UNIVERSITI SAINS MALAYSIA

Second Semester Examination
2015/2016 Academic Session

June 2016

EKC 367 – Plant Safety
[Keselamatan Loji]

Duration : 3 hours
[Masa : 3 jam]

Please ensure that this examination paper contains NINE printed pages and SIX printed pages of Appendix before you begin the examination.

[Sila pastikan bahawa kertas peperiksaan ini mengandungi SEMBILAN muka surat yang bercetak dan ENAM muka surat Lampiran sebelum anda memulakan peperiksaan ini.]

Instruction: Answer **ALL** questions.

*[**Arahan:** Jawab **SEMUA** soalan.]*

In the event of any discrepancies, the English version shall be used.

[Sekiranya terdapat sebarang percanggahan pada soalan peperiksaan, versi Bahasa Inggeris hendaklah diguna pakai].

Answer ALL questions.

1. [a] As a safety engineer, under what circumstance would you recommend air-purifying respirators?

[2 marks]

[b] Figure Q.1.[b] shows the curves for toxic response versus log dose. From the figure, briefly explain the notations for ED_{10}, ED_{50}, TD_{50}, and LD_{90}.

[4 marks]

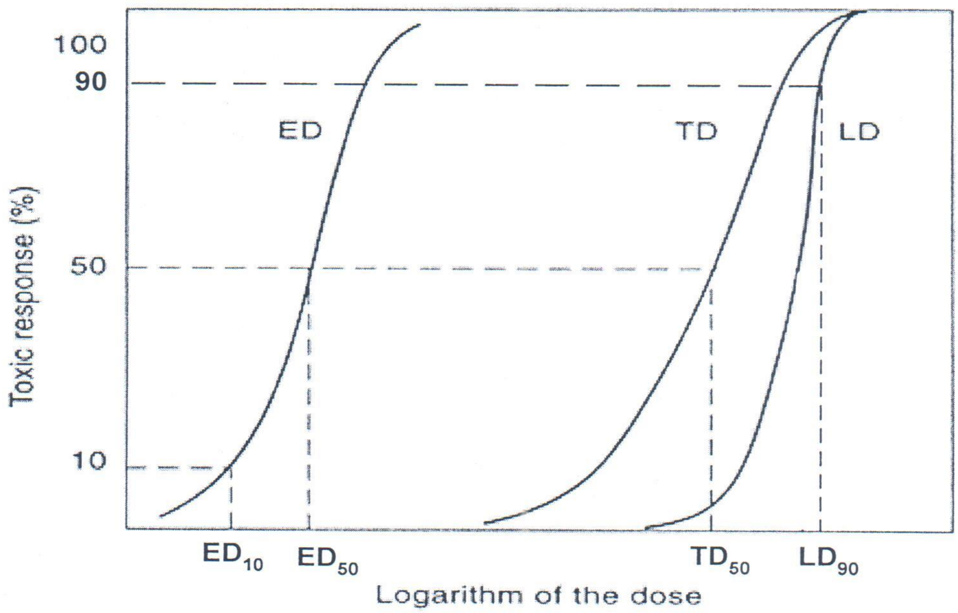


Figure Q.1.[b]

[c] The following air samples shows the following contaminant concentrations in 8-hour shift (from 8:00 A.M. to 4:00 P.M.)

- Propylene: 0.03% from 11:00 A.M. to 2.00 P.M.
- Phosphine: 0.1 ppm (full-shift)
- Phosgene: 1.2 ppm at 2:00 P.M. with duration of 15 minutes

[i] Determine the 8-hour TLV-TWA for this gas mixture exposure.

[5 marks]

[ii] Conclude your results related to workplace exposure.

[1 mark]

[d] A 1 m diameter storage vessel containing ethyl acetate has been used to produce 2-methoxyethyl acetate in a chemical research laboratory. This laboratory is equipped with perfect ventilation. The temperature and pressure inside this laboratory are controlled at 30 °C and 1 atm, respectively. There is an incident happen due to the carelessness of the worker where the lid of the vessel is left open after being filled with 130 L of ethyl acetate.

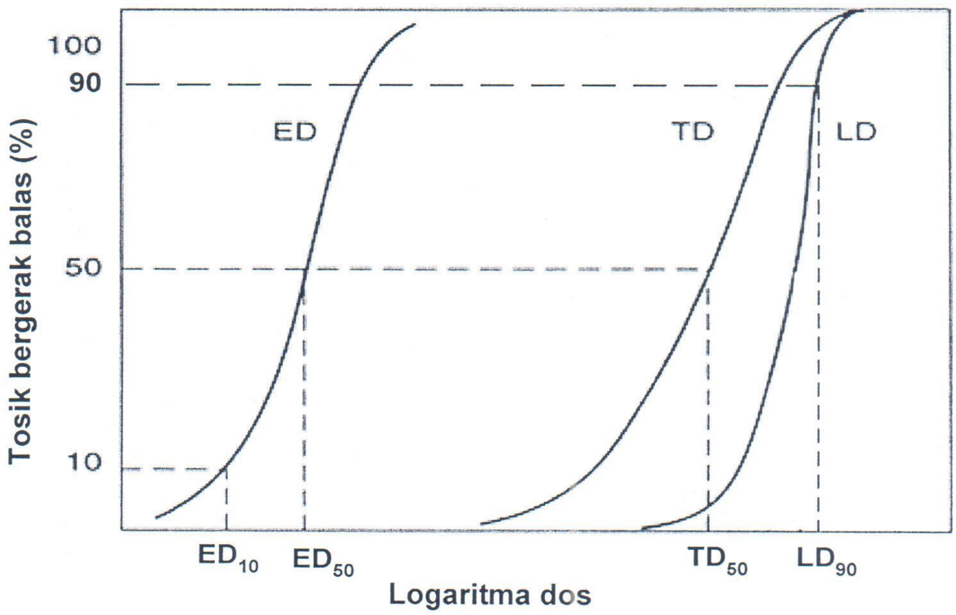
Jawab SEMUA soalan.

1. [a] *Sebagai seorang jurutera keselamatan, dalam keadaan apakah anda akan cadangkan penggunaan respirator penapisan udara?*

[2 markah]

[b] *Rajah S.1.[b] menunjukkan lengkung toksik bergerak balas lawan log dos. Dari rajah tersebut, terangkan secara ringkas notasi untuk ED_{10}, ED_{50}, TD_{50}, dan LD_{90}.*

[4 markah]



Rajah S.1.[b]

[c] *Sampel udara berikut menunjukkan kepekatan bahan cemar dalam masa giliran 8-jam (dari 8:00 A.M. hingga 4:00 P.M.)*

- *Propilena: 0.03% dari 11:00 A.M. hingga 2.00 P.M.*
- *Fosfina: 0.1 ppm (masa giliran penuh)*
- *Fosgen: 1.2 ppm pada 2:00 P.M. dengan tempoh 15 minit*

[i] *Tentukan masa giliran 8-jam TLV-TWA untuk pendedahan campuran gas ini.*

[5 markah]

[ii] *Berikan kesimpulan atas keputusan anda yang berkaitan dengan pendedahan tempat kerja.*

[1 markah]

[d] *Bekas simpanan berdiameter 1 m mengandungi etil asetat telah digunakan untuk menghasilkan 2-metoksietil asetat di dalam makmal kajian kimia. Makmal ini dilengkapi pengudaraan sempurna. Suhu dan tekanan di dalam makmal dikawal masing-masing pada 30 ℃ dan 1 atm. Ada kejadian yang berlaku yang disebabkan kecuaian pekerja dimana penutup bekas telah dibiarkan terbuka setelah diisi dengan 130 L etil asetat.*

[i] Calculate the time (in min) required to evaporate all the ethyl acetate inside the storage vessel

[8 marks]

[ii] Determine the concentration of ethyl acetate (in ppm) near the vessel, if the local ventilation rate is 25 m^3/min.

[4 marks]

[iii] Conclude your results in part [ii] in term of workplace incident exposure.

[1 mark]

Data:
Molecular weight of ethyl acetate = 88.10
Molecular weight of water = 18
Mass transfer coefficient (water) = 0.83 cm/s
$SG_{ethyl\ acetate} = 0.902$
$\rho_{water} = 1$ g/cm^3
TLV-TWA (ethyl acetate) = 400 ppm

2. [a] Fire and explosion are two primary hazards associated with flammable and combustible liquids. In general, which one is more hazardous, flammable or combustible liquids? Explain why.

[3 marks]

[b] Momentum and buoyancy of the initial material released are the parameter affecting atmospheric dispersion of toxic materials. With the aid of a suitable figure, discuss what do you understand about the momentum and buoyancy of the initial material released.

[3 marks]

[c] Hydrogen sulfide is being stored in a pressurized cylinder of 8.0 atm at temperature of 25 °C. During inspection by lab technician, a small hole is found creating a gas leakage from the cylinder. Calculate the diameter (in mm) of the hole which gives to local hydrogen sulfide concentration of 30 ppm if the local ventilation rate is 75 m^3/min and the discharge coefficient is uncertain. Assume a non ideal mixing factor of 0.5 and ambient pressure of 1 atm.

[10 marks]

[d] Risk assessment to identify potential emergency scenario has been conducted in a 370,000 tonne/year ammonia plant in order to develop emergency evacuation response plans. The ammonia plant is located in a rural area. One of the identified scenario is ammonia pipeline rupture accident. If the pipeline rupture, ammonia will be released at 273 kg/min and it is decided that anyone exposed to more than 100 ppm of ammonia must be evacuated until the repair of pipeline is made. What evacuation distance downwind (in m) will you recommend? Assume ambient condition of 25 °C and 1 atm, steady state plume, leak at ground level, the stability class is F and 2 m/s wind speed (for worst-case conditions).

[9 marks]

[i] *Kirakan masa (dalam minit) yang diperlukan untuk menyejatkan kesemua etil asetat di dalam bekas simpanan.*

[8 markah]

[ii] *Tentukan kepekatan etil asetat (dalam ppm) berdekatan bekas, jika kadar pengudaraan tempatan adalah 25 m^3/min.*

[4 markah]

[iii] *Berikan kesimpulan jawapan anda di bahagian [ii] berdasarkan pendedahan kejadian tempat kerja.*

[1 markah]

Data:
Berat molekul etil asetat = 88.10
Berat molekul air = 18
Pekali pemindahan jisim (air) = 0.83 sm/s
$GT_{etil\ asetat} = 0.902$
$\rho air = 1\ g/sm^3$
TLV-TWA (etil asetat) = 400 ppm

2. [a] *Api dan letupan adalah dua bahaya utama yang dikaitkan dengan cecair mudah bakar dan boleh bakar. Secara amnya, manakah yang lebih merbahaya, cecair mudah bakar atau cecair boleh bakar? Terangkan mengapa.*

[3 markah]

[b] *Momentum dan keapungan bahan awal yang dibebaskan adalah salah satu parameter yang mempengaruhi penyebaran atmosfera bahan toksik. Dengan bantuan gambarajah yang sesuai, bincangkan apakah yang anda faham dengan momentum dan keapungan bahan awal yang dibebaskan ini.*

[3 markah]

[c] *Hidrogen sulfida telah disimpan di dalam silinder bertekanan 8.0 atm pada suhu 25 °C. Semasa pemeriksaan oleh juruteknik makmal, lubang kecil telah dijumpai yang menyebabkan kebocoran gas dari silinder tersebut. Kirakan diameter lubang (dalam mm) yang membawa kepada kepekatan hidrogen sulfida tempatan 30 ppm jika kadar pengudaraan tempatan adalah 75 m^3/min dan pekali kadar alir adalah tak pasti. Andaikan faktor pencampuran tak ideal ialah 0.5 dan tekanan persekitaran ialah 1 atm.*

[10 markah]

[d] *Penilaian risiko untuk mengenal pasti keupayaan senario kecemasan telah dijalankan di sebuah loji amonia berkapasiti 370,000 ton/tahun bagi mendapatkan pelan gerak balas pemindahan kecemasan. Loji amonia ini berada di kawasan luar bandar. Salah satu senario yang dikenalpasti adalah kemalangan talian paip pecah. Sekiranya talian paip ini pecah, amonia akan dibebaskan dengan kelajuan 273 kg/min dan diputuskan bahawa sesiapa yang terdedah kepada amonia lebih daripada 100 ppm harus berpindah sehingga talian paip dibaiki. Berapakah jarak pemindahan ikut angin (dalam m) yang akan anda cadangkan? Andaikan keadaan persekitaran adalah 25 °C dan 1 atm, plum berkeadaan mantap, kebocoran di aras bumi, kelas kestabilan F dan kelajuan angin ialah 2 m/s (untuk keadaan kes paling buruk).*

[9 markah]

3. [a] Describe the following hazard analyses in design phase of system development:

[i] Contribution of the Inherently Safety Design (ISD) approach.

[2 marks]

[ii] Contribution of Preliminary Hazard List (PHL) to the overall system safety hazard identification.

[2 marks]

[iii] State 3 categories of system information produced by Preliminary Hazard Analysis (PHA) but not produced by PHL.

[6 marks]

[b] Reactor safety study is performed to determine the risk associated with the nuclear power plant. An initial event is initiated as "pipe break in the cooling subsystem" and to identify all the safety system that can mitigate the consequences of fission release. If electric power does not fail during pipe break, the Emergency Core Cooling System (ECCS) will be initiated. The failure of both pipe breaking and corresponding loss of electrical power to the plant would lead to a very large fission release. The ECCS could be either succeed or fail. If the ECCS succeeds, the fission product removal will be carried out and leads to a small release. If the case of ECCS failure, the fission product removal will not be carried out and leads to a very large release. Safety containment to prevent the accidental release of radioactive material from a reactor is designed after fission product removal. The failure of the both fission product removal and safety containment after the success of ECSS would lead to a large release.

[i] Use the probability of failure for the 4 safety functions shown in Table Q.3. [b], develop an event tree for this system with the Initial Event as "pipe break in the cooling subsystem".

[5 marks]

Table Q.3. [b]

Description	Probability of failure
ECCS system to cool the reactor	0.01
Electricity to start the ECCS system	0.001
Safety containment after fission product removal	0.004
Fission product removal procedure	0.002

[ii] Calculate the probability of each final event category (very small release, small release, large release and very large release) in the event tree.

[3 marks]

[iii] The initial event frequency is 20/year on the event tree. For each final event of your tree, calculate the final event frequency.

[3 marks]

3. [a] *Jelaskan analisis bahaya berikut dalam fasa rekabentuk pembangunan sistem:*

[i] *Sumbangan pendekatan Kewujudan Rekabentuk Lebih Selamat (ISD).*

[2 markah]

[ii] *Sumbangan Senarai Bahaya Awal (PHL) untuk pengenalpastian sistem keseluruhan bahaya keselamatan.*

[2 markah]

[iii] *Nyatakan 3 kategori maklumat sistem yang dihasilkan oleh Analisis Bahaya Awal (PHA) tetapi tidak dikemukakan oleh PHL.*

[6 markah]

[b] *Kajian keselamatan reaktor telah dijalankan untuk menentukan risiko yang berkaitan dengan loji tenaga nuklear. Acara awal dimulai sebagai "paip pecah dalam subsistem penyejukan" dan untuk mengenal pasti semua sistem keselamatan yang boleh mengurangkan kesan akibat pelepasan pembelahan. Jika kuasa elektrik tidak gagal semasa paip pecah, Sistem Kecemasan Penyejukan Teras (ECCS) akan dimulakan. Kegagalan kedua-dua pecah paip dan kegagalan kuasa elektrik ke kilang akan menyebabkan pelepasan pembelahan yang sangat besar. ECCS mungkin boleh berjaya fungsi atau gagal. Jika ECCS berjaya, penyingkiran produk pembelahan akan dijalankan dan menyebabkan pelepasan pembelahan kecil. Sekiranya ECCS mengalami kegagalan, penyingkiran produk pembelahan tidak dapat dijalankan dan akan menyebabkan pelepasan pembelahan yang sangat besar. Pengurungan keselamatan untuk mengelakkan pelepasan bahan radioaktif secara tidak sengaja dari reaktor telah direka selepas penyingkiran produk pembelahan. Kegagalan kedua-dua penyingkiran produk pembelahan dan pengurungan keselamatan selepas kejayaan ECCS akan menyebabkan pelepasan pembelahan yang besar.*

[i] *Gunakan kebarangkalian kegagalan untuk 4 fungsi keselamatan yang ditunjukkan dalam Jadual S.3.[b], bangunkan pokok acara untuk sistem ini dengan menggunakan acara mula sebagai "paip pecah dalam subsistem penyejukan".*

[5 markah]

Jadual S.3.[b]

Penerangan	*Kebarangkalian kegagalan*
Sistem ECCS untuk menyejukkan reaktor	*0.01*
Elektrik untuk memulakan sistem ECCS	*0.001*
Pengurungan keselamatan selepas penyingkiran produk pembelahan	*0.004*
Prosedur penyingkiran produk pembelahan	*0.002*

[ii] *Hitungkan kebarangkalian untuk setiap kategori acara akhir (pelepasan sangat kecil, pelepasan kecil, pelepasan besar dan pelepasan sangat besar) dalam pokok acara.*

[3 markah]

[iii] *Kekerapan acara mula ialah 20/tahun untuk pokok acara tersebut. Kirakan kekerapan acara untuk setiap acara akhir dalam pokok anda.*

[3 markah]

[iv] For each final event category (very small release, small release, large release and very large release), calculate the total frequency of all scenarios leading to that final event category.

[4 marks]

4. [a] What are the differences between HAZOP and HAZID.

[4 marks]

[b] Explain the key materials and procedures to complete a HAZOP analysis.

[5 marks]

[c] Phosphoric acid and ammonia are mixed to produce diammonium phosphate (DAP), as shown in Figure Q.4.[c]. If too little phosphoric acid is added, the reaction is incomplete, and ammonia is in excess. Too little ammonia available to the reactor results in a safe but undesirable product purity. Both raw materials will be used in large quantities and in concentrated form. Perform HAZOP analysis on the node of "phosphoric acid delivery line" by using the following guidewords and parameters:

[16 marks]

[i] Less Flow

[ii] Part of Concentration

[iii] Other than Material

[iv] No Flow

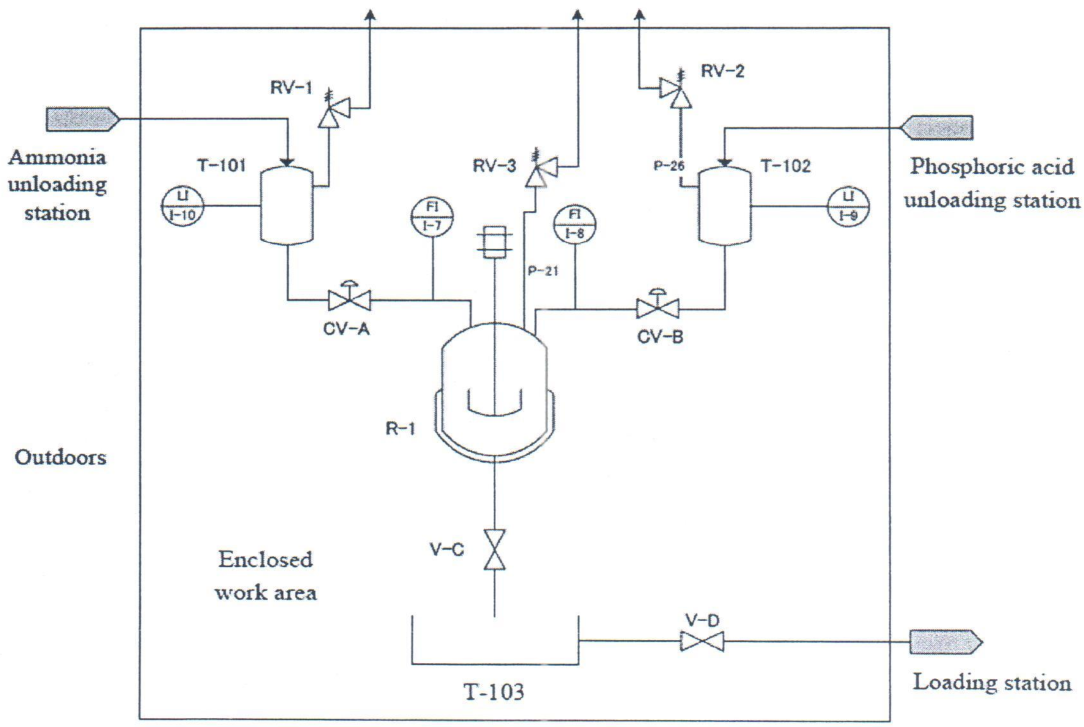


Figure Q.4.[c].

[iv] Untuk setiap kategori acara akhir (pelepasan sangat kecil, pelepasan kecil, pelepasan besar dan pelepasan sangat besar), kirakan jumlah kekerapan untuk semua keadaan yang membawa kepada yang kategori acara akhir tersebut.

[4 markah]

4. *[a] Apakah perbezaan antara HAZOP dan HAZID.*

[4 markah]

[b] Terangkan elemen-elemen penting dan prosedur untuk melengkapkan analisis HAZOP.

[5 markah]

[c] Asid fosforik dan amonia dicampur untuk menghasilkan fosfat diammonium (DAP), seperti yang ditunjukkan dalam Rajah S.4 [c]. Jika asid fosforik terlalu sedikit ditambah, tindak balas adalah tidak lengkap, dan amonia adalah dalam lebihan. Terlalu sedikit amonia dalam reaktor menghasilkan produk yang selamat tetapi ketulenan produk yang tidak diingini. Kedua-dua bahan mentah akan digunakan dalam kuantiti yang besar dan dalam kepekatan tinggi. Lakukan analisis HAZOP untuk nod "saluran paip penghantaran fosforik asid" dengan menggunakan panduan-kata dan parameter berikut:

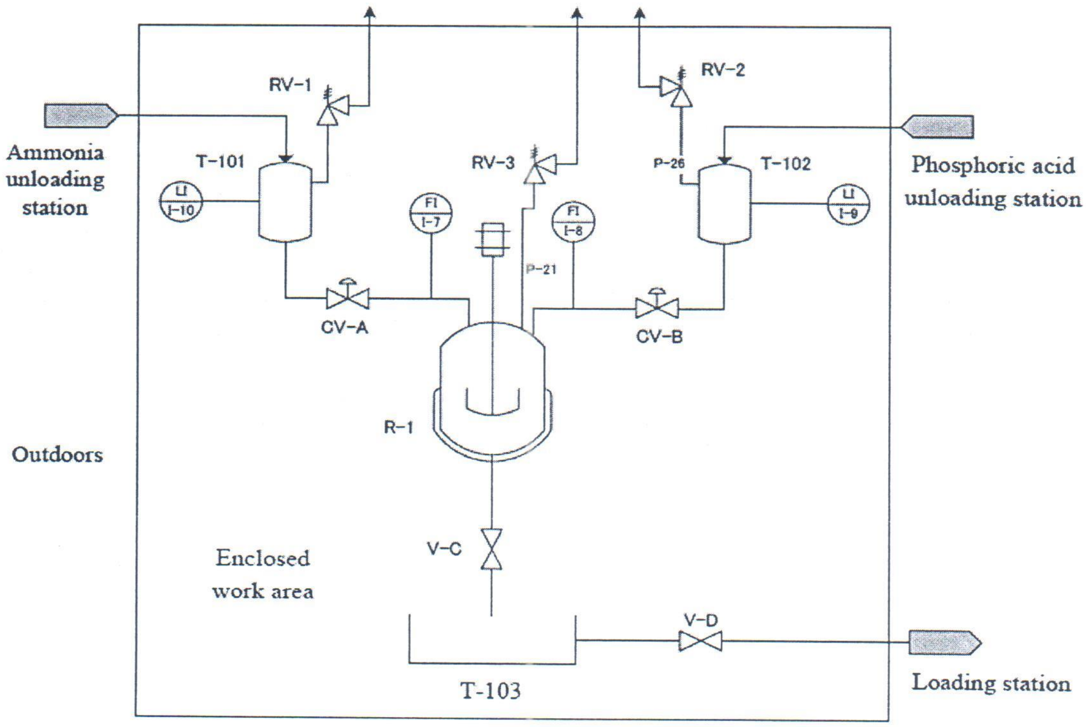
[16 markah]

[i] Aliran Rendah

[ii] Sebahagian Kepekatan

[iii] Selain daripada Bahan

[iv] Tiada Aliran



Rajah S.4 [c].

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Appendix

Formulae

$$TWA = \frac{1}{8}\int_0^{t_w} C(t)\,dt$$

$$TWA = \frac{C_1T_1 + C_2T_2 + \cdots + C_nT_n}{8\ hr}$$

$$\sum_{i=1}^{n} \frac{C_i}{(TLV - TWA)_i}$$

$$\int \frac{dP}{\rho} + \Delta\left(\frac{\bar{u}^2}{2\alpha g_c}\right) + \frac{g}{g_c}\Delta z + F = -\frac{W_s}{\dot{m}}$$

$$C_{ppm} = 0.08205\left[\frac{T}{PM}\right]\left(\frac{mg}{m^3}\right)$$

$$C_{ppm} = \frac{P^{sat}}{kQ_vP}(\phi r_f V_c + KA) x\ 10^6$$

$$C_{ppm} = \frac{Q_m R_g T}{kQ_v PM}\ x\ 10^6$$

$$C_{ppm} = \frac{KAP^{sat}}{kQ_vP}\ x\ 10^6$$

$$Q_m = \frac{MKAP^{sat}}{R_g T_L}$$

$$(Q_m)_{choked} = C_0AP_0\sqrt{\frac{\gamma g_c M}{R_g T_0}\left(\frac{2}{\gamma+1}\right)^{(\gamma+1)/(\gamma-1)}}$$

$$K = aD^{2/3}$$

$$K = K_o\left[\frac{M_o}{M}\right]^{1/3}$$

$$\frac{P_{choked}}{P_0} = \left(\frac{2}{\gamma+1}\right)^{\gamma/(\gamma-1)}$$

$$\langle C\rangle(x,0,0) = \frac{Q_m}{\pi\sigma_y\sigma_z u}$$

$$\langle C\rangle(x,y,0) = \frac{Q_m}{\pi\sigma_y\sigma_z u}\exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2\right]$$

$$\langle C\rangle(x,y,z) = \frac{Q_m}{\pi\sigma_y\sigma_z u}\exp\left[-\frac{1}{2}\left(\frac{y^2}{\sigma_y^2}+\frac{z^2}{\sigma_z^2}\right)\right]$$

$$\langle C\rangle(x,0,0) = \frac{Q_m}{\pi\sigma_y\sigma_z u}\exp\left[-\frac{1}{2}\left(\frac{H_r}{\sigma_z}\right)^2\right]$$

$$\langle C\rangle(x,y,0,t) = \frac{Q_m^*}{\sqrt{2}\,\pi^{3/2}\sigma_x\sigma_y\sigma_z}\exp\left[-\frac{1}{2}\left\{\left(\frac{x-ut}{\sigma_x}\right)^2+\frac{y^2}{\sigma_y^2}\right\}\right]$$

$$A = \frac{\pi d^2}{4}$$

$$u = \frac{\text{Rate of flow}}{A}$$

$$V = Ah = \frac{m}{\rho}$$

$$\ln(P^{sat}) = A - \frac{B}{C+T}$$, where P^{sat} in $mmHg$ and T in K

Conversion & constants

1 atm = 101325 N/m^2 = 101325 Pa = 14.696 psia = 760 mm Hg
1 N = 1 kg.m/s^2
1 J = 1 N.m
1 L = 1000 cm^3 = 10^{-3} m^3 = 0.0353 ft^3 = 0.264 gal
1 m = 3.2808 ft = 39.37 in.
1 kg = 2.2046 lbm
1% = 10^4 ppm
R_g = 82.06 × 10^{-3} m^3.atm/kgmol.K = 8314.34 J/kgmol.K = 8314.34 kg.m^2/s^2.kgmol.K = 1.9872 cal/gmol.K
g = 9.8 m/s^2 = 32.174 ft/s^2
g_c = 1 kg.m/N.s^2 = 32.174 lbm.ft/lbf.s^2

Table 1

Atmospheric Stability Classes for Use with the Pasquill-Gifford Dispersion Model[1,2]

Surface wind speed (m/s)	Daytime insolation[3]			Nighttime conditions[4]	
	Strong	Moderate	Slight	Thin overcast or >4/8 low cloud	≤3/8 cloudiness
<2	A	A–B	B	F[5]	F[5]
2–3	A–B	B	C	E	F
3–4	B	B–C	C	D[6]	E
4–6	C	C–D	D[6]	D[6]	D[6]
>6	C	D[6]	D[6]	D[6]	D[6]

Stability classes:
- A, extremely unstable
- B, moderately unstable
- C, slightly unstable
- D, neutrally stable
- E, slightly stable
- F, moderately stable

[1]F. A. Gifford, "Use of Routine Meteorological Observations for Estimating Atmospheric Dispersion," *Nuclear Safety* (1961), 2(4): 47.
[2]F. A. Gifford, "Turbulent Diffusion-Typing Schemes: A Review," *Nuclear Safety* (1976), 17(1): 68.
[3]Strong insolation corresponds to a sunny midday in midsummer in England. Slight insolation to similar conditions in midwinter.
[4]Night refers to the period 1 hour before sunset and 1 hour after dawn.
[5]These values are filled in to complete the table.
[6]The neutral category D should be used, regardless of wind speed, for overcast conditions during day or night and for any sky conditions during the hour before or after sunset or sunrise, respectively.

Table 2

Recommended Equations for Pasquill-Gifford Dispersion Coefficients for Plume Dispersion[1,2] (the downwind distance x has units of meters)

Pasquill-Gifford stability class	σ_y (m)	σ_z (m)
Rural conditions		
A	$0.22x(1 + 0.0001x)^{-1/2}$	$0.20x$
B	$0.16x(1 + 0.0001x)^{-1/2}$	$0.12x$
C	$0.11x(1 + 0.0001x)^{-1/2}$	$0.08x(1 + 0.0002x)^{-1/2}$
D	$0.08x(1 + 0.0001x)^{-1/2}$	$0.06x(1 + 0.0015x)^{-1/2}$
E	$0.06x(1 + 0.0001x)^{-1/2}$	$0.03x(1 + 0.0003x)^{-1}$
F	$0.04x(1 + 0.0001x)^{-1/2}$	$0.016x(1 + 0.0003x)^{-1}$
Urban conditions		
A–B	$0.32x(1 + 0.0004x)^{-1/2}$	$0.24x(1 + 0.0001x)^{+1/2}$
C	$0.22x(1 + 0.0004x)^{-1/2}$	$0.20x$
D	$0.16x(1 + 0.0004x)^{-1/2}$	$0.14x(1 + 0.0003x)^{-1/2}$
E–F	$0.11x(1 + 0.0004x)^{-1/2}$	$0.08x(1 + 0.0015x)^{-1/2}$

A–F are defined in Table 5-1.
[1]R. F. Griffiths, "Errors in the Use of the Briggs Parameterization for Atmospheric Dispersion Coefficients," *Atmospheric Environment* (1994), 28(17): 2861–2865.
[2]G. A. Briggs, *Diffusion Estimation for Small Emissions*, Report ATDL-106 (Washington, DC: Air Resources, Atmospheric Turbulence, and Diffusion Laboratory, Environmental Research Laboratories, 1974).

Table 3

Recommended Equations for Pasquill-Gifford Dispersion Coefficients for Puff Dispersion[1,2] (the downwind distance x has units of meters)

Pasquill-Gifford stability class	σ_y (m) or σ_x (m)	σ_z (m)
A	$0.18x^{0.92}$	$0.60x^{0.75}$
B	$0.14x^{0.92}$	$0.53x^{0.73}$
C	$0.10x^{0.92}$	$0.34x^{0.71}$
D	$0.06x^{0.92}$	$0.15x^{0.70}$
E	$0.04x^{0.92}$	$0.10x^{0.65}$
F	$0.02x^{0.89}$	$0.05x^{0.61}$

A–F are defined in Table 5-1.

[1] R. F. Griffiths, "Errors in the Use of the Briggs Parameterization for Atmospheric Dispersion Coefficients," *Atmospheric Environment* (1994), 28(17): 2861–2865.

[2] G. A. Briggs, *Diffusion Estimation for Small Emissions*, Report ATDL-106 (Washington, DC: Air Resources, Atmospheric Turbulence, and Diffusion Laboratory, Environmental Research Laboratories, 1974).

Table 4

Heat Capacity Ratios γ for Selected Gases

Gas	Chemical formula or symbol	Approximate molecular weight (M)	Heat capacity ratio $\gamma = C_p/C_v$
Acetylene	C_2H_2	26.0	1.30
Air	–	29.0	1.40
Ammonia	NH_3	17.0	1.32
Argon	Ar	39.9	1.67
Butane	C_4H_{10}	58.1	1.11
Carbon dioxide	CO_2	44.0	1.30
Carbon monoxide	CO	28.0	1.40
Chlorine	Cl_2	70.9	1.33
Ethane	C_2H_6	30.0	1.22
Ethylene	C_2H_4	28.0	1.22
Helium	He	4.0	1.66
Hydrogen	H_2	2.0	1.41
Hydrogen chloride	HCl	36.5	1.41
Hydrogen sulfide	H_2S	34.1	1.30
Methane	CH_4	16.0	1.32
Methyl chloride	CH_3Cl	50.5	1.20
Natural gas	–	19.5	1.27
Nitric oxide	NO	30.0	1.40
Nitrogen	N_2	28.0	1.41
Nitrous oxide	N_2O	44.0	1.31
Oxygen	O_2	32.0	1.40
Propane	C_3H_8	44.1	1.15
Propene (propylene)	C_3H_6	42.1	1.14
Sulfur dioxide	SO_2	64.1	1.26

Table 5

Saturation vapor pressure data

Species	Formula	Range(K)	A	B	C
Acetone	C_3H_6O	241–350	16.6513	2940.46	−35.93
Benzene	C_6H_6	280–377	15.9008	2788.51	−52.36
Carbon tetrachloride	CCl_4	253–374	15.8742	2808.19	−45.99
Chloroform	$CHCl_3$	260–370	15.9732	2696.79	−46.19
Cyclohexane	C_6H_{12}	280–380	15.7527	2766.63	−50.50
Ethyl acetate	$C_4H_8O_2$	260–385	16.1516	2790.50	−57.15
Ethyl alcohol	C_2H_6O	270–369	18.9119	3803.98	−41.68
n-Heptane	C_7H_{16}	270–400	15.8737	2911.32	−56.51
n-Hexane	C_6H_{14}	245–370	15.8366	2697.55	−48.78
Methyl alcohol	CH_4O	257–364	18.5875	3626.55	−34.29
n-Pentane	C_5H_{12}	220–330	15.8333	2477.07	−39.94
Toluene	$C_6H_5CH_3$	280–410	16.0137	3096.52	−53.
Water	H_2O	284–441	18.3036	3816.44	−46.11

Table 6

Hazardous Chemicals Data for a Variety of Chemical Substances

Compound	Molecular Weight	Threshold limit value[a] (TLV) TWA ppm	STEL ppm	C ppm	OSHA[b] 8-hour PEL ppm	NFPA ratings[c] Health	Flammability	Instability
Ozone	48.00				0.1			
Heavy work:		0.05						
Moderate work:		0.08						
Light work:		0.10						
<2 hours:		0.20						
Pentane, all isomers	72.15	600			1000	1	4	[illegible]
Phenol	94.11	5			5^{S}	4	2	0
Phosgene	98.92	0.1			0.1	4	0	1
Phosphine	34.00	0.3			0.3	4	4	2
Phosphoric acid	98.00	1 mg/m³	3 mg/m³		1 mg/m³	3	0	0
Phthalic anhydride	148.11	1			2	3	1	0
Picric acid	229.11	0.1 mg/m³			0.1 mg/m³	3	4	4
Polyvinyl chloride		1 mg/m³						
Propylene	42.08	500				1	4	1
Propylene oxide	58.08	2			100	3	4	2
Pyridine	79.10	1			5	3	3	0
Sodium	22.9					3	3	2[W]
Sodium cyanide	49.0					3	0	0
Sodium hydroxide	40.0			2 mg/m³	2 mg/m³	3	0	1
Styrene, monomer	104.16	20	40		2 mg/m³	2	3	2
Sulfur dioxide, liq.	64.07		0.25		5	3	0	0
Sulfuric acid, aq.	–	0.2 mg/m³			1 mg/m³	3	0	2[W]
Tetrachloroethylene	165.80	25	100		2 mg/m³	2	0	0
Toluene	92.13	20			2 mg/m³	2	3	0
Trichloroethylene	131.40	10	25		2 mg/m³	2	1	0
Triethylamine	101.19	1	3			3	3	0

…6/-

Table 7

Nonideal Mixing Factor k for Various Dilution Ventilation Conditions[a]

Vapor concentration (ppm)	Dust concentration (mppcf)	Mixing factor: Ventilation condition			
		Poor	Average	Good	Excellent
over 500	50	1/7	1/4	1/3	1/2
101–500	20	1/8	1/5	1/4	1/3
0–100	5	1/11	1/8	1/7	1/6

[a]Sax, *Dangerous Properties*, p. 29. The values reported here are the *reciprocal* of Sax's values.