Fire Consequence Modelling – A comparison of the results from PHAST and KFX

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Fire consequence modelling is routinely performed as part of safety studies for onshore and offshore installations in the oil and gas industry. While PHAST software is commonly used for this purpose, the use of KFX software has increased considerably in recent times to provide better accuracy in the results. KFX uses Computational Fluid Dynamics (CFD) techniques for modelling the flow field, flame front and thermal radiation levels leading to a higher degree of accuracy in the results but is more expensive in terms of the time and hardware resource requirement. PHAST on the other hand employs empirical formulae and curve fitting techniques for fire modelling resulting in shorter timescales at the cost of accuracy.

The objective of this paper is to study the difference between PHAST and KFX in jet fire modelling, evaluate the potential impact on safety studies, and identify a correlation between the results obtained from both these software. Such correlations could then be used to scale the results obtained from PHAST for any facility.

In the current work, horizontal releases of methane were modelled for four different hole sizes (10 mm, 25 mm, 50 mm and 75 mm) and four different pressures (10 barg, 30 barg, 60 barg and 90 barg). The jet fire consequence results obtained by PHAST and KFX were extracted for three different thermal radiation levels corresponding to the damage criteria suggested by CCPS and UK HSE namely, 37.5 kW/m^2, 12.5 kW/m^2 and 5 kW/m^2. These thermal radiation contours obtained from both the software were compared in terms of the maximum downwind distance and crosswind distance. Some suggestions are made on how the PHAST results may be interpreted and used in the industry.

Keywords: Fire Consequence Modelling, Jet Fire, KFX, PHAST, Correlations

Introduction

Fire consequence modelling is routinely performed as part of safety studies for onshore and offshore installations in the oil and gas industry. The end result of this modelling is to obtain thermal radiation levels at various structural receptors, safety critical elements and escape routes in the facility. While DNVGL's commercially available PHAST software is commonly used for this purpose, the use of KFX software by ComputIT has increased considerably in recent times to provide better accuracy in the results. KFX uses Computational Fluid Dynamics (CFD) techniques to model the flow field, flame front and thermal radiation levels leading to a higher degree of accuracy in the results but is more expensive in terms of the time and hardware resource requirement. KFX can also model flame deflection due to obstructions which PHAST cannot model. PHAST on the other hand employs empirical formulae and curve fitting techniques for fire modelling resulting in shorter timescales at the cost of accuracy (DNV, 2010) (ComputIT, 2014).

The objective of this paper is to study the difference between PHAST and KFX in jet fire modelling, evaluate the potential impact on safety studies, identify a correlation between the results obtained from both these software and hence design a future course of action by making it possible to use the best of both tools. The end objective is to improve accuracy in fire modelling results at the short timescales that are obtained using PHAST.

Scenarios Assessed

In the current work, jet fires for horizontal releases of pure methane gas were modelled for four different hole sizes (10 mm, 25 mm, 50 mm and 75 mm) and four different pressures (10 barg, 30 barg, 60 barg and 90 barg) at a wind speed of 2m/s blowing towards the same direction as that of the jet fire. Table 1 presents the release rates obtained for various combinations of hole sizes and operating pressures. The jet fire modelling in PHAST is performed using the Johnson correlation (Johnson, 1994). The jet fire modelling in KFX was performed in an open terrain assuming no geometric obstruction to the fire to ensure the results are comparable with those obtained using PHAST. The jet fire consequence results obtained by PHAST and KFX were extracted for three different thermal radiation levels namely, 37.5 kW/m^2, 12.5 kW/m^2 and 5 kW/m^2 that correspond to 99%, 50% and 1% lethality levels (with 20 seconds exposure time) respectively as suggested by CCPS and UK HSE (CCPS, 2000) (HSE, 2016). It is worth noting that the radiation levels for escalation i.e. structural failure, is 15 kW/m^2. Although a comparison of the results at 15 kW/m^2 has not been carried out at this stage, the findings related to 12.5 kW/m^2 can be used as an indicator of the 15 kW/m^2 results. The thermal radiation contours of 37.5 kW/m^2, 12.5 kW/m^2 and 5 kW/m^2 obtained from both the software were compared in terms of their maximum downwind distance and maximum crosswind distance. Maximum downwind distance is defined as the longest possible distance between the release location and relevant radiation contour along the direction of the release. Maximum crosswind distance is defined as the longest possible distance between the centreline of the jet fire and relevant radiation contour in a direction perpendicular to that of the release.

Table 1. Release Rates for various combinations of Hole Sizes and Operating Pressures.

Hole Size (mm)	Release Rates (kg/s) for Different Operating Pressures			
	10 barg	**30 barg**	**60 barg**	**90 barg**
10	0.13	0.37	0.76	1.17
25	0.80	2.33	4.73	7.29
50	3.21	9.30	18.93	29.15
75	7.22	20.93	42.58	65.60

Results and Discussion

Maximum Thermal Radiation Level

The maximum thermal radiation level obtained in KFX and PHAST results were found to be different, with PHAST results being lower than those obtained using KFX in almost all the cases as shown in Table 2. For example, a jet fire following a horizontal release from a 10mm hole size at 10 barg operating pressure does produce thermal radiation contours of 12.5 kW/m^2 extending up to 4.9m based on the CFD results in KFX. But PHAST predicts that such a scenario will not have any 12.5kw/m^2 radiation contour.

Thermal radiation levels are used to determine the lethality of a consequence and the availability of safety critical elements such as escape routes, life boats, etc. during an incident. Since this trend of PHAST under-predicting the maximum thermal radiation is observed for release hole sizes as small as pinhole sizes, which generally have the highest leak frequencies, the overall risk picture of a facility can be underestimated if the Fire Risk Analysis is performed using only PHAST.

Table 2. Comparison of KFX and PHAST Results for different Thermal Radiation Levels following a Horizontal Jet Fire from 10 mm Hole Size and 2m/s Wind Speed.

Process Operating Pressure (barg)	Release Rate (kg/s)	Thermal Radiation Level (kW/m^2)	KFX Results		PHAST Results	
			Maximum Downwind Distance (m)	**Maximum Crosswind Distance (m)**	**Maximum Downwind Distance (m)**	**Maximum Crosswind Distance (m)**
10	0.13	37.5	0.0	0.0	0.0	0.0
10	0.13	12.5	4.9	2.3	0.0	0.0
10	0.13	5.0	6.4	3.2	2.3	1.7
30	0.37	37.5	6.5	1.8	7.5	0.5
30	0.37	12.5	9.3	3.7	8.5	1.9
30	0.37	5.0	16.6	11.7	9.5	3.9
60	0.76	37.5	9.3	3.2	10.5	1.2
60	0.76	12.5	14.0	9.4	12.2	3.7
60	0.76	5.0	22.8	14.6	13.9	6.6
90	1.17	37.5	11.8	4.2	12.9	1.9
90	1.17	12.5	16.0	11.7	15.2	5.2
90	1.17	5.0	26.2	16.0	17.5	9.0

Maximum Downwind Distance

Each hole size modelled is associated with a particular release rate depending upon the operating pressure and the hydrocarbon material. The variation in maximum downwind distance as a function of release rate obtained using both KFX and PHAST, is shown in Figure 1, 2 and 3 for all 3 radiation levels 37.5 kW/m^2, 12.5 kW/m^2 and 5 kW/m^2 respectively. Naturally, the maximum downwind distance will increase with an increase in the release rate. However, the important point to note is that the KFX and PHAST results are comparable with each other and a curve fit for each of these set of results leads to nearly parallel curves with the KFX result generally being more conservative.

Figure 1. Comparison of KFX and PHAST Results for Maximum Downwind Distance obtained for Thermal Radiation Contour of 37.5 kW/m^2.

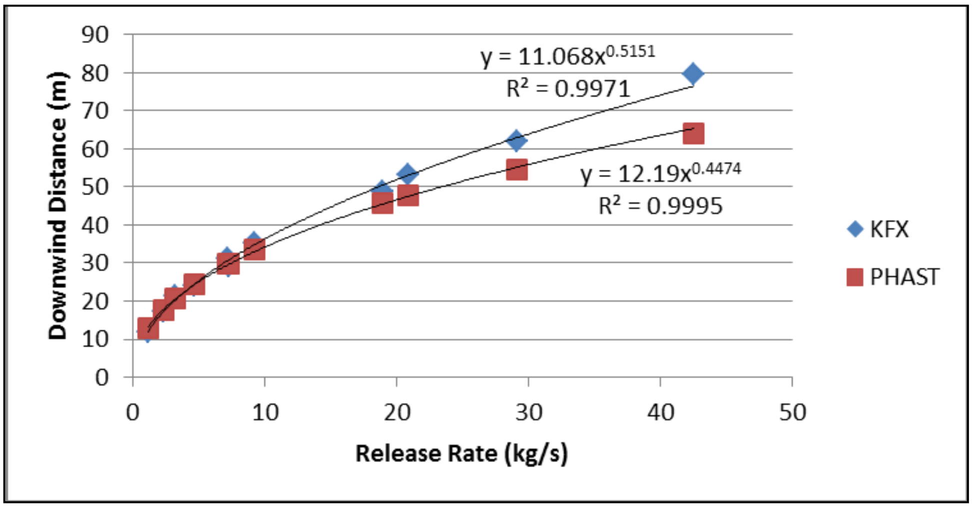


Figure 2. Comparison of KFX and PHAST Results for Maximum Downwind Distance obtained for Thermal Radiation Contour of 12.5 kW/m^2.

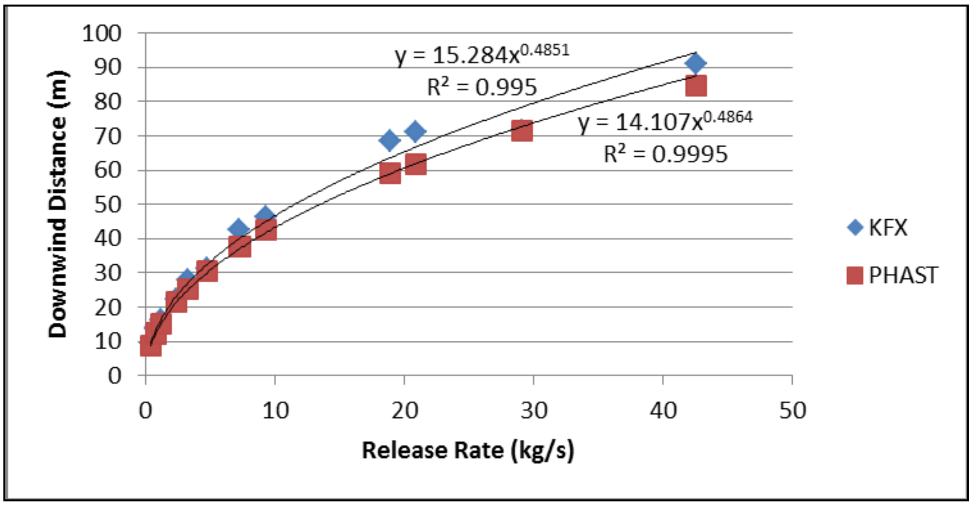
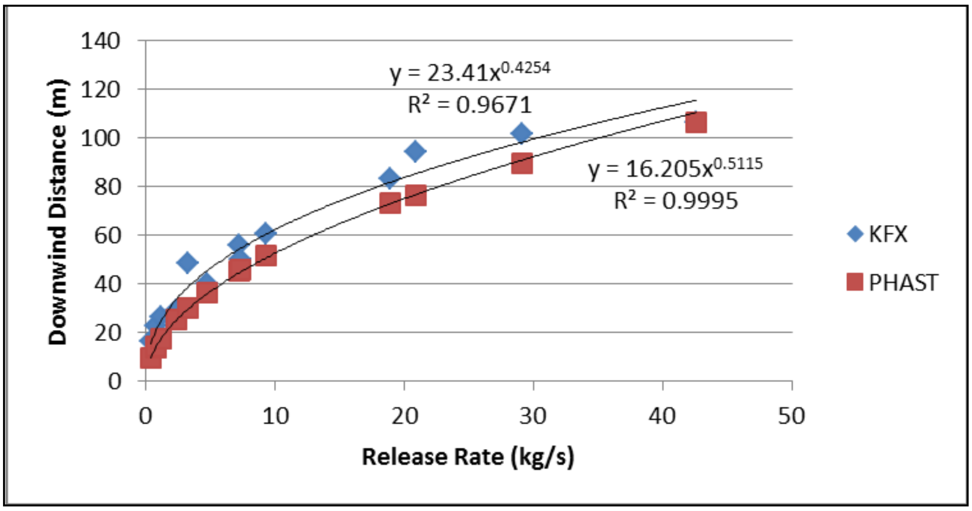


Figure 3. Comparison of KFX and PHAST Results for Maximum Downwind Distance obtained for Thermal Radiation Contour of 5 kW/m^2.



The relationship between maximum downwind distance (y) and release rate (x) can be approximated using the general equation (1), for both KFX and PHAST for different radiation levels as shown in Figure 4, 5 and 6 respectively. By fitting the result to this equation, the correlation factor 'A' can be obtained for different radiation levels with excellent coefficient of determination (R-square) values ranging from 0.967 to 0.999 as observed in Figure 4, 5 and 6. Since the generalised version of the equation is same for both KFX and PHAST results, it is possible to compare their correlation factors. The ratio of the correlation factors from KFX and PHAST could be called as a Scaling Factor. The idea is that this scaling factor when multiplied to the PHAST results would lead to the results that would more or less be obtained if CFD simulations had been performed instead of using PHAST. The scaled PHAST results would lead to a greater accuracy (similar to those of CFD results) while keeping the computational time short (similar to those obtained by PHAST). Table 3 shows the scaling factors obtained for different thermal radiation levels, which is in the range of 8-19%. The PHAST manual states that for horizontal vapour phase releases, the Jet Fire Johnson model predicts flame lengths to within 10% of the available field data (DNV, 2010). The maximum downwind distance for any thermal radiation contour level from a horizontal vapour phase release will be directly proportional to the predicted flame length. Hence the scaling factor range obtained is deemed to be in-line with the expectation from the Jet Fire Johnson model used in PHAST.

However, the scaling factor determined here is only applicable to the scenarios assessed here and cannot be generalised to all jet fire results from PHAST. Although the scaling factor appears to be independent of the release rate, it could be dependent on the wind speed, wind direction, jet fire direction (horizontal / vertical). This needs to be tested further in future studies.

$$y = Ax^{0.5} \qquad \text{Equation (1)}$$

Figure 4. Correlation between KFX and PHAST Results for Maximum Downwind Distance obtained for Thermal Radiation Contour of 37.5 kW/m^2.

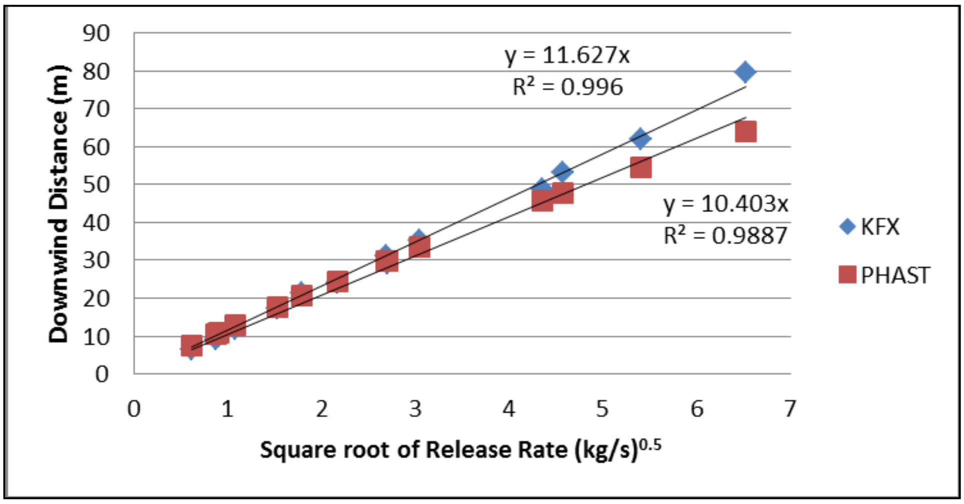


Figure 5. Correlation between KFX and PHAST Results for Maximum Downwind Distance obtained for Thermal Radiation Contour of 12.5 kW/m^2.

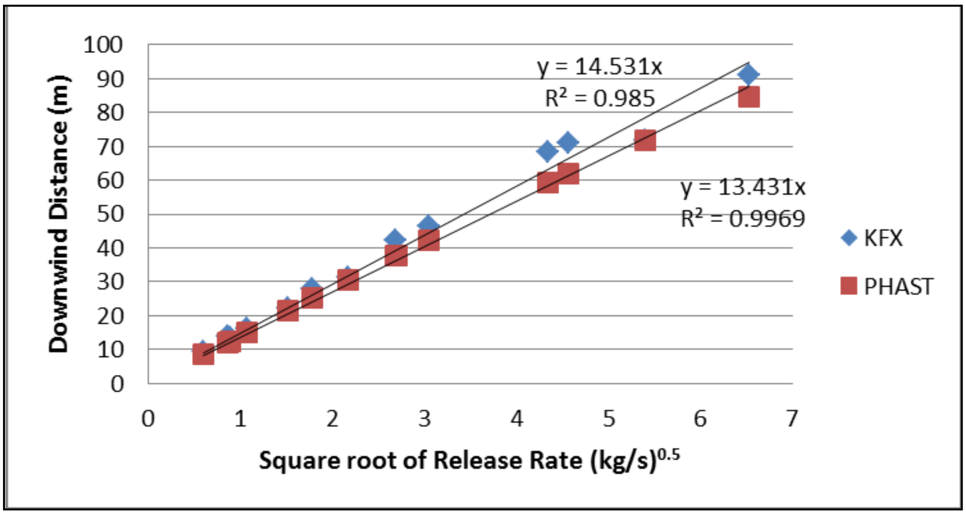


Figure 6. Correlation between KFX and PHAST Results for Maximum Downwind Distance obtained for Thermal Radiation Contour of 5 kW/m^2.

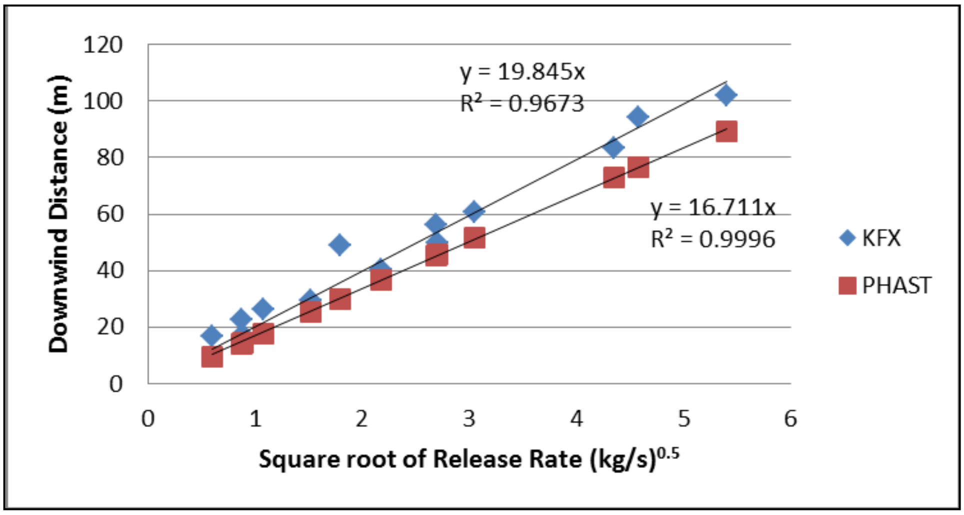


Table 3. Scaling Factor of Maximum Downwind Distance for PHAST Results obtained at 2m/s Wind Speed.

Thermal Radiation (kW/m^2)	A_{PHAST}	A_{KFX}	Scaling Factor for Maximum Downwind Distance $N_{downwind} = A_{KFX} / A_{PHAST}$
37.5	10.40	11.63	1.12
12.5	13.43	14.53	1.08
5	16.71	19.85	1.19

Maximum Crosswind Distance

The analysis performed for the variation in maximum downwind distance was repeated for maximum crosswind distance obtained for different levels of thermal radiation from the jet fire. Similar to the findings for maximum downwind distance, the maximum crosswind distances obtained using KFX and PHAST were found to be different, with PHAST results being consistently lower than those obtained using KFX. The relationship between maximum crosswind distance (y) and release rate (x) can be approximated using equation (1) for both KFX and PHAST for different radiation levels as shown in Figure 7, 8 and 9 respectively. By fitting the result to this equation, the correlation factor 'A' was obtained for different radiation levels with excellent coefficient of determination (R-square) values ranging from 0.968 to 0.991 as observed in Figure 7, 8 and 9.

The scaling factor obtained for maximum crosswind distance is however, quite different from that obtained for maximum downwind distance. Table 4 shows the maximum crosswind distance scaling factors obtained for different thermal radiation levels, which is about 40-56%. This is again in-line with the expectation from PHAST. According to PHAST technical reference manual, the predicted incident radiation over a wide range of observer locations and orientations generally lies within 40% of the field data measurements (DNV, 2010). The close match between the scaling factors obtained and the uncertainty range given in PHAST lends greater credibility to the CFD results obtained using KFX.

The high scaling factor that needs to be applied to PHAST results suggests that the flame shape and the corresponding radiation contours are narrower in PHAST when compared to those obtained using CFD in KFX. While performing safety studies such as Quantitative Risk Assessments (QRA), the coverage area of a consequence has a direct bearing on the fatality estimated from that consequence. Hence, a narrower consequence contour such as those obtained from PHAST could under-predict the risk presented in the facility when compared to a similar study performed using KFX.

The scaling factor shown here should be assumed to be valid only for single component pure gas release and not be generalised to all jet fire results from PHAST. The scaling factors could be dependent on the type of release such as liquid release and two-phase release and also on the components of a gaseous hydrocarbon mixture. It could also be dependent on the wind speed, wind direction and jet fire direction. This needs to be tested further in future studies.

Figure 7. Correlation between KFX and PHAST Results for Maximum Crosswind Distance obtained for Thermal Radiation Contour of 37.5 kW/m^2.

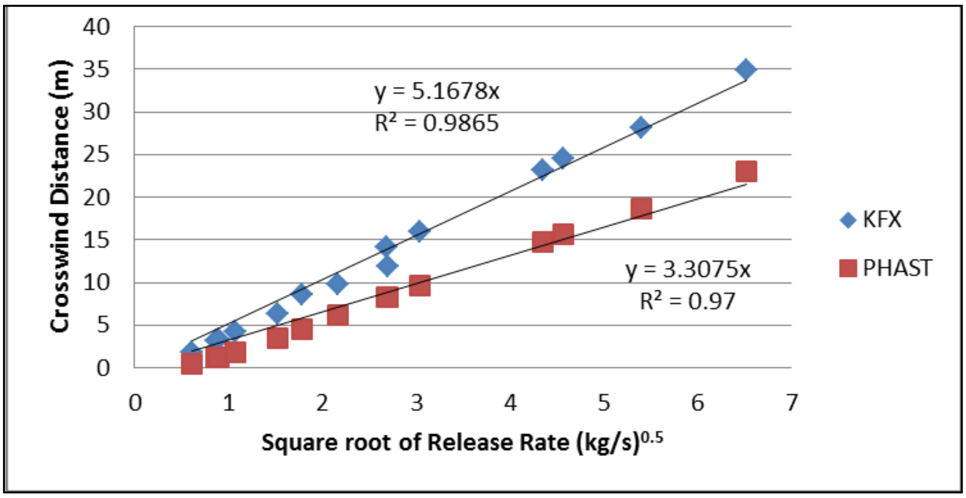


Figure 8. Correlation between KFX and PHAST Results for Maximum Crosswind Distance obtained for Thermal Radiation Contour of 12.5 kW/m^2.

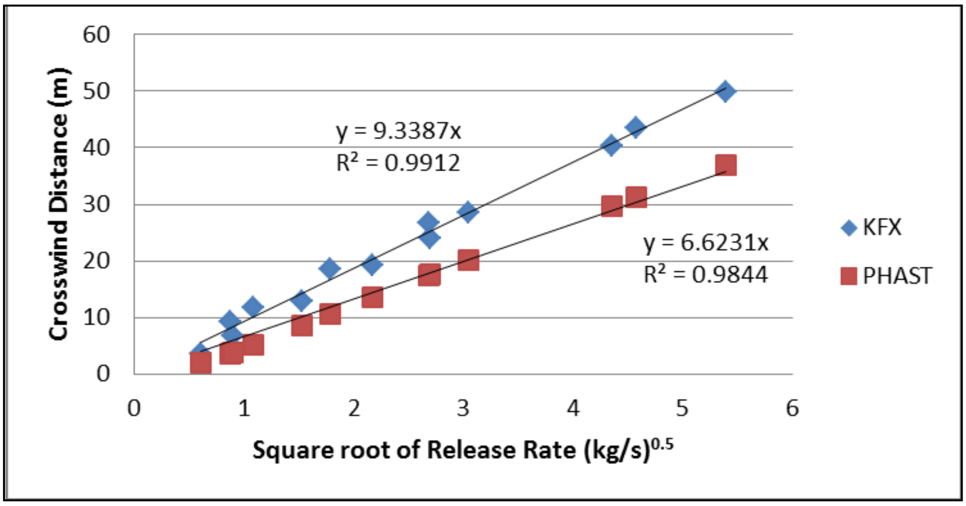


Figure 9. Correlation between KFX and PHAST Results for Maximum Crosswind Distance obtained for Thermal Radiation Contour of 5 kW/m^2.

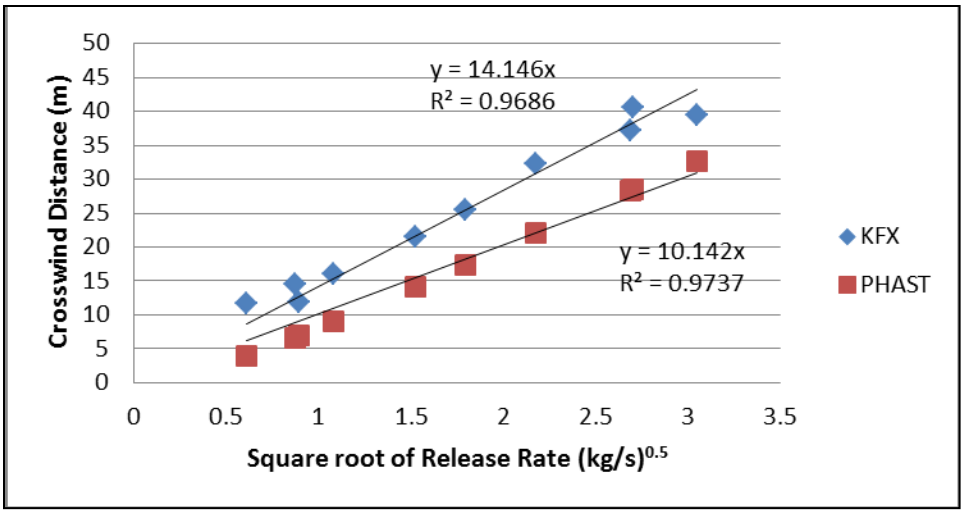


Table 4. Scaling Factor of Maximum Crosswind Distance for PHAST Results obtained at 2m/s Wind Speed.

Thermal Radiation (kW/m^2)	A_{PHAST}	A_{KFX}	Scaling Factor for Maximum Crosswind Distance $N_{crosswind} = A_{KFX} / A_{PHAST}$
37.5	3.31	5.17	1.56
12.5	6.62	9.34	1.41
5	10.14	14.15	1.40

Conclusion

Various horizontal jet fire scenarios for different hole sizes and operating pressures were assessed using two different industry standard software – empirical formulae based models such as Johnson model in PHAST and CFD based models in KFX. The results obtained for different thermal radiation levels were compared in terms of maximum downwind distance and maximum crosswind distance. Correlations were developed for these distances as a function of the release rate, for results obtained from both the software used. The comparison of these correlations helped determine the scaling factors which when multiplied to PHAST results would lead to a closer match with the KFX results. The scaled PHAST results would aid decision-making with greater confidence (such as those obtained from CFD models in KFX) whilst still maintaining the short analysis timescales that are obtained using PHAST.

It was noted that the results obtained using PHAST generally underestimated the maximum radiation level obtained compared to KFX results. This led to cases such as those of jet fires from pinhole sizes having high leak frequency, resulting in no 12.5 kW/m^2 contour (or 50% fatality level) in PHAST but the same was obtained in KFX. The Fire Risk Analysis results obtained using PHAST could hence be underestimating the risk compared to a similar analysis performed using CFD simulations in KFX.

The maximum downwind distance for different radiation levels obtained from PHAST were found to be in agreement with those obtained in KFX. A scaling up factor of around 10% if applied to PHAST results brought them closer to the KFX results. However, the maximum crosswind distance predicted by PHAST was significantly lower than the KFX results. To ensure that the PHAST results match up to those obtained using KFX, a scaling up factor of at least 40% was required to be applied on the PHAST results. However, the scaling factor determined here should be assumed as valid only for single component pure gas releases and not be generalised to all jet fire results from PHAST.

Further Study

The scaling factors obtained in this study are found to be independent of the release rate, hole size and operating pressure. However, they may be dependent on external factors such as wind speed and direction and possibly the jet fire direction (horizontal / vertical). These aspects need to be tested further to help obtain generalised scaling factors which can then be used for any facility. Also, only a single component system with methane release has been assessed in this paper; further studies need to be carried out using different materials, or even more complex releases like multicomponent releases, liquid / two-phase release, etc.

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Abbreviations

CCPS	:	Center for Chemical Process Safety
CFD	:	Computational Fluid Dynamics
KFX	:	Kameleon FireEx
HSE	:	Health and Safety Executive, UK
PHAST	:	Process Hazard Analysis Software Tool
QRA	:	Quantitative Risk Assessment