the Section 5.3.2 of API521.

The maximum surface area of 460 m^2 as the fire zone size is normally used by process engineers for identification of simultaneous discharging of PSVs or depressurisation of process isolation blocks in a fire case.

For this purpose, process engineers mark up a fire zone around equipment about 12.5m horizontally and 7.6 m vertically from a sustaining pool level regardless of the type and size of a fire. In a process facility, equipment is normally located densely and in close proximity to each other either horizontally or vertically. In such cases it is very common that these individual fire zones overlap with each other and this leads to a bigger fire zone beyond an isolation block. Therefore in such cases the overlapped fire zones are treated as the related fire envelope for that particular section of a facility for depressurization calculations.

As mentioned in Section A, the radius and height of a fire zone is strongly related to type of a fire, containment of a process system and process conditions. Application of suggested generic size for a fire by API 521 due the introduced facts and study results can be an unrealistic simplification in the calculations and that may lead to an underestimated depressurization network design.

Therefore process safety engineers are responsible for providing precise information for size of fire zoning by fire modelling studies. The results of these studies as the size of fire envelope and the level of heat radiation at the equipment external surface shall be provided to process teams for depressurisation load calculations and corresponding network sizing.

Conclusions

Fire zoning for PSV sizing and depressurization system calculations in a fire scenario is very critical. API 521 addresses the size of a fire zone in vertical and horizontal directions as 7.6m and 12.5m respectively. These numbers are regardless of level of the heat radiation from a specific fire at the surface of equipment. These distances are normally used by process engineers in the depressurization systems calculations. It seems that these numbers are associated with maximum heat radiation level of 100 kW/m2 as it has been addressed in Table A.1 in API 521.

The level of heat radiation and the size of a fire envelope vertically and horizontally strongly depend on the type of a flammable substance, size of a leak, process conditions inside a system, amount of an inventory, and wind weather conditions.

The case studies' results which have been provided in this paper indicate that the vertical and horizontal size of a fire envelope as 7.6m and 12.5m is very optimistic and cannot be applied generically for PSV and depressurization systems sizing. For instance as it has been presented in this paper, the height and radius of a fire envelope for a system containing butane with a 25mm leak size, 16 barg and 45 C is leading to a 100 kW/m2 of heat radiation at 35m height and 57m radius if the fire is modelled vertically and horizontally. Also this substance will lead to higher heat radiation intensities than 100 kW/m2 in closer points to the fire origin.

API 521 is providing two types of methodologies; one empirical and the other as analytical. The empirical equation is associated with maximum heat radiation level of 100 kW/m2. In reality the level of heat radiation can be much higher than 100 kW/m2 and application of empirical method cannot lead to precise results as expected. API 521 has also presented analytical method that needs to be applied for the calculations of absorbed heat when the level of heat radiation is higher than 100 kW/m2.

Therefore process safety engineers shall perform fire assessment studies in process facilities to address the type of fires which can be either jet fire or pool fire and address the size of the associated fire zones. The results of these assessments will provide accurate information to process engineers for PSV sizing and depressurization system design.

Abbreviations

API American Petroleum Institute

PSV Pressure Safety Valve

References

API 521 "Pressure-relieving and Depressuring Systems" Sixth Edition, January 2014