DETERMINATION OF FLAMMABLE LIQUID POOL SIZES AND THE RESULTANT HAZARDOUS DISTANCES

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Abstract –
This paper provides guidance for determining flammable liquid pool sizes and the resultant vapour release rate for hazardous area classification purposes in accordance with IEC 60079-10-1. The discussion is restricted to evaporative pool secondary grades of release at ambient temperatures below the boiling point of the liquid.

Factors that impact the size of a pool release include:

1) process pressure and temperatures (ambient temperature, liquid temperature, and ground temperature);
2) rate of release;
3) presence of sumps, drains, or containment walls;
4) evaporation rate due to the liquid's vapour pressure;
5) ground composition (metal, concrete, asphalt, clay, silt, loam, gravel, etc.);
6) dryness of the ground; and
7) time before the sources of release are identified and mitigation measures are implemented.

Additional factors that impact the extent of a hazardous location include:

1) pool shape based on the slope of the ground; and
2) wind direction

Index Terms — IEC 600079-10-1, hazardous area classification, flammable liquid pool, evaporative liquid pool, secondary grade of release, normal operations.

I. INTRODUCTION

IEC 60079-10-1, EI15, API (RP) 505, and NFPA 497 provide little guidance in determining the size of a pool release to be used in hazardous area classification assessments.

Knowing the pool size is important when determining the amount of liquid that will evaporate for calculating the hazardous distances. This is not normally an issue where containment is present as the pool area will equal the containment area. But what about situations where there is no containment? The end user is forced to use engineering judgment with little to no guidance provided. These typically result in undocumented assumptions that directly affect the determination of the hazardous classification and hazardous distances.

The larger the pool, the greater the extent of the hazard from the point of release. The nature and extent of the hazard can be difficult to assess, especially where no pool containment is present.

Note that cryogenic liquids or liquids under high pressures whose boiling points are below the ambient temperature will normally only form a small pool during a secondary grade of release. These liquids are not considered in this paper.

II. BACKGROUND DISCUSSION

A secondary grade pool release occurs when process equipment or connecting piping carrying liquids develops a leak. A flammable liquid pool results in the vicinity of the release which then changes state from a liquid to a vapour potentially creating an explosive atmosphere.

Secondary grades of release are defined in IEC 60079-10-1 as releases that are not expected to occur in normal operation and, if they do occur, are likely to do so only infrequently and for short periods.

Normal operations are defined in IEC 60079-10-1 as a situation when the equipment is operating within its designed parameters. Area classification assessments do not address catastrophic release conditions resulting from a loss of containment

III. EVAPORATIVE POOL SIZE EQUATIONS

A. Maximum Theoretical Pool Area (MTPA)

The starting point for determining an evaporative pool size is to first determine the Maximum Theoretical Pool Area (MTPA).

A pool will be created from a secondary release of liquid in the form of a hole in process equipment or connecting pipes. The amount of liquid escaping is defined by equation (1) (Equation B.1 of IEC 60079-10-1) as follows:

$$W = C_d \cdot S \cdot \sqrt{2 \cdot \rho \cdot \Delta p} \qquad \text{(kg/s)} \qquad (1)$$

where

W	release rate of liquid (mass per time, kg/s);
C_d	discharge coefficient (dimensionless) which is a characteristic of the release openings, typically 0,50 to 0,75 for sharp orifices and 0,95 to 0,99 for rounded orifices;
S	cross-section of the opening (hole), through which the liquid is released (m^2); Refer to Table B.1 from IEC 60079-10-1 for suggested hole sizes.
ρ	liquid density (kg/m^3); and
Δp	pressure difference across the opening that leaks in (Pa).

In most cases, liquid leaks will likely be somewhat less than those calculated using equation (1). The leak will often approximate a 'dribble' that slowly forms a pool over time.

The resultant pool will reach the MTPA when the liquid release rate using equation (1) equals the flammable liquid evaporation rate using equation (2) (Equation B.6 of IEC 60079-10-1).

$$W_e = \frac{18{,}3 \cdot 10^{-3} \cdot {u_w}^{0{,}78} \cdot p_v \cdot A_p \cdot M^{0{,}667}}{R \cdot T} \quad \text{(kg/s)} \quad (2)$$

where

W_e	evaporation rate of liquid (kg/s);
u_w	wind speed at the liquid pool surface (m/s);
A_p	pool surface area (m^2);
p_v	liquid vapour pressure at temperature T (Pa);
M	molar mass of the substance (kg/kmol);
R	universal gas constant (8314,5 J/kmol K); and
T	temperature of the liquid (K).

The MPTA equation can be calculated when W from equation (1) equals W_e from equation (2) and rearranging for Ap as follows:

$$A_{p(MTP)} = \frac{C_d \cdot S \cdot R \cdot T \cdot \sqrt{2 \cdot \rho \cdot \Delta p}}{18{,}3 \cdot 10^{-3} \cdot {u_w}^{0{,}78} \cdot p_v \cdot M^{0{,}667}} \quad (\text{m}^2) \quad (3)$$

where

$A_{p(MTP)}$	maximum theoretical pool area (m^2).

The attributes of equation (3) when determining pool size are as follows:

1) the equation does not introduce any new variables;
2) it is mathematically self-evident;
3) it takes into account the dynamic nature of the changing pool area created by a process leak;
4) the result is independent of pool depth caused by ground undulations or slopes as the equation only needs to consider the pool surface area; and
5) the result is a worst-case scenario that represents a safe and conservative value for the pool size, and the resultant hazardous distance from the source.

All subsequent equations introduced in this paper follow from the determination of the MTPA. These subsequent equations look at mitigating factors that will reduce the equation (3) pool area.

B. Ground Permeability (GP)

Ground permeability is the ability of the soil to allow fluids to pass through and is a function of the ground composition and dryness. Ground permeability is important in outdoor applications as it determines how much liquid enters the ground and is therefore not subject to evaporation.

To account for ground permeability, the pool area can be approximated using the following equation [5]:

$$A_{p(GP)} = \frac{1{,}7715 \cdot Q \cdot v}{g \cdot k_i \cdot k_{r,NAPL}} \quad (\text{m}^2) \quad (4)$$

where

$A_{p(GP)}$	pool surface area accounting for ground permeability (m^2);
Q	volumetric release rate (m^3/s);
v	liquid kinematic viscosity (m^2/s);
g	acceleration due to gravity = 9,81 m/s^2;
k_i	ground intrinsic permeability (m^2) - Refer to Table 1; and
$k_{r,NAPL}$	relative permeability of oil which vary with different grades of water saturation - Refer to Table 2.

The liquid release rate (Q) is determined using equation (5)

$$Q = \frac{W}{\rho} \quad (\text{m}^3/\text{s}) \quad (5)$$

where

W	release rate of liquid (mass per time, kg/s); and
ρ	liquid density (kg/m^3).

Site geotechnical reports normally include permeability data for soils.

TABLE 1 [6]
TYPICAL INTRINSIC PERMEABILITY VALUES (k_i)

Ground	k_i
Metallic (Steel, Aluminum)	$1 \cdot 10^{-20}$
Finished Concrete	$1 \cdot 10^{-18}$
Rough concrete	$1 \cdot 10^{-16}$
Asphalt	$1 \cdot 10^{-15}$
Clay	$1 \cdot 10^{-15}$
Clay/Silt	$1 \cdot 10^{-14}$
Silt	$1 \cdot 10^{-13}$
Silt/Sand	$1 \cdot 10^{-12}$
Sand	$1 \cdot 10^{-11}$
Sand/Gravel	$1 \cdot 10^{-10}$
Gravel	$1 \cdot 10^{-08}$

TABLE 2 [5]
RELATIVE PERMEABILITY ($k_{r,\ NAPL}$) FOR DIFFERENT SCENARIOS OF ACCIDENTAL SPILLAGE

Ground Saturation	$k_{r,\ NAPL}$
Dry	1,0
Slightly Wet	0,9
Wet	0,5
Very Wet	0,3
Saturated	-

C. Combining Equation (COMBO)

Equation (4) does not give useful results for impermeable surfaces such as clay, asphalt, or concrete as it does not consider pool evaporation. This results in overly large and unrealistic pool areas exceeding the MTPA.

A more pragmatic approach is possible by combining equation (3) and equation (4) as follows:

$$A_{p(COMBO)} = A_{p(MTP)} \cdot \left(1 - \frac{A_{p(MTP)}}{A_{p(MTP)} + A_{p(GP)}}\right) (\text{m}^2) \quad (6)$$

As $A_{p(GP)}$ becomes very large for lower values of intrinsic permeability ground, $A_{p(COMBO)}$ approaches equation (3) $A_{p(MTP)}$. As $A_{p(GP)}$ approaches zero for higher values of intrinsic permeability ground, $A_{p(COMBO)}$ approaches the equation (4) $A_{p(GP)}$ results.

Figure 1 shows a graphical representation of the change in pool area where $A_{P(MTP)}$ =100 m^2 and $A_{p(GP)}$ varies from 10 m^2 to 1000 m^2.

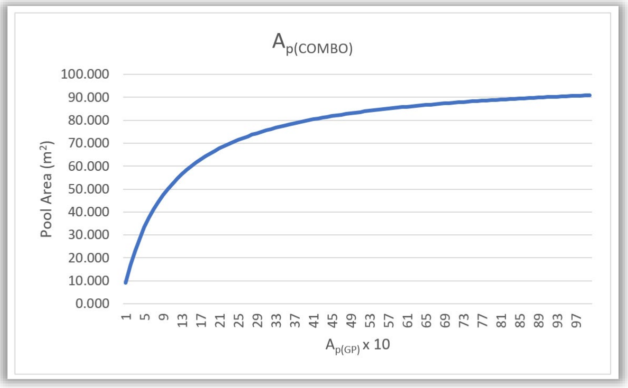


Fig. 1 $A_{p(COMBO)}$ at Fixed $A_{p(MTP)}$ & Variable $A_{p(GP)}$

D. Operator Intervention (OI)

Determining the size of the pool area based on operator intervention requires good engineering judgment and knowledge of how the facility is operated.

The rate of increase of the pool size will slowly decline to zero as the pool approaches its maximum size. This can be modeled using the following 'half-life' exponential decaying equation as the evaporation rate approaches the secondary source of release (*SR*) rate: [7]

$$N(t) = N(0) \cdot 0{,}5^{\frac{t}{t_{1/2}}} \qquad (7)$$

where

- *N(t)* is the quantity that still remains and has not yet decayed after a time t, (grams, moles, etc.);
- *N(0)* is the initial quantity of the substance that will decay, (grams, moles, etc.);
- *t* time where N(t) is determined (hours); and
- $t_{1/2}$ half-life of the decaying quantity (hours).

The following equation can then be derived from equation (6) to model the pool size by the time operators intervene to halt an evaporative pool that is increasing in size.

$$A_{p(OI)} = A_{p(COMBO)} \cdot \left(1 - 0{,}5^{\frac{t_{oi}}{t_{1/2}}}\right) (\text{m}^2) \qquad (8)$$

where

- $A_{p(OI)}$ operator intervention pool area (m^2);
- $A_{p(COMBO)}$ combination equation pool area (m^2) (6);
- t_{oi} time between the start of the release and operator intervention to stop the release (hr); and
- $t_{1/2}$ time to reach one-half of the final pool area (hr).

NOTE Equation (8) is the inverse of equation (7) as $A_{p(OI)}$ increases with time whereas N(t) decreases with time, hence the $\left(1 - 0{,}5^{\frac{t_{oi}}{t_{1/2}}}\right)$ term.

The following equation defines the time to reach one-half of the final pool area.

$$t_{1/2} = \frac{A_{p(MTP)1/2} \cdot h}{Q - Q_{1/4}} \qquad (9)$$

where

- $A_{p(MTP)1/2}$ one-half of the MTPA = $A_{p(MTP)} / 2$;
- $Q_{1/4}$ one-quarter of the average evaporation rate which is equivalent to one-quarter Q; (See Note)
- *h* average pool height (m) - Refer to Table 3.

$$t_{1/2} = \frac{A_{p(MTP)} \cdot h}{Q \cdot 0{,}667} \qquad (10)$$

NOTE As the pool gets larger from its inception, some of the liquid evaporates before the pool reaches its final size. When the pool reaches one-half its final size this evaporation rate is approximately one-quarter the final evaporation rate between pool inception and when the pool reaches half of its final size.

TABLE 3 [8]
AVERAGE POOL HEIGHT

Ground Description	Avg. pool height (*h*) (m)
Flat sandy soil, concrete, stones, industrial site	0,005
Normal sandy soil, gravel, railway yard	0,01
Rough sandy soil, farmland grassland	0,02
Very rough grown over sandy soil with potholes	0,025

Substituting equation (10) into equation (8) results in the following equation:

$$A_{p(OI)} = A_{p(COMBO)} \cdot \left(1 - 0{,}5^{\frac{t_{oi} \cdot Q \cdot 5400}{A_{p(MTP)} \cdot h}}\right) \qquad (11)$$

NOTE The term 5400 in equation (10) is derived from 3600 sec/hr 1/0,667 from equation (10).

Figure 2 shows a graphical representation of the change in pool area over time for a benzene release from a 0,25 mm^2 hole at 1200 kPa gauge onto a clay surface over 20 hours with a pool wind velocity of 0,25 m/s and an average pool height of 10 mm where the maximum pool area is 409 m^2.

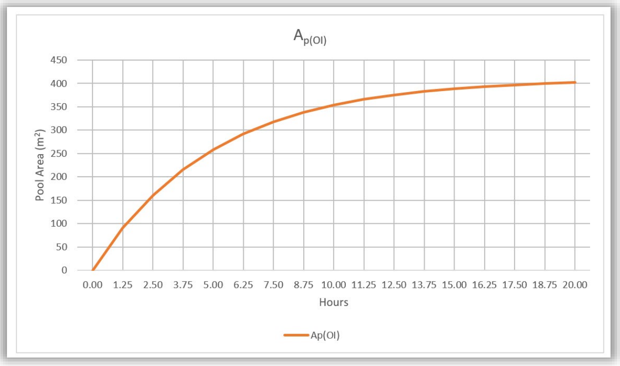


Fig. 2 Benzene release pool area over time

It is recommended that a conservative approach be adopted when using the equation (11). A short time to intervene may be warranted if the facility is continuously manned and operators carry out regular inspections every few hours. On the other hand, it could potentially be days before a leak is detected if the area is not regularly inspected. The same philosophy applies to average pool height. A shallower pool height is recommended over a deeper pool height as this results in a larger, more conservative pool size for similar release rates.

IV. POOL SHAPE

Determining the likely evaporative pool size is the first step when calculating the hazardous distance from the edge of the pool. Knowing the approximate shape of an evaporative pool is the next step.

Modeling done by Pacific Northwest National Laboratory (PNNL) indicates that liquid pools will take on the following shapes when on flat or slightly sloped impermeable ground such as clay, asphalt or steel as shown in Figure 3.

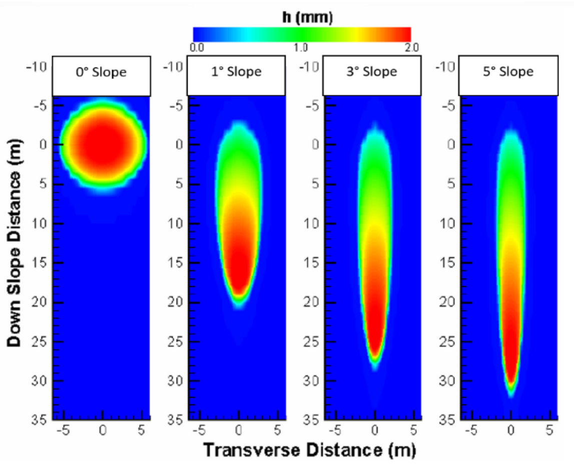


Fig. 3 Simulated spills on impermeable flat & inclined ground [9]

Once the pool area has been determined, a simplification can be used by assuming the pool is rectangular and the surface is impermeable. This allows the calculation of the approximate pool length and breadth (width) using equations (12) and (13).

$$L = \sqrt{A_{p(MTP)} \cdot PAR} \quad \text{m} \qquad (12)$$

$$B = \frac{A_{p(MTP)}}{L} \quad \text{m} \qquad (13)$$

where

PAR	pool area ratio – refer to Table 4 & 5;
L	approximate pool length;
B	approximate pool breadth

TABLE 4 [9]
POOL AREA RATIO (PAR) ON IMPERMEABLE GROUND
(See Fig. 3)

Slope	PAR (pool length to pool breadth)
0°	2 (See Notes)
1°	4,3
2°	5,5
3°	6,7
4°	7,9
5°	9,1

The spill shapes on permeable ground such as sand are much less pronounced than shown in Figure 3. Table 5 is a rough approximation of the PARs on silt, sand, or gravel surfaces as determined by the interpolation and extrapolation of data in figures provided by PNNL [10].

TABLE 5 [10]
POOL AREA RATIO (PAR) ON PERMEABLE GROUND

Slope	PAR (pool length to pool breadth)
0°	1,5 (See Notes)
1°	1,8
2°	2,4
3°	2,9
4°	3,4
5°	3,9

NOTE 1 A pool on flat ground will more likely form an oblong shape than a perfect circle. The resultant PAR is approximately 2:1 on impermeable ground and 1,5 to 1 on permeable ground.

NOTE 2 The delineation between permeable and impermeable ground is not a defined value. Engineering judgment is required when using Tables 4 & 5.

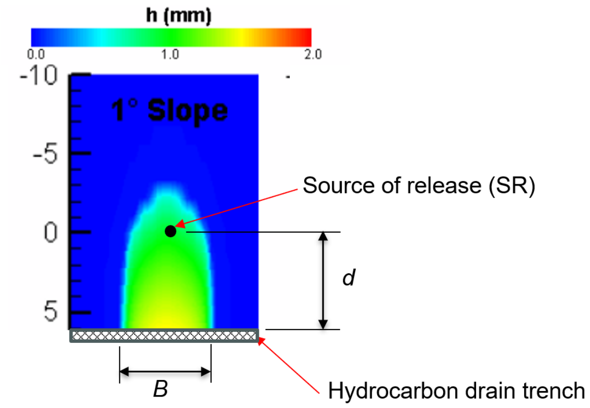
Civil grading plans will show the ground slopes. Typically, a site is graded with a 2% (1°) downward slope away from buildings to ensure that surface water drains while alleviating erosion concerns.

V. FLOOR DRAINS AND TRENCHES

The presence of floor drains and trenches will affect the pool size and is dependent on the slope of the ground and the distance from the source of release (*SR)* to the drain. The exposed liquid stream traveling from the *SR* to the drain is treated as a pool. for calculation purposes.

Although the distance from the *SR* to the drain may be straightforward, the breadth (width) of the stream is more difficult to determine.

A method for determining the breadth of the stream can be found by determining the *MTPA* using equation (3) on the basis that any surface with a drain system will normally be impermeable such as concrete, asphalt, or steel. From there you can use equations (12) & (13) and Table 4 to determine the breadth of the ‘pool’ which will approximate the breadth of an equivalent stream where a hydrocarbon drain trench is present. The breadth of the stream generally remains fairly constant for a given slope as can be seen from Figure 3, so the equivalent pool size ‘downstream’ of the *SR* can be determined by multiplying the distance from the *SR* to the hydrocarbon drain trench x the pool breadth to arrive at the approximate equivalent pool size.



PLAN VIEW

Fig. 4 Simulated spill on an impermeable ground with a hydrocarbon drain trench and a 2% (1°) slope [9]

The equivalent pool also includes a portion that is 'upstream' of the general flow direction from the *SR*. By inspection, this area can be represented by a triangle with a base equal to *B*, and a height of 0,5 x *B*. The approximate area is therefore:

$$A_{p(UP)} = (B \cdot B \cdot 0{,}5) \cdot 0{,}5 \qquad (14)$$

where

$A_{p(UP)}$	upper pool area (m^2);
B	approximate pool breadth (m).

Substituting equations (12) and (13):

$$A_{p(UP)} = \frac{(A_{p(MTA)})^2 \cdot 0{,}25}{A_{p(MTA)} \cdot PAR} \qquad (15)$$

The final pool area where a drain is present can be approximated by the following equation:

$$A_{P(D)} = \sqrt{\frac{A_{p(MTP)}}{PAR}} \cdot d + \frac{A_{p(MTP)}}{PAR} \cdot 0{,}25 \qquad (16)$$

where

$A_{p(D)}$	pool area with drain (m^2)
$A_{p(MTP)}$	Maximum Theoretical; Pool Area - Refer to Eqn 3
PAR	pool area ratio – refer to Table 4;
B	approximate pool breadth (m)
d	distance from *SR* to drain (m)

VI. DETERMINING HAZARDOUS DISTANCE BEYOND THE POOL EDGE

The next consideration is to determine how much additional distance beyond the edge of the pool should be considered as hazardous.

Equation (2) is used to determine the evaporation rate which is then used to calculate the volumetric release characteristic of the source (Qc) to determine both the degree of dilution and to estimate the hazardous distance (h_d) using Figures 5 and 6 (Figures C.1 and D.1 from IEC 60079-10-1) respectively.

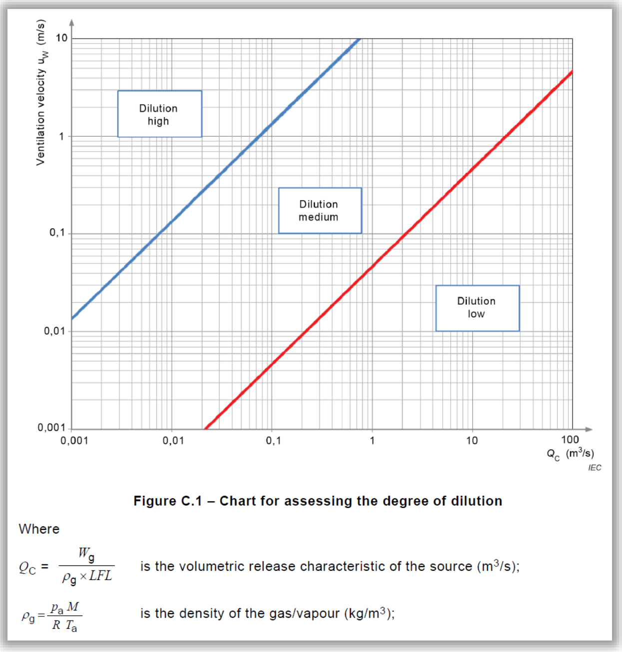


Fig. 5 Chart for assessing the degree of dilution

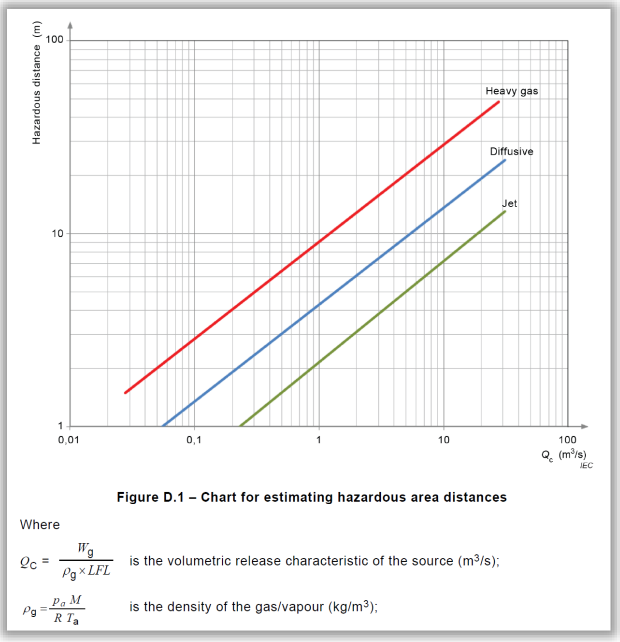
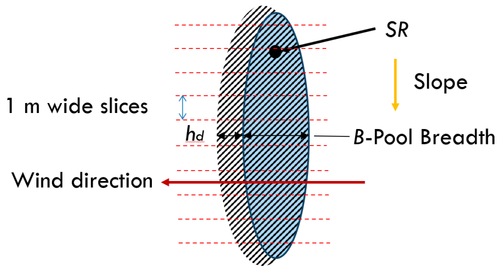


Fig. 6 Chart for estimating the hazardous area distance

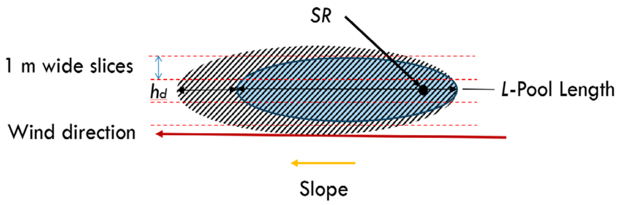
Qc is predicated on a point *SR* rather than an area *SR* from an evaporative pool. This is not an issue in an indoor environment when applying a homogeneous hazardous classification to the interior space. The concern is with outdoor areas where the hazardous classification is not homogeneous and different classifications are needed. Using the total pool area to calculate the hazardous distance for outdoor locations results in unreasonable hazardous distances. A novel approach is to divide the pool into 1 m wide slices depending on wind direction.

The wind direction with respect to the pool's axis affects the hazardous distance from the edge of outdoor pools as illustrated in Figures 7 and 8.



PLAN VIEW

Fig. 7 Wind perpendicular to the pool long axis



PLAN VIEW

Fig. 8 Wind parallel to the pool long axis

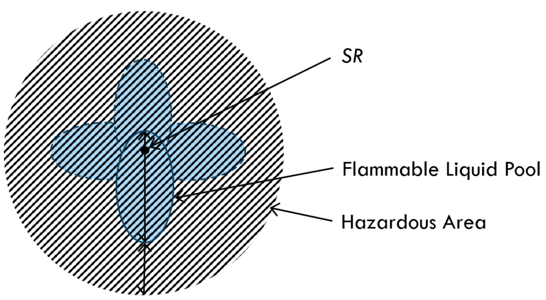
where

h_d Hazardous distance beyond the edge of the pool (m)

There will be more evaporative vapours present per one-meter slice when the wind direction is parallel to the pool's long axis. This results in a greater hazardous distance than when the wind direction is perpendicular to the pool's long axis. Therefore, a nominal pool size of 1 m x the pool long axis is proposed for outdoor evaporation rate calculation purposes to determine the greatest hazardous distance.

The symbol $A_{p(Ol)}$' is used for the pool area of the 1m x pools long axis pool, W_e' for the resultant evaporation rate, and Q_c' for the volumetric release characteristic of the source. Figure 4 is then used to determine the hazardous distance from the edge of the pool at the end of the pool's long axis. Refer to Appendix A & B for case studies.

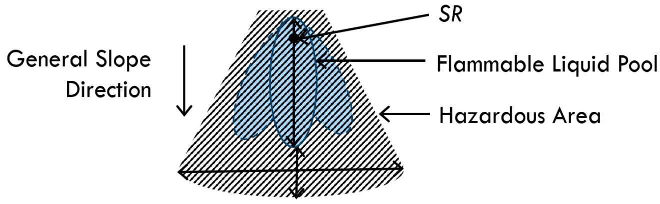
It is recommended that the hazardous area form a circle as shown in Figure 9 where the slope or wind direction are not known using the rationale of Figure 1 of IEC 60079-10-1.



PLAN VIEW

Fig. 9 Possible pool locations with unknown slope direction

It is further recommended that the hazardous area form a tear-drop shape where the general slope direction is known as shown in Figure 10.



PLAN VIEW

Fig. 10 Possible pool locations with known slope direction

VII. CONCLUSIONS

Existing hazardous area classification standards do not address how to determine unconstrained flammable pool sizes from a secondary grade of release for determining the hazardous classification and distances. This paper proposes an approach to estimating a pool size release for area classification purposes.

A method for determining a pool size area and the associated classification extent is discussed. The concept of maximum theoretical pool size is used as the starting point. Other factors including soil permeability and operator intervention are then introduced as factors that could be used to reduce the expected size of the evaporative pool.

Once the pool size has been determined, the pool shape must be assessed. This may be influenced by ground slope or grade.

The classification extent from the pool edge may then be determined based on pool size shape, wind direction and the presence of a drain system.

As more variables are introduced, sound engineering judgement is required in choosing values. Experience plays a role in selecting appropriate values.

The equations and procedures presented are based on mathematical models of pool release behavior. They provide reasonable results in most applications. Computational Fluid Dynamic (CFD) modeling and laboratory experiments may confirm the basis of the approach used.

VIII. ACKNOWLEDGEMENTS

The authors wish to acknowledge the contributions of Brian Brooks, P.Eng. who provided Civil engineering expertise and insights in the preparation of this paper.

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X. APPENDICES

Appendix A – Case Study 1 (No drain)
Appendix B - Case Study 2 (With drain)

XI. VITA

Doug Brooks, P.Eng. graduated from the Royal Military College in 1976 with a BScEE degree. Since leaving the Canadian Armed Forces, Doug has worked as an electrical engineer for numerous manufacturing and engineering companies in Alberta, Canada. He is currently employed as an Engineer with EngWorks Inc. providing hazardous location consulting services to industry. Doug is a Senior Member of the IEEE and is on the IEC 60079-10-1 Maintenance Team. Doug. has authored three previous PCIC papers. He can be reached at doug.brooks@engworks.ca

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Appendix A
Case Study 1 (No drain)

A normal industrial pump with mechanical (diaphragm) seal, mounted at ground level, located outdoor on flat sandy ground, pumping flammable liquid. Operators intervene 6 hours after the start of the leak.

<u>Characteristics of location:</u>

Outdoor situation	Un-obstructed area
Ambient pressure, p_a	101 325 pa
Ambient temperature, T_a	20 °C (293 K)
Ventilation velocity, u_w	0,25 m/s
Ventilation availability	Good (wind speed at calm conditions)

<u>Characteristics of release:</u>

Flammable substance	Benzene (CAS no. 71-43-2)
Molar mass	78,11 kg/kmol
Lower flammable limit, LFL	1,2% vol. (0,012 vol./vol.)
Auto-ignition temperature, AIT	498°C
Vapour density, ρ_g	3,247 kg/m^3 using equation for ρ_g from Figures 4 & 5 considering universal gas constant R= 8314,5 J/kmol K
Source of release, *SR*	Mechanical seal
Grade of release	Secondary (leakage due to seal rupture)
Liquid release rate, *W*	0,0192 kg/s using equation (1) considering a discharge coefficient C_d = 0,75, a hole size S = 0,5 mm^2, a liquid density ρ = 876,5 kg/m^3 and a pressure difference Δp =15 bar
Maximum theoretical pool area, $A_{p(MTP)}$	41,25 m^2 using equation (3) considering temperature of the liquid T= 20°C, vapour pressure of the liquid at ambient temperature p_v = 10 kPa,
Pool area accounting for ground permeability, $A_{p(SP)}$	5,5 m^2 using equation (4) considering a release rate $Q = W/\rho$ = 2,19 x 10^{-5} m^3/s, a kinematic viscosity of benzene v = 6.93 x 10^{-7} m^2/s, an intrinsic permeability of silt/sand k_i = 1,0 x 10^{-12} m^2 , and a water saturation factor k_r = 0,5
Combination pool area, $A_{p(COMBO)}$	4,8 m^2 using equation (6)
Operator intervention pool area, $A_{p(OI)}$	3.4 m^2 using equation (11) considering a pool height h = 10 mm for a normal sandy soil, operator intervention time t_{oi} = 6 hours
Pool shape	2,3 m long x 1,5 m wide using equations (12) & (13) considering a pool with *PAR* = 1,5:1 for nominally flat permeable ground
Pool evaporation, W_e'	0,00105 kg/s using equation (2) considering a 1,0 m wide slice of the pool along the long axis so that $A_{p(OI)}'$ = 2,3 m^2 and the wind over the pool is parallel and in the same direction as the long axis of the pool

Appendix A
Case Study 1 (No drain)

Volumetric release characteristic of the source, Q_c'	0,0269 m^3/s using equation for Q_c from Figures 4 & 5
<u>Effects of release:</u>	
Degree of dilution	Medium (See Figure A.1)
Type of zones(s)	Zone 2
Equipment group and temperature class	IIA T1

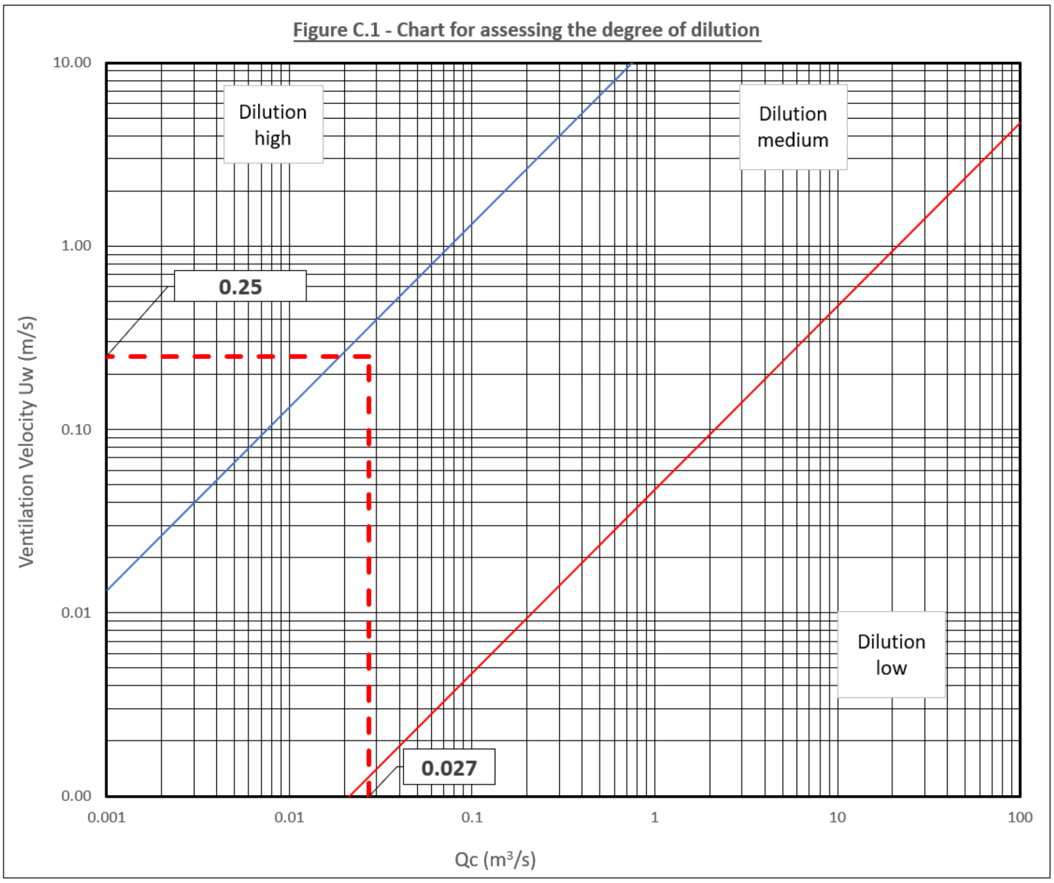


Figure A.1 – Degree of dilution

Case Study 1 (No drain)

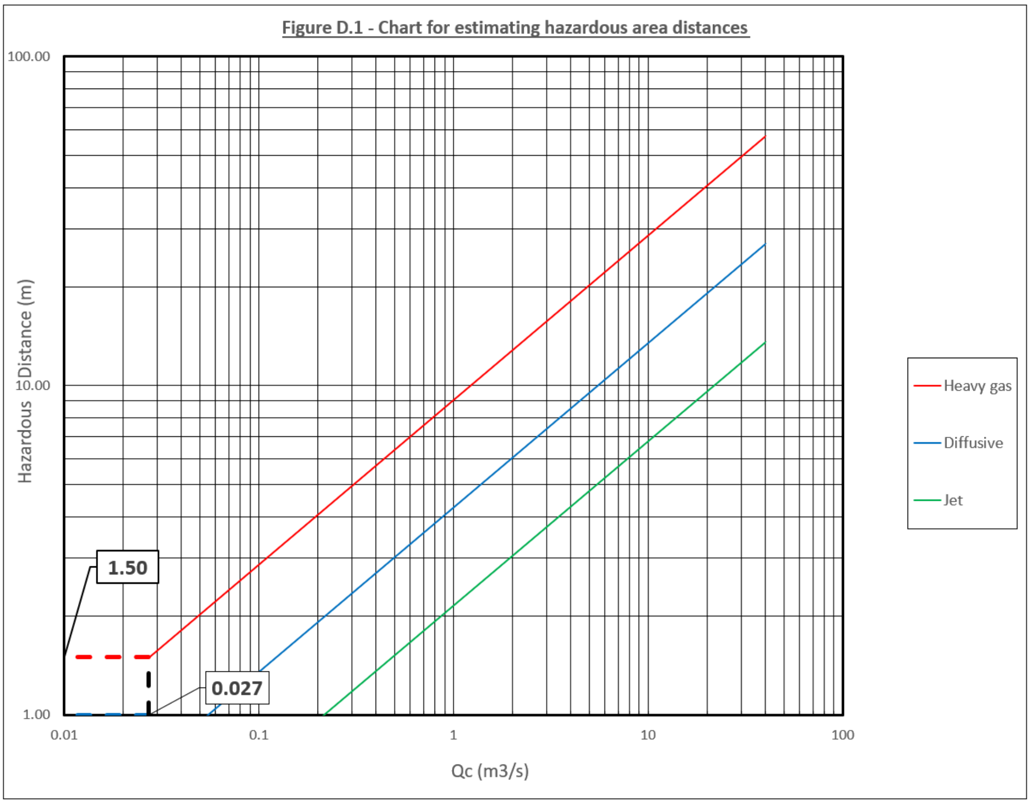
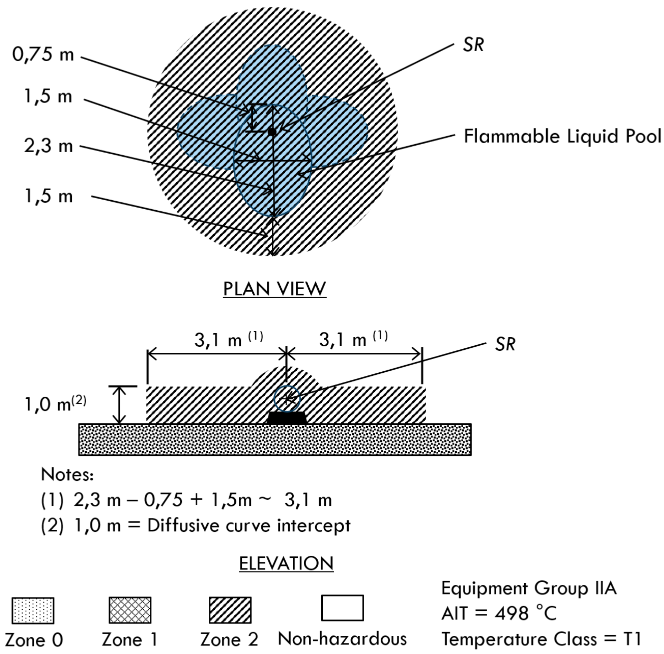


Figure A.2 – Hazardous distance

Hazardous area classification:

Hazardous area distances are based on the assessment from Figure A.2 plus the length of the pool. As the ground is considered flat, the hazardous area will form a circle at approximately 3,1 m out from the source of release.



Appendix B
Case Study 2 (With drain)

A normal industrial pump with mechanical (diaphragm) seal, mounted at ground level, located outdoor on 1° sloped concrete surface located 2,5 m from a drain trench, pumping flammable liquid.

<u>Characteristics of location:</u>

Outdoor situation	Un-obstructed area
Ambient pressure, p_a	101 325 pa
Ambient temperature, T_a	20 °C (293 K)
Ventilation velocity, u_w	0,25 m/s
Ventilation availability	Good (wind speed at calm conditions)

<u>Characteristics of release:</u>

Flammable substance	Benzene (CAS no. 71-43-2)
Molar mass	78,11 kg/kmol
Lower flammable limit, LFL	1,2% vol. (0,012 vol./vol.)
Auto-ignition temperature, AIT	498°C
Vapour density, ρ_g	3,247 kg/m^3 using equation for ρ_g from Figures 4 & 5 considering universal gas constant R= 8314,5 J/kmol K
Source of release, *SR*	Mechanical seal
Grade of release	Secondary (leakage due to seal rupture)
Liquid release rate, *W*	0,0192 kg/s, determined using IEC 60079-10-1 equation B.1 considering a discharge coefficient C_d = 0,75, a hole size S = 5 mm^2, a liquid density ρ = 876,5 kg/m^3 and a pressure difference Δp =15 bar
Maximum theoretical pool area, $A_{p(MTP)}$	41,25 m^2 using equation (3) considering temperature of the liquid T= 20°C, vapour pressure of the liquid at ambient temperature p_v = 10 kPa, (See Note)
Pool shape without drain	13,3 m long x 3,1 m wide using equations (12) & (13) considering a pool with PAR = 4,3:1 for a 1° (2%) impermeable ground slope
Pool area with drain, $A_{p(D)}$	10,1 m^2 using equation (15) considering a pool with PAR = 4,3:1, a distance from the *SR* to the hydrocarbon drain trench d = 2,5 m. and W= 3,1 m
Pool evaporation, W_e'	0,0019 kg/s using equation (2) considering a 1,0 m wide slice of the pool along the long axis so that $A_{p(MTP)}$' = 4,05 m^2 and wind over the pool is parallel and in the same direction as the long axis of the pool
Characteristics of release, Q_c'	0,049 m^3/s using equation for Q_c from Figures 4 & 5

Appendix B
Case Study 2 (With drain)

Effects of release:

Degree of dilution	Medium (See Figure B.1)
Type of zones(s)	Zone 2
Equipment group and temperature class	IIA T1

Note - MTPA used as ground is assumed to be impermeable and operator intervention is irrelevant as the 'pool' size will have reached equilibrium well before the operators intervene.

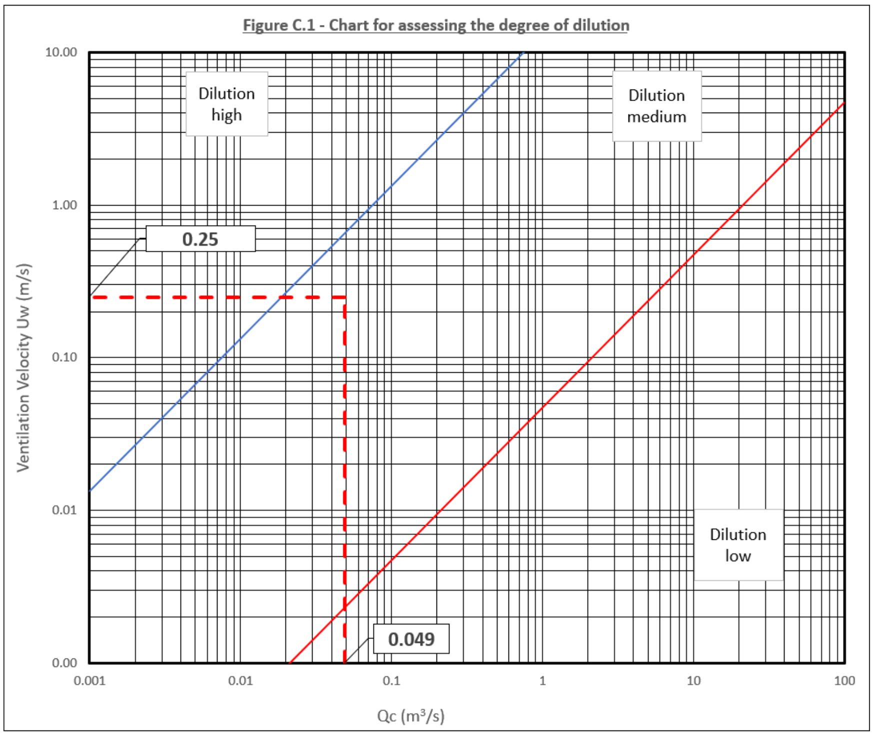


Figure B.1 – Hazardous distance

Appendix B
Case Study 2 (With drain)

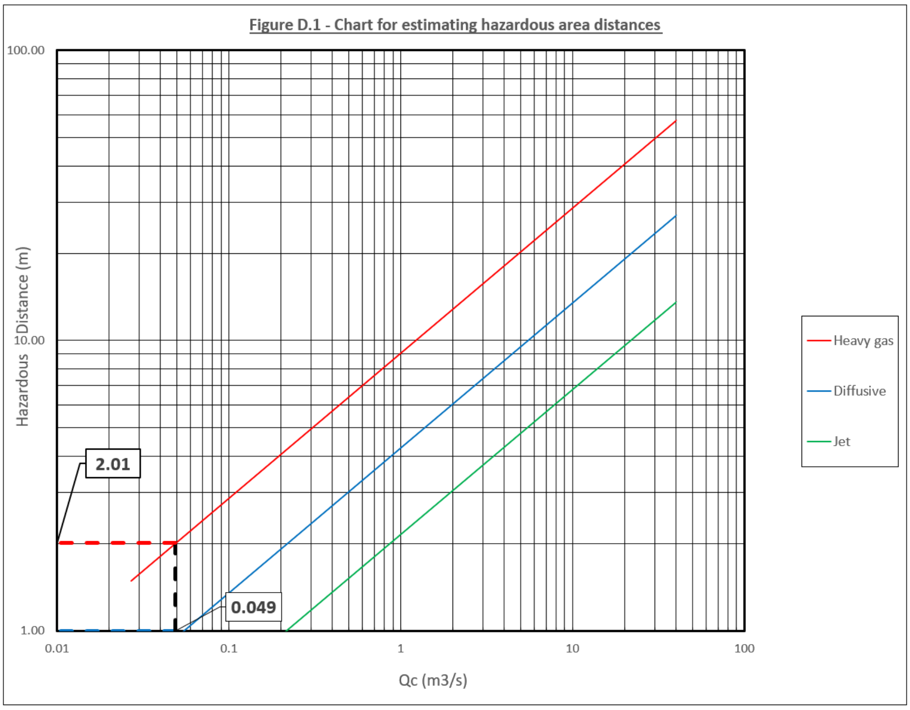


Figure B.2 – Hazardous distance

Hazardous area classification:

Hazardous area distances are based on the assessment from Figure B.2 plus the length of the pool.