INDEPENDENT REVIEW OF SOME ASPECTS OF IP15 AREA CLASSIFICATION CODE FOR INSTALLATIONS HANDLING FLAMMABLE FLUIDS

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1. INTRODUCTION

The third edition of IP *Area classification code for installations handling flammable fluids* (IP15) was published in July 2005 and incorporated both technical clarifications and editorial amendments. It is widely used in both the upstream and downstream sectors of the petroleum industry. In addition, IP15 is regarded as a key methodology for addressing the area classification requirements of the Dangerous Substances and Explosive Atmospheres Regulations (DSEAR) 2002.

In developing the second edition of IP15, some research studies were commissioned to strengthen its evidence base; this included the research published as IP *Calculations in support of IP15: The area classification code for petroleum installations*. Further issues were identified with a weak evidence base whilst developing the third edition of IP15. These were held over to form the subject of further research conducted by DNV for the Energy Institute's Area Classification Working Group, as part of their technical work programme. The research is reported in Energy Institute (2007).

2. OBJECTIVE AND SCOPE OF WORK

The purpose of the research was to provide an independent evidence based review of some aspects of the IP15 methodology by researching the following technical issues:

1. Sensitivity effects of input parameters on dispersion characteristics.
2. Area classification for liquid pools.
3. Application of area classification methodology to LNG.

It is intended that the Energy Institute's Area Classification Working Group will restructure and update IP15 (to be rebranded EI15) during 2008, informed by the results from this study.

3. APPROACH

3.1 FLUID COMPOSITIONS

The fluid compositions as set out in IP15 Annex C were used.
The categories refer to:

Liquids	Gases
A: LPG	G(i): Natural gas
B: Hot process intermediate (e.g. crude oil flashing or gasoline above its boiling point)	G(ii): 80% Hydrogen (typical petroleum refinery hydrogen stream)
C: Straight run gasoline	

3.2 SENSITIVITY EFFECTS OF INPUT PARAMETERS ON DISPERSION CHARACTERISTICS

The previous dispersion analysis, as published in IP15 Annex C, was carried out essentially for a single set of parameters as set out in Table 1, which also sets out the parameter sensitivities analysed here.

Table 1. Parameter values used for dispersion values

Parameter	Value modelled for IP15	Range of values modelled here
Ambient temperature	30°C	–20°C, 0°C, 20°C, 40°C
Storage/process temperature	20°C	Same as ambient + Fluid Category A (LPG) at –40°
Relative humidity	70%	50%, 90%
Wind speed	2 m/s	1.5 m/s 2 m/s 5 m/s 9 m/s
Stability class	D	F D D D
Surface roughness length	0.03 m	0.1 m, 0.3 m, 1.0 m
Release direction	Horizontal	Horizontal
Release height	For R1: 5 m For R2: 1 m	For R1: 5 m For R2: 1 m
Release angle	For R_1: horizontal For R_2: unknown	For R_1: horizontal For R_2: –30°, –45°, –60°
Sample time	18.75 s	No variation
Reference height	10 m	No variation
Hazard distances	To LFL	To LFL and 0.5 LFL

Most of the parameters were initially varied singly in turn, however all four stability-windspeed combinations were modelled for the other parameter variations. The investigations were carried out for all the fluid categories listed in Section 3.1.

Dispersion was characterised by the distance to LFL measured by two different radii: R_1 represents the hazard distance for a release that does not interact with the ground; R_2 represents the hazard distance for a release that does interact with the ground. These are illustrated in IP15 Figure 5.6.

3.3 AREA CLASSIFICATION FOR LIQUID POOLS

For the liquids listed in Section 3.1 and the ambient temperatures, surface roughness lengths and weathers given in Table 1, the following parameter variations were analysed:

• Pool sizes and depths:	as set out in Table 2
• Surface types:	concrete, dry soil
• Fluid temperature:	ambient, except fluid category A: refrigerated at −40°C Fluid category C also modelled at 100°C

The spill volume has been modelled as being released instantaneously onto the ground and allowed to spread until it reaches the pool diameter shown in Table 2. Evaporation and dispersion will take place as soon as the pool starts spreading outwards.

3.4 APPLICATION OF AREA CLASSIFICATION METHODOLOGY TO LNG

LNG is largely methane but also typically includes small quantities of ethane, propane and CO_2 and sometimes other component. However, based on DNV's experience in several LNG studies, it has been modelled it as pure methane for the present study.

Typical rundown, storage and loading temperatures for LNG are in the range −170° to −160°C; therefore releases from a storage temperature of −165°C have been modelled.

Typical pressures in LNG systems range from 1.5 bar(a) to 10 bar(a); therefore these two pressures have been modelled, and also an intermediate pressure of 5 bar(a).

Table 2. Pool spill volumes modelled

	Spill volume (m^3) for pool depth			
Pool diameter (m)	Concrete (0.005 m)	Dry soil (0.02 m)	0.1 m	1 m
1	0.0039	0.015	(Not modelled)	(Not modelled)
3	0.035	0.14	0.71	(Not modelled)
10	0.39	1.6	7.9	79
30	(Not modelled)	(Not modelled)	70	707
100	(Not modelled)	(Not modelled)	(Not modelled)	7854

Two ambient temperatures have been modelled, approximately bracketing the range of values given in Table 1: –20°C and 30°C. Other parameters have been varied as in Table 1.

3.5 SOFTWARE

DNV's proprietary, commercial software PHAST (**P**rocess **H**azard **A**nalysis **S**oftware **T**ool) has been used for this study. PHAST has been licensed to over 500 organisations worldwide. PHAST's modelling has undergone extensive validation, as described in Witlox & Oke (2008) being presented at this conference.

The key model within PHAST for this study is the Unified Dispersion Model, described in Witlox & Holt (1999). The atmospheric dispersion modelling takes account, at every time-step, of whether the plume spreading and dilution is driven by initial momentum, plume density, or atmospheric turbulence. It also includes liquid pool spreading and evaporation, for which different models are adopted depending whether the spill is on land or water, and whether it is an instantaneous or a continuous release (Witlox & Holt 1999). The pool spreads until it reaches a bund or a minimum pool thickness. The pool may either boil or evaporate while simultaneously spreading. For spills on land, the model takes into account heat conduction from the ground, ambient convection form the air, radiation and vapour diffusion. These effects are modelled numerically, maintaining mass and heat balances for both boiling and evaporating pools. This allows the pool temperature to vary as heat is either absorbed by the liquid or lost during evaporation.

4. INVESTIGATION OF SENSITIVITY EFFECTS OF INPUT PARAMETERS ON DISPERSION CHARACTERISTICS

4.1 VARIATION WITH WEATHER (WINDSPEED AND STABILITY)

4.1.1 R_1 Distances to LFL (releases at 5 m height above ground)

For lower pressures, the weather has no discernible impact on the hazard distances for the two gases G(i) and G(ii). This is because the releases are momentum driven jets, with the velocity difference between the released fluid and its surroundings driving the entrainment of air and resulting lowering of concentration. For higher pressures, higher windspeeds do lead to more rapid dilution and hence shorter hazard distances for the two gases, compared with lower windspeeds. The higher windspeeds also lead, at all pressures, to shorter hazard distances for the three liquids A, B and C released at ambient temperature and for fluid A (LPG-like), refrigerated and released under 5 bar(a) head (e.g. pump pressure).

However, for fluid A (LPG-like), refrigerated and stored at atmospheric pressure (modelled as a discharge under 10 m tank head), a case not considered in IP15, higher wind speeds give longer dispersion distances. The refrigerated fluid forms an evaporating pool on the ground, with evaporative mass transfer therefore increasing with wind speed.

Contrary to what is often believed regarding atmospheric dispersion, stability F does not always give the longest hazard distances (except for fluid B released from a 10 mm hole, and then the distance is only marginally longer than for weather 2D). Stability F does occur sufficiently frequently that it cannot be discounted. The received wisdom only applies when passive (sometimes called “gaussian”) dispersion is the dominant mechanism of dispersion. In the case of flammable materials discharged under pressure, the dominant dispersion mechanisms in the early stages are turbulence induced by the momentum of the release and then dense gas dispersion (i.e. dispersion of a cloud substantially denser than air). Usually the LFL is reached before the cloud is moving with a velocity close to the ambient windspeed and the cloud’s density has approached neutral with respect to air, the conditions for passive dispersion to dominate. Hence atmospheric stability tends to have less influence on dispersion to LFL. However, it does influence dispersion to lower concentrations.

4.1.2 R_2 Distances to LFL (releases at 1 m height above ground)

Based on preliminary analysis, releases at 1 m height above ground have been modelled at an angle of 60° below horizontal in order to examine the influence of ground effects on the hazard distances.

At 10 bar(a) and for all hole sizes, fluid C shows much longer hazard distances for weathers 2D and 1.5F, i.e. low windspeeds, than for weathers 5D and 9D, i.e. moderate to high windspeeds. For fluids A and B the same behaviour is exhibited at 10 bar(a) for the 2 mm hole size. The behaviour can be understood by looking at side views of the plumes. For fluid A at low windspeeds, the plume centreline hits the grounds whilst the concentration is still well above LFL. This results in the plume losing much of its momentum and being directed horizontally (so long as it is not buoyant), with the concentration decreasing to the LFL. At the higher windspeeds, the centreline concentration is close to or below LFL when the centreline hits the ground. By contrast, for fluid C similar behaviour is shown for all weathers, with the plume centreline having hit the ground with the concentration well above LFL.

For fluid G(i), distances to LFL vary reasonably consistently with windspeed. By contrast, for releases of fluid G(ii) at 100 bar(a), for a 2 mm hole there is sharp <u>de</u>crease in hazard distance from low windspeeds to a windspeed of 5 m/s, and for a 10 mm hole there is a sharp <u>in</u>crease in hazard distance from low windspeeds to a windspeed of 5 m/s. This can be understood as follows. For the smaller hole size (2 mm), the behaviour is similar to that noted above for fluid C. For the larger hole size (10 mm), at the lower windspeeds the plume becomes buoyant and lifts off, whereas at the higher windspeeds it is “knocked down” to remain at ground level.

For refrigerated fluid A (LPG-like), both under tank head (10 m) and under pressure (5 bar(a)), the hazard distances are much shorter at higher windspeeds as compared with low windspeeds, with the longest hazard distances being for weather 1.5F. The dispersion is similar to that for fluid A at ambient temperature and under 10 bar(a) pressure.

The modelling results indicate hazard distances in most cases much smaller for leaks up to 5 mm that might be expected from scaling down of the hazard distances for 10 mm leaks. Closer examination of the dispersion modelling, and in particular the pool evaporation, indicates that the pool area decreases much more quickly with hole size than the release rate and that in many cases there is no significant pool evaporation. The fraction of the initial release that rains out (and forms a pool) decreases slightly with hole size (74% to 81% for 10 mm leaks vs. 65% to 72% for 2 mm leaks, depending on wind speed).

Overall, for all fluids except G(ii), weather F1.5 gives the longest hazard distances for releases where ground effects influence dispersion. For fluid G(ii), the low molecular weight renders the fluid buoyant even when the concentration approaches LFL, so at high windspeeds the plume resulting from larger releases is knocked down and higher windspeeds give the longest hazard distances.

4.2 VARIATION WITH AMBIENT TEMPERATURE

For the gases G(i) and G(ii), variations with ambient temperature are mostly small and not systematic. The exception is for G(i) at −20°C, which has a hazard distance 10% to 20% higher than under the IP15 base case conditions.

For fluids B and C, there is a small systematic increase in hazard distance with ambient temperature but this is less than 10%. Compared with the base case results, the variation is only a few percent. Hence the variation with ambient temperature for these fluids is not significant.

For fluid A under pressure there is an apparent decrease in hazard distance with increasing ambient temperature, especially for the smaller leak sizes. This results from the thermodynamics: as the ambient temperature increases, the liquid fraction in the discharge and the liquid droplet diameter decrease, and the velocity increases. The velocity increase enhances entrainment of air and hence promotes more rapid dispersion, reducing the hazard distance. The larger liquid fraction and droplet size at lower ambient temperatures maintain the centreline concentration well above LFL to a greater distance, also increasing the hazard distance at lower temperatures. Hence in colder climates it may be necessary to increase the classified area dimensions compared with the values given in IP15 around equipment containing a fluid similar to A (i.e. LPG-like) under pressure, by up to 70%.

For fluid A (LPG-like), refrigerated at −40°C, the hazard distances increase slightly with ambient temperature both for atmospheric storage with 10 m tank head and for pressure of 5 bar(a) (Figure 1). For the case of a release under pressure, the increase is less than 10% over the ambient temperature range modelled except for 10 mm holes, for which the increase is 11%. However, compared with releases under IP15 conditions (i.e. fluid A under pressure of 6.8 bar(a) and at 20°C), these releases give hazard distances up to 80% higher. For the case of a release under tank head, a 1 mm hole gives hazard distances up to 50% longer than a release under IP15 conditions, a 2 mm hole hazard distances only slightly longer, and a 10 mm hole hazard distances up to 40% shorter. Based on these results, hazard distances for refrigerated LPG significantly exceed those given in IP15 for fluid category A stored under pressure.

4.3 VARIATION WITH HUMIDITY

The modelling results show that there are no significant variations in hazard distance with humidity for any of the fluids, hole sizes or pressures, including fluid A (LPG-like) refrigerated.

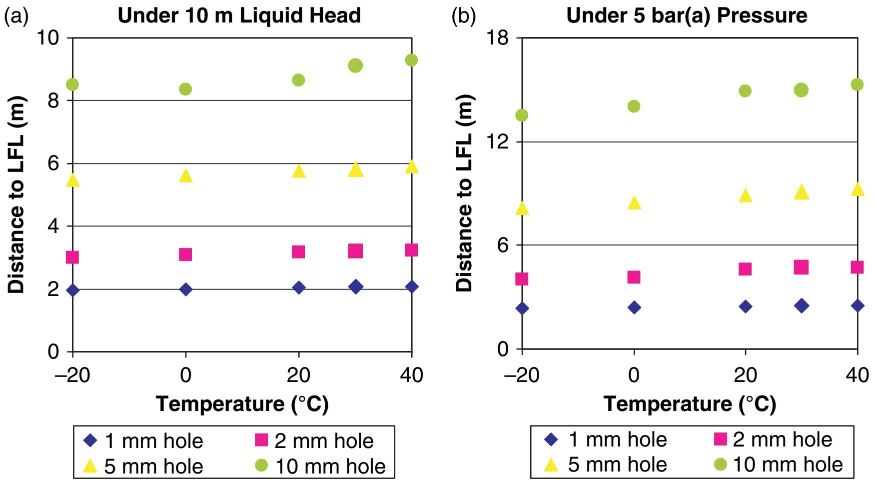

Figure 1. Comparisons of R1 hazard distances to LFL for refrigerated LPG between different ambient temperatures

4.4 VARIATION WITH SURFACE ROUGHNESS

For all fluids except G(i) the hazard distance falls off with increasing surface roughness. This is as expected, since increasing surface roughness promotes turbulence, enhancing dilution of the vapour cloud and hence reducing the hazard distances.

For fluid G(i) the hazard distance is more-or-less independent of surface roughness. This is because the dispersion is driven by the initial momentum of the release and atmospheric turbulence does not influence the dispersion before the cloud centreline concentration has reached LFL.

5 INVESTIGATION OF AREA CLASSIFICATION FOR LIQUID POOLS

5.1 HAZARD DISTANCES: BASE CASE

There is no distinction between R1 and R2 for the results presented in this section, since all releases are at ground level.

Several general observations can be made on the modelling results:

- Pools of fluid A generally give larger hazard distances than those for other fluids studied for various pool diameters/depths, surface types and weathers.
- Going from the smallest spills to the largest, there is a trend in the maximum distance with weather from 9D to 1.5F. This means that, for very small spills (such as might result from the breaking of a coupling), the hazard distances are longest for high winds; for larger spills, the hazard distances are longest for low windspeeds and stable conditions.

- For spills of 0.1 m and 1 m depth, the hazard distance is independent of surface type for fluids B and C whereas the variation of hazard distances with surface roughness for fluid A is slight and shows no systematic variation.
- For fluid C released at 100°C, the hazard distances are longer than for the corresponding releases at 20°C at low windspeeds.

5.2 HAZARD DISTANCES: SENSITIVITIES

As the results presented in Section 4.3 showed no significant variation of hazard distances with humidity, this sensitivity has not been examined. The sensitivities with temperature and surface roughness are presented in Sections 5.2.1 and 5.2.2 respectively.

5.2.1 Variation with ambient temperature

Figure 2 shows distances to LFL for a range of ambient temperatures (releases of fluid A are refrigerated; releases of fluids B and C are at ambient temperature), for weather conditions 1.5F and 9D (i.e. the lowest and highest windspeeds).

For spills of fluid A onto concrete (Figure 2(a)) there is a general increase with temperature in the distance to LFL for low windspeed; for high windspeed the smallest spill gives a much longer hazard distance for higher temperatures whereas the temperature has little influence on the hazard distance for larger spills. For spills of fluid A onto dry soil (Figure 2(b)), the hazard distances are generally shorter than for spills onto concrete but the trends with temperature are stronger.

Spills of fluid B onto concrete (Figure 2(c)) generally show a similar influence of temperature to fluid A. For low windspeed, at temperatures of −20°C and 0°C there is minimal pool evaporation and hence the hazard distance under these conditions is zero or negligible. Fluid B shows little dependence on surface type (compare Figure 2(c),(d)).

Spills of fluid C show very little variation with temperature other than for high windspeed and a temperature of 40°C, which results in much longer distances to LFL for a 3 m diameter, 0.1 m deep pool. Fluid C shows little dependence on surface type.

5.2.2 Variation with surface roughness

Figure 3 shows distances to LFL for a range of surface roughnesses, for weather conditions 1.5F and 9D (i.e. the lowest and highest windspeeds).

In general these show the expected decrease in hazard distance with increasing surface roughness, by a factor of at least 2 over the range modelled for both low and high windspeeds. However, there were some anomalous results which should be disregarded as they are artefacts of the modelling.

6 INVESTIGATION OF APPLICATION OF AREA CLASSIFICATION METHODOLOGY TO LNG

6.1 LIQUID RAINOUT

When a liquid is released, the droplets will evaporate as they travel through the air but will also fall towards the ground under the influence of gravity. Whether or not they reach the

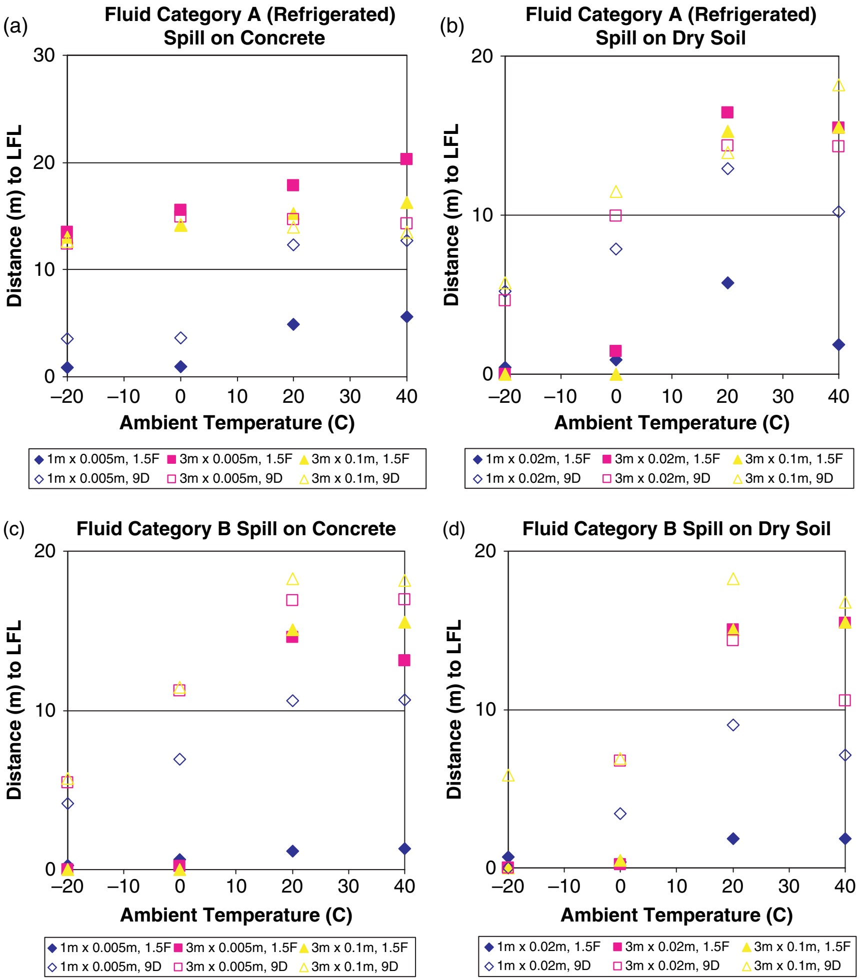

Figure 2. Example comparisons of R_1 hazard distances between different temperatures for spills of fluid categories A and B

ground depends on the release height, rate and velocity as well as the material properties. If they do reach the ground, they form a spreading and evaporating liquid pool.

The amount of rain-out was calculated for releases initially horizontal at three heights: 5 m, 1 m, and 0.1 m. Rain-out only exceeds 50% for releases at 0.1 m height and 1.5 bar(a). For higher pressures there is no rain-out at all; for releases at 0.1 m, the larger

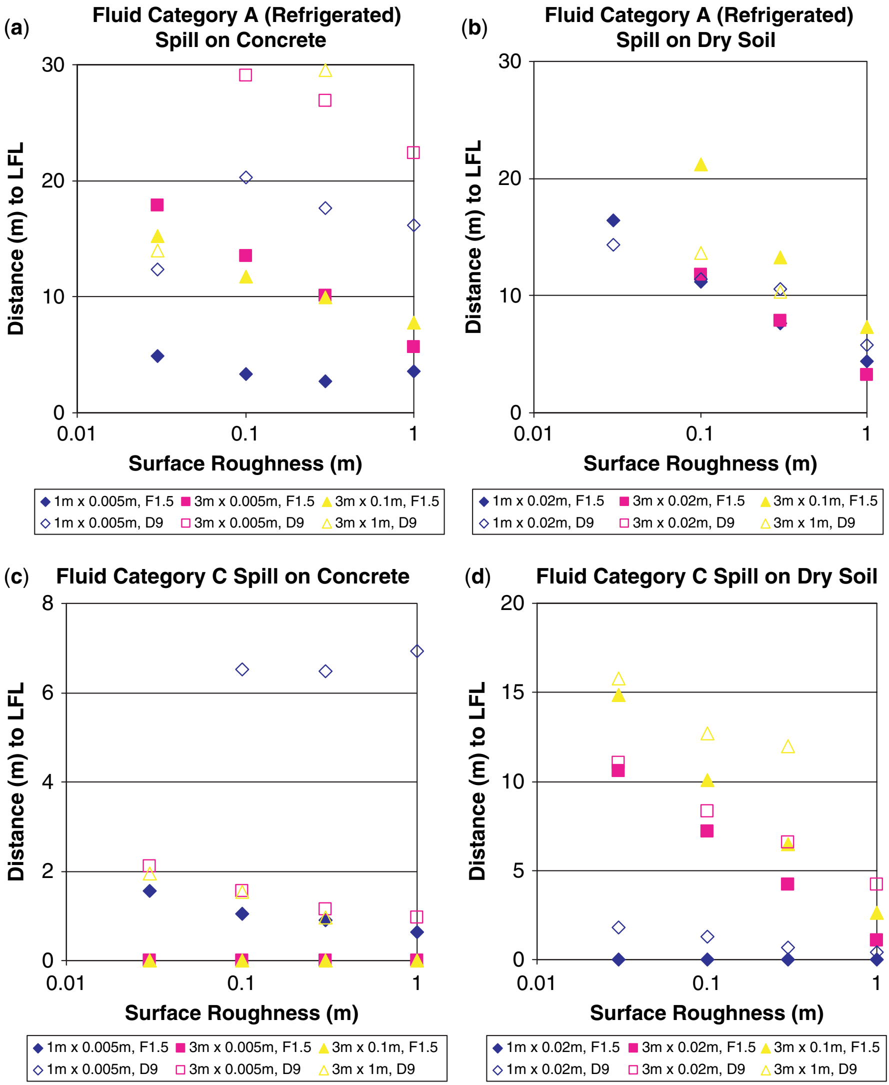

Figure 3. Example comparisons of R_1 hazard distances to LFL between different surface roughnesses for liquid spills

hole sizes (5 mm, 10 mm) do give some rain-out for a pressure of 1.5 bar(a). In order to see the effect of significant rain-out and evaporation, releases at 0.1 m height and 1.5 bar(a) have been modelled in addition to releases at 1 m and 5 m height and all three pressures.

6.2 BASE CASE AND VARIATION WITH WEATHER

Broadly, the modelling results show that the distances to LFL (equivalent to R_1 in Section 4.0) increase with windspeed for the lower pressures (1.5 bar(a), 5 bar(a)) but decrease with windspeed for the highest pressure (10 bar(a)).

Of the materials for which hazard distances are presented in IP15, fluid G(i) is the closest in composition to LNG. However, releases of this fluid were originally modelled for a storage temperature of 20°C and have been modelled in this study for temperatures down to −20°C. It is interesting to compare the results for LNG with these other results. The dispersion behaviour of fluid G(i) shows little variation with temperature.

It was found that LNG gives much longer hazard distances than fluid G(i). This is not surprising as the release rates are much higher, LNG being liquid and fluid G(i) gas; also the modelled release velocity is about 43 m/s for LNG but sonic for fluid G(i), which means that fluid G(i) will entrain air much more rapidly through induced turbulence at the edge of the plume. Hence results for fluid G(i) should not be used as a surrogate for LNG.

The same trends with windspeed for releases at 1 m and 0.1 m height above ground are seen as for releases at 5 m height. Considering first the releases at 1 m height, the distances to LFL are shorter than for releases at 5 m height for the lower pressures and smaller hole sizes, increasing to exceed them for the higher pressures and larger hole sizes. These variations can be explained by a combination of plume interaction with the ground and rain-out. Only the largest releases 5 m interact with the ground, and then only at the lowest windspeed, but the larger releases at 1 m do interact with the ground, even for the highest pressure and highest windspeed.

For releases at 0.1 m height, the distances to LFL are smaller than from releases at 1 m height for the smaller hole sizes (1 mm, 2 mm) but larger for the larger hole sizes (5 mm, 10 mm).

Figure 4 shows the variation with weather conditions graphically. The effect referred to above of weather 1.5F on the distance to 0.5 LFL for 10 mm holes is clearly seen. More generally, the distances are more sensitive to weather conditions for the lower pressures; alternatively, the windspeed is less important for the higher pressure releases as dispersion is driven more by the turbulence induced by the resulting higher release velocities. The distance to 0.5 LFL is more sensitive to weather conditions: as the plume becomes more dispersed, it is also losing the effect of the initial momentum and hence the windspeed becomes more significant.

6.3 VARIATION WITH AMBIENT TEMPERATURE

For releases at both 1 m and 5 m height above ground at ambient temperatures, the distances to LFL are up to 20% shorter for releases at −20°C compared with 30°C.

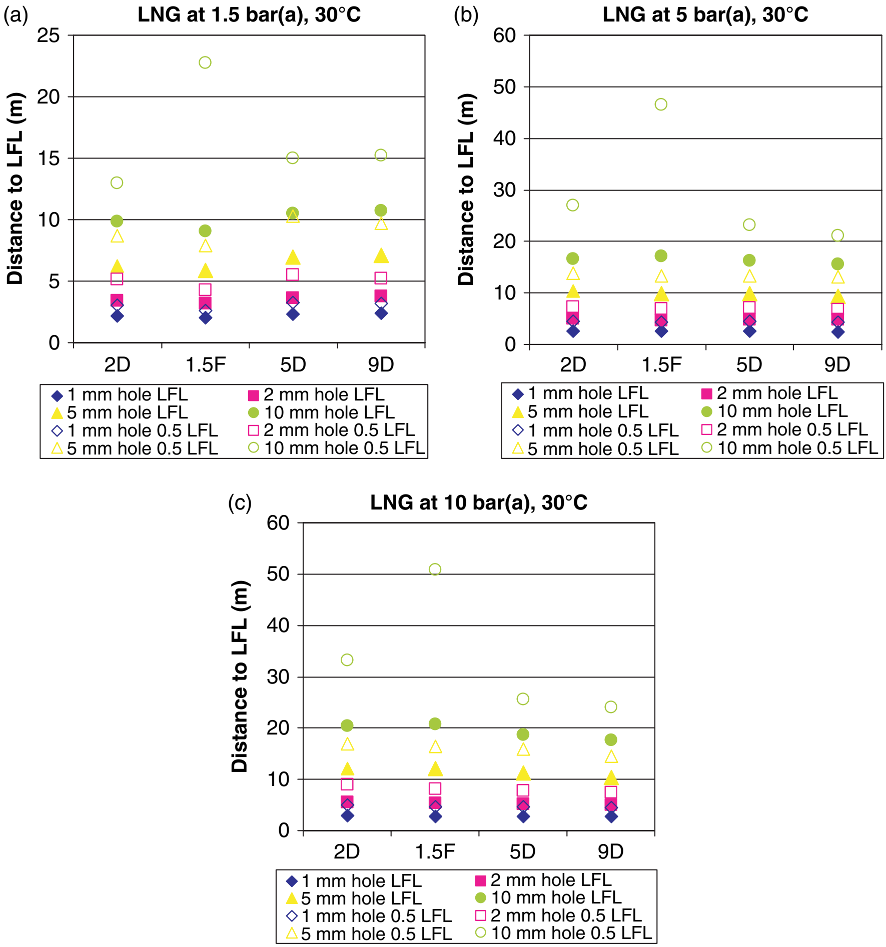

Figure 4. Variation of distances to LFL with weather for LNG spills (Release height 5 m)

6.4 VARIATION WITH HUMIDITY

The effect of varying the relative humidity (RH) is no more than about 10%, and no clear trend is apparent.

This contrasts with the results in major hazard releases of LNG, where the effect of relative humidity is marked: as RH increases, hazard distances decrease. These results are seen in modelling and have been observed in experiments (e.g. Maplin Sands). However, the size of the releases in both trials and major hazard modelling is much greater than in the present study and so the absence of any identifiable trend with RH for such small releases does not conflict with the results for large releases.

6.5 VARIATION WITH SURFACE ROUGHNESS

For releases at 5 m height above ground there is a consistent decrease in hazard distances from the Base Case surface roughness of 0.03 m to 1 m, the largest roughness modelled, of around 25%. This trend is as expected. For releases at 1 m height, most cases exhibit the same trend but the largest releases (10 mm) under weather 2D do not show such a clear trend. This is because the plume centre grounds and hence dispersion behaviour is modified by the interaction with the ground.

6.6 VARIATION WITH SURFACE TYPE

All releases over water will result in longer hazard distances than the equivalent releases over land because the surface roughness is lower, following the trend demonstrated in the previous section (6.5). The results show modest increases in distance to LFL: up to about 7% for weather 2D, 25% for weather 9D.

An additional effect can be expected when the release results in a spill onto the water surface due to the different heat transfer properties of land and water. Only the releases at 0.1 m height and 1.5 bar(a) result in significant rain-out. There are larger increases in hazard distance (up to 38% longer) for weather 2D, showing the enhanced vapour generation on water compared with land. For weather 9D the increase is generally less marked than for releases at 5 m.

For spills onto water, the phenomenon of “rapid phase transition” (RPT) has not been considered.

7 CONCLUSIONS AND RECOMMENDATIONS

7.1 SENSITIVITY TO PARAMETER VARIATIONS

In the following summary, variations of ±20% in hazard distance from base cases are discounted given the uncertainties in dispersion modelling.

7.1.1 Fluid category A

- For fluid category A under pressure:
  - the variation in hazard distance with weather category compared with the base case (2D) is mostly less than ±20%, whereas for higher windspeeds and larger hole sizes the reduction in hazard distance compared with base case reaches 27%.
  - the variation of hazard distance with relative humidity is negligible.
  - the reduction in hazard distance with increasing surface roughness (up to 1 m) is less than 20%.

- For fluid category A, refrigerated at –40°C and stored at atmospheric pressure:
    - the hazard distances are up to 80% higher than for the same fluid stored under pressure at ambient temperature. Figure 1 indicates suitable hazard distances for refrigerated LPG.
    - higher wind speeds give longer dispersion distances than the same fluid stored under pressure at ambient temperature. This needs to be taken account of for installations storing refrigerated LPG.
    - the variation of hazard distance with relative humidity is negligible.
    - the reduction in hazard distance with increasing surface roughness (up to 1 m) is up to 31%. However, in most cases the surface roughness will be significantly less than this hence the distances shown in Figure 1 should be used.

7.1.2 Other fluid categories

For fluid categories B, C, G(i) and G(ii):

- For lower storage/process pressures, the weather has no discernible impact on the hazard distances for the two gases G(i) and G(ii). For fluid G(ii), high windspeeds give the longest hazard distances. Higher windspeeds also lead, at all pressures, to shorter hazard distances for the three fluid categories A, B and C.
- The variation of hazard distance with ambient temperature is less than 20% over the range modelled.
- The variation of hazard distance with relative humidity is negligible.
- The reduction in hazard distance with increasing surface roughness (up to 1 m) is less than 20%.

7.2 LIQUID POOLS

7.2.1 Base case

A comprehensive approach to area classification for liquid pools due to spillage has been developed for various fluid categories, pool diameters/depths and weathers for two surface types. The following specific points may be noted:

- For very small spills, the hazard distances are longest for high windspeeds; for larger spills, the hazard distances are longest for low windspeeds and stable conditions.
- In the majority of cases, the surface type (concrete or dry soil) makes no significant or systematic difference to hazard distances.

7.2.2 Sensitivity to parameter variations

- For fluid category A there is significant variation with increasing ambient temperature compared with the base case results. Figure 2(a),(b) indicates the range of variation.
- For fluid category B the variation for a higher ambient temperature than base case (20°C) is less than 10%. For lower temperatures, it is recommended that the hazard distances in Figure 2(c),(d) are used as they are significantly shorter than the base case.

- For fluid category C the variations of hazard distance with ambient temperature are mostly small.
- For all of fluid categories A, B and C the variation of hazard distance with relative humidity is negligible .
- For all of fluid categories A, B and C the variation of hazard distance with surface roughness is significant as illustrated in Figure 3.

7.3 LNG

- Figure 4 provides a suitable basis for guidance on hazard distances for IP15.
- Except for very small releases (i.e. 1 mm hole size), the hazard distances for releases initially horizontal at 0.1 m height are mostly longer than for the corresponding releases at 1 m height due to rain-out, liquid pool formation and re-evaporation occurring.
- The variation in hazard distance between ambient temperatures of –20°C and (+)30°C is less than 20%.
- The variation in hazard distance with relative humidity is less than 10%.
- The reduction in hazard distance with increasing surface roughness (up to 1 m) is less than 25%. However, in most cases the surface roughness will be significantly less than this.
- For releases resulting in significant rain-out (those at 0.1 m height and 1.5 bar(a) pressure), the hazard distances are significantly increased at low windspeed compared with releases onto land.

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