UNIVERSITI SAINS MALAYSIA

Second Semester Examination
2016/2017 Academic Session

June 2017

EKC 367 – Plant Safety
[Keselamatan Loji]

Duration : 3 hours
[Masa : 3 jam]

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

[Sila pastikan bahawa kertas peperiksaan ini mengandungi TIGA BELAS muka surat yang bercetak dan TUJUH muka surat Lampiran sebelum anda memulakan peperiksaan ini.]

Instruction: Answer **ALL** (4) questions.

*[**Arahan:** Jawab **SEMUA** (4) 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 <u>ALL</u> questions.

1. [a] The most common example of local ventilation is the hood. Briefly explain the difference between standard utility and standard bypass laboratory hoods.

[4 marks]

[b] Most accidents follow a three-step sequence. Briefly explain in theory and in practice, how to eliminate the accident process based on this sequence.

[4 marks]

[c] Analyze the potential deaths resulting from the exposure of $2.86 \times 10^{16} \mu g/m^3$ SO_2 for 43 min.

<u>Data:</u>

At STP condition, 1 mole of an ideal gas occupies 22.4 L
MW SO_2 = 64

[10 marks]

[d] A worker was exposed to n-butyl acetate (*TLV-TWA* of 150 ppm) at his workplace. He began a work shift at 8:00 am and completed the shift at 5:00 pm. A 1 h lunch break was included between 12 noon and 1:00 pm, where it can be assumed that no exposure to the chemical. Data were taken in the work area at the times as indicated in Table Q.1 [d]. Has the worker been overexposed?

Table Q.1 [d] : Time–concentration data of n-butyl acetate

Time	Concentration (ppm)
8:00	110
9:00	130
10:00	143
11:00	162
12:00	142
1:00	157
2:00	159
3:00	165
4:00	153
5:00	130

[7 marks]

Jawab *<u>SEMUA</u>* *soalan*

1. [a] *Contoh yang paling lazim bagi pengudaraan setempat adalah tudung. Terangkan secara ringkas perbezaan di antara tudung makmal utiliti piawai dan pintas piawai.*

[4 markah]

[b] *Kebanyakan kemalangan berlaku mengikut tiga langkah turutan. Terangkan secara teori dan amalan, bagaimana untuk menghindari proses kemalangan berdasarkan turutan tersebut.*

[4 markah]

[c] *Buat analisis potensi kematian akibat dari pendedahan $2.86 \times 10^{16} \mu g/m^3$ SO_2 selama 43 minit.*

<u>Data:</u>

Pada keadaan STP, 1 mol gas ideal mengisi 22.4 L.
Jisim molekul SO_2 = 64

[10 markah]

[d] *Seorang pekerja terdedah kepada n-butil asetat (*TLV-TWA *= 150 ppm) di tempat kerjanya. Dia memulakan kerja pada 8:00 pagi dan tamat pada 5:00 petang. 1 jam waktu makan tengah hari termasuk dalam masa kerja iaitu antara jam 12.00 tengah hari dan 1:00 petang, di mana ia boleh dianggap bahawa tiada pendedahan bahan kimia. Data telah diambil di kawasan kerja pada waktu seperti dalam Jadual S.1.[d]. Adakah pekerja itu telah terdedah terlampau?*

Jadual S.1.[d] : Data masa-kepekatan n-butil asetat

Masa	*Kepekatan (ppm)*
8:00	110
9:00	130
10:00	143
11:00	162
12:00	142
1:00	157
2:00	159
3:00	165
4:00	153
5:00	130

[7 markah]

2. [a] Briefly explain why flashpoint is very important to chemical process safety.

[3 marks]

[b] Figure Q.2.[b] shows a transfer system between two tanks. The system is used to transfer a hazardous liquid. The pipe is commercial steel pipe with an internal diameter of 100 mm with a total length of 10 m. The piping system contains two standard flanged 90° elbows and a standard full-line gate valve. A 3-kW pump with an efficiency of 70% is used to transfer the liquid. The maximum fluid height in the supply tank is 3 m, and the elevation change between the two tanks is as shown in Figure Q.2.[b]. Determine the maximum discharge rate (in kg/s) of liquid from the pipe. Assume fully developed turbulent flow in the pipe and no pressure changes.

Data:

Fluid density (ρ) = 1600 kg/m^3

Fluid viscosity (μ) = 1.8 × 10^{-3} kg/m·s

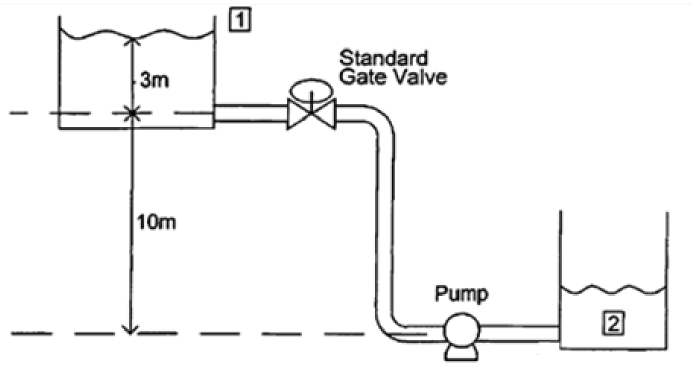


Figure Q.2.[b]

[12 marks]

[c] Nitrogen monoxide gas (MW=30) is being used in a certain chemical process. From the gas source model study at 25 °C and 1 atm, an amount of 1,000 g of this gas can be released instantaneously after a specific accident occurred. If the fence line of the plant is located 500 m away from the gas release and the wind speed is 2 m/s,

[i] Calculate the time (in min) required after the accident for the gas to reach the plant fence line.

[1 mark]

[ii] Determine the maximum concentration (in ppm) of the gas (which will occur at the center of the cloud directly downwind from the release) reached outside the plant fence line. (***Hint: To maximize ⟨C⟩, stability condition need to be selected, i.e. requires minimum dispersion coefficients***).

[5 marks]

[iii] Calculate the distance of the cloud (in km) which must be travelled downwind in order to have a maximum gas concentration of 0.5 ppm. Apply the stability conditions of part [ii].

[4 marks]

…5/-

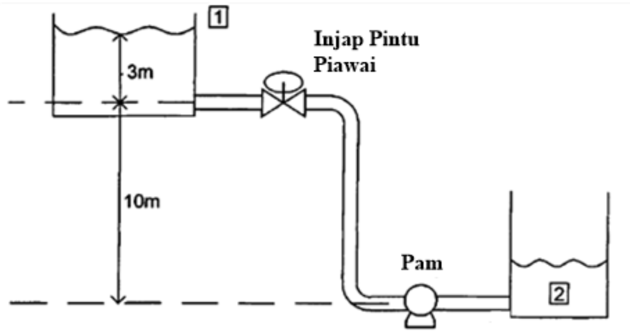
2. [a] *Terangkan secara ringkas mengapa takat kilat adalah sangat penting kepada keselamatan proses kimia.*

[3 markah]

[b] *Rajah S.2.[b] menunjukkan sistem pemindahan antara dua buah tangki. Sistem ini digunakan untuk memindahkan cecair berbahaya. Paip yang digunakan ialah paip keluli komersial dengan diameter dalaman 100 mm dan panjang keseluruhan 10 m. Sistem paip ini mengandungi dua buah bebibir piawai 90° siku dan sebuah injap pintu penuh talian piawai. Sebuah pam 3-kW dengan kecekapan 70% digunakan untuk pemindahan cecair ini. Ketinggian cecair maksimum dalam tangki bekalan adalah 3 m dan perubahan ketinggian di antara dua tangki adalah seperti yang ditunjukkan dalam Rajah S.2.[b]. Tentukan kadar pelepasan (dalam kg/s) cecair dari paip. Andaikan aliran gelora sepenuhnya di dalam paip dan tiada sebarang perubahan tekanan.*

<u>*Data:*</u>

Ketumpatan bendalir (ρ) *=* $1600\ kg/m^3$
Kelikatan bendalir (μ) *=* $1.8 \times 10^{-3}\ kg/m{\cdot}s$



Rajah S.2.[b]

[12 markah]

[c] *Gas nitrogen monoksida (Jisim molekul=30) digunakan dalam suatu proses kimia. Dari kajian model sumber gas pada 25 °C dan 1 atm, sejumlah 1,000 g gas ini akan terlepas dengan serta-merta selepas kemalangan tertentu berlaku. Jika garisan pagar loji itu terletak 500 m dari pelepasan gas dan kelajuan angin ialah 2 m/s,*

[i] *Kirakan masa (dalam minit) yang diperlukan untuk gas sampai ke pagar loji selepas kemalangan berlaku.*

[1 markah]

[ii] *Tentukan kepekatan maksimum (dalam ppm) gas (yang akan berlaku di pusat awan bawah angin daripada pelepasan) untuk sampai ke luar garisan pagar loji.* ***(Petunjuk: Untuk memaksimumkan ⟨C⟩, keadaan kestabilan perlu dipilih, iaitu memerlukan pekali penyebaran minimum).***

[5 markah]

[iii] *Kirakan jarak awan (dalam km) yang mesti dilalui ikut bawah angin untuk mempunyai kepekatan gas maksimum 0.5 ppm. Guna keadaan kestabilan di bahagian [ii].*

[4 markah]

3. [a] Explain Risk Assessment in terms of the process safety in chemical process industries.

[4 marks]

[b] In a pumping system, the filled-in time for a tank is 10 min. The timer is set to stop the filling after 10 min. If the mechanism fails, the alarm horn sounds and the operator opens the switch to prevent overfilling to the tank. The tank may rupture due to different failure causes of the system which can be categorised as primary failure (probability = 0.12) and secondary failure (probability = 0.08). Based on the Fault Tree Analysis presented in Figure Q.3.[b], compute the probability of the top event.

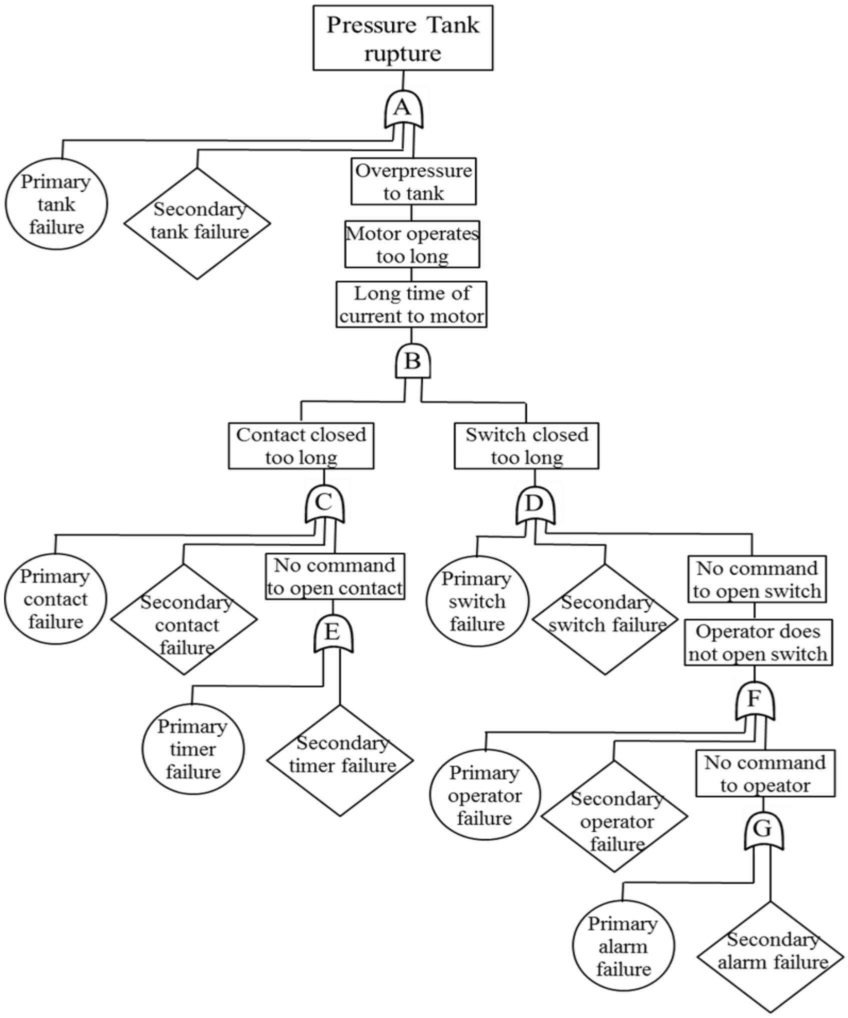


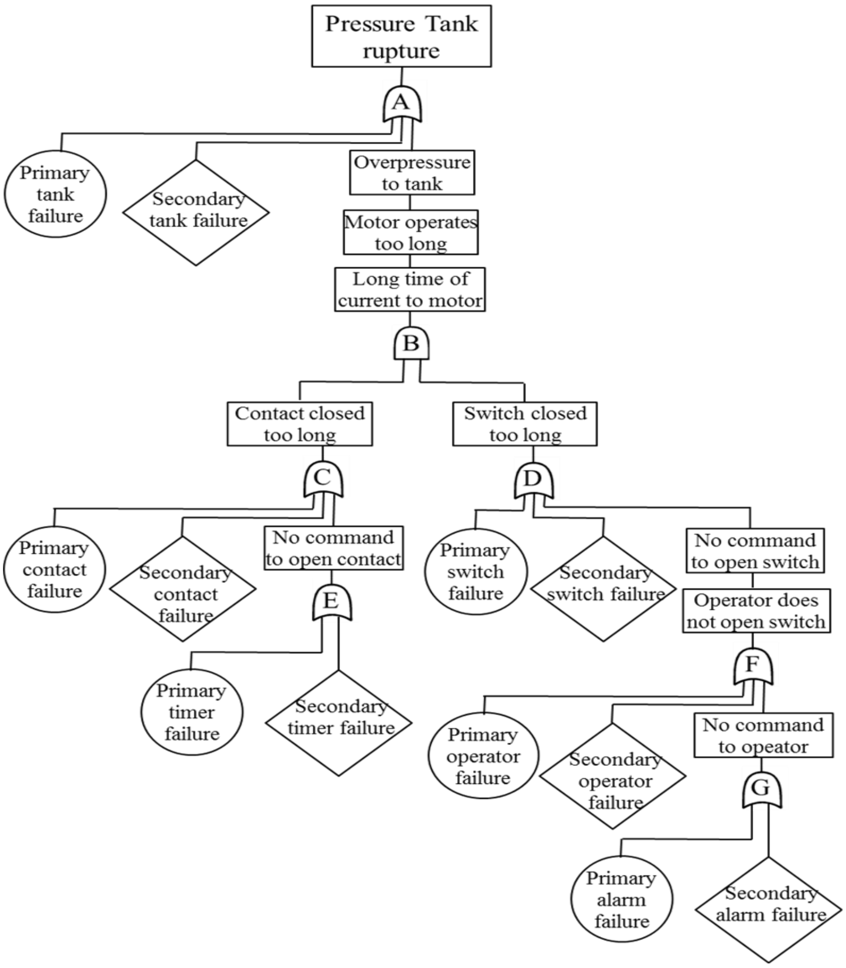
Figure Q.3.[b]

[6 marks]

3. [a] *Terangkan Penilaian Risiko dari segi keselamatan proses dalam industri proses kimia.*

[4 markah]

[b] *Dalam suatu sistem pam, masa untuk mengisi tangki adalah 10 minit. Pemasa ditetapkan untuk menghentikan pengisian selepas 10 minit. Jika mekanisma tersebut gagal, penggera akan berbunyi dan pengendali akan membuka suis untuk mencegah pengisian lebih ke tangki. Tangki mungkin retak disebabkan punca kegagalan sistem yang berbeza yang boleh dikategorikan sebagai kegagalan primer (kebarangkalian = 0.12) dan kegagalan sekunder (kebarangkalian = 0.08). Berdasarkan Analisis Pokok Kesesaran yang ditunjukkan dalam Rajah S.3.[b], kirakan kebarangkalian peristiwa atas.*



Rajah S.3.[b]

[6 markah]

[c] The storage tank system shown in Figure Q.3.[c] is used to store process feedstock. Overfilling of storage tank is a common problem in the process industries. To prevent overfilling, the storage tank is equipped with a high-level alarm to alert the operator and a high-level shutdown system if the system failed to close manually. The high-level shutdown system is connected to a solenoid valve that stops the flow of input stock. By using the following data :

System	Failures / Demand
High-level shutdown system	0.03
High-level alarm	0.05
Operator stops flow	0.1

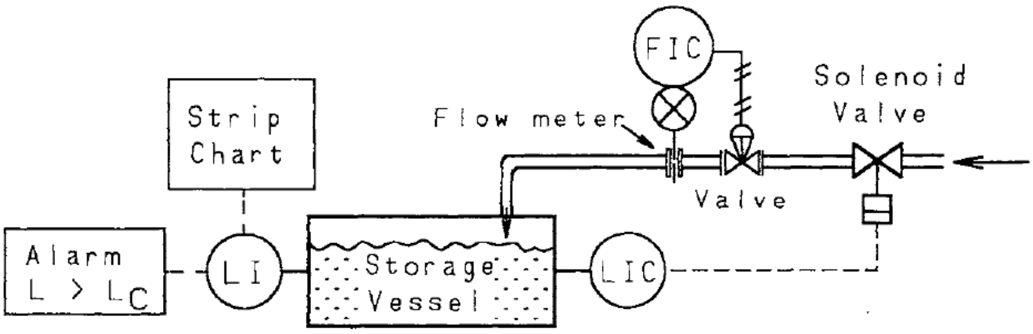


Figure Q.3.[c]

[i] Develop an Event Tree for this system by using the "*failure of level indicator*" as the initiating event.

[5 marks]

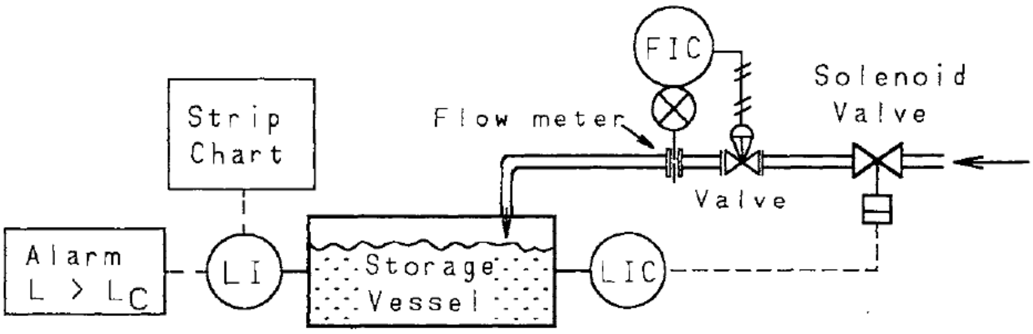
[ii] Given that the level indicator fails 500 times/yr, estimate the number of overflows expected per year.

[10 marks]

4. Phenol is produced through direct oxidation of benzene by hydrogen peroxide, as illustrated in Figure Q.4.1 and Figure Q.4.2. In each reactor, benzene and 70 wt% hydrogen peroxide react in the presence of vanadyl pyrophosphate catalyst dissolved in acetonitrile to form phenol and water. An overall conversion of 75 % is obtained over each reactor. The vapor effluents of each reactor are combined and sent to separation process section. Oxygen vapor from the hydrogen peroxide decomposition is vented out from the reactors with minimal benzene, acetonitrile, phenol, and water. Methane is added in case of benzene concentration in vapor effluent is above the upper flammability limit for benzene in oxygen. In the reaction process, intermediate storage tanks (*ST-101* and *ST-102*) are included to allow for a constant supply of reactor effluent. Perform *HAZOP* analysis on the node by using the following guidewords :

[c] *Sistem tangki penyimpanan yang ditunjukkan dalam Rajah S.3.[c] digunakan untuk menyimpan bahan mentah proses. Pengisian terlebih dalam tangki simpanan adalah masalah biasa dalam industri proses. Untuk mengelakkan pengisian terlebih, tangki penyimpanan dilengkapi dengan penggera aras tinggi untuk memberi amaran kepada pengendali dan sistem penutupan aras tinggi jika sistem gagal untuk menutup secara manual. Sistem penutupan aras tinggi disambungkan kepada sebuah injap solenoid yang menghentikan pengaliran stok masuk. Dengan menggunakan data berikut :*

Sistem	***Kegagalan / Permintaan***
Sistem penutupan aras tinggi	0.03
Penggera aras tinggi	0.05
Penggendali hentikan aliran	0.1



Rajah S.3.[c]

[i] *Bangunkan sebuah Acara Pokok untuk sistem ini dengan menggunakan* "kegagalan penunjuk aras" *sebagai acara mula.*

[5 markah]

[ii] *Diberikan bahawa penunjuk aras gagal 500 kali/tahun, anggarkan bilangan limpahan yang dijangka setiap tahun.*

[10 markah]

4. *Fenol dihasilkan melalui pengoksidaan terus benzena oleh hidrogen peroksida, seperti yang ditunjukkan dalam Rajah S.4.1 dan Rajah S.4.2. Dalam setiap reaktor, benzena dan 70 %berat peroksida hidrogen bertindak balas dengan kehadiran pemangkin pirofosfat vanadil yang larut dalam asetonitril untuk menghasilkan fenol dan air. Penukaran keseluruhan 75 % diperolehi dalam setiap reaktor. Wap kumbahan dari setiap reaktor digabungkan dan dihantar ke bahagian proses pemisahan. Wap oksigen daripada penguraian hidrogen peroksida disalur keluar dari reaktor dengan benzena yang minimum, asetonitril, fenol, dan air. Metana disalurkan sekiranya kepekatan benzena dalam wap kumbahan melebihi had kemudahbakaran atas bagi benzena dalam oksigen. Dalam proses tindak balas, tangki simpanan perantaraan (*ST-101 *dan* ST-102*) dibekal untuk membenarkan bekalan berterusan bagi kumbahan reaktor. Laksanakan analisis* HAZOP *pada nod dengan menggunakan kata-kata panduan berikut :*

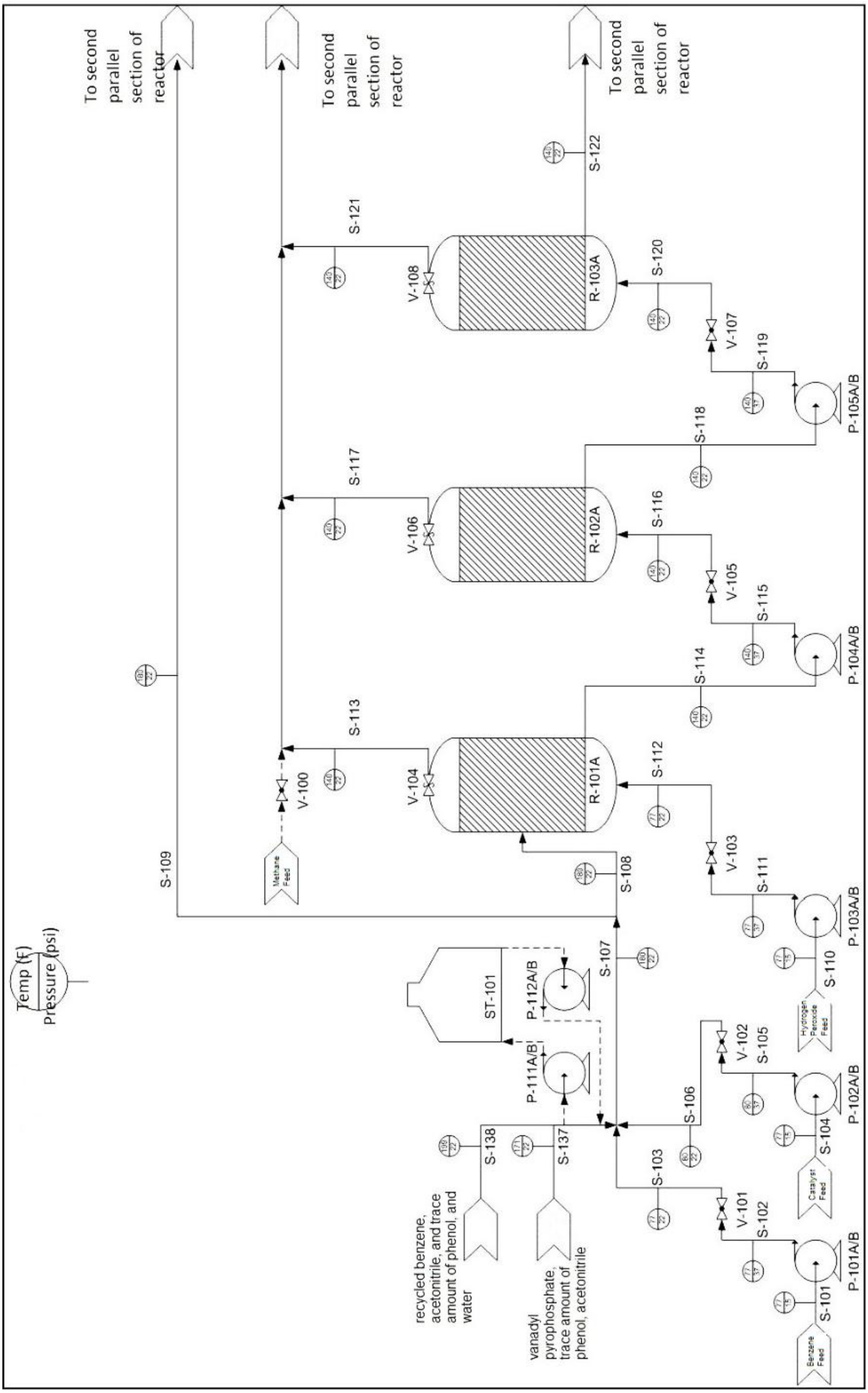


Figure Q.4.1
Rajah S.4.1

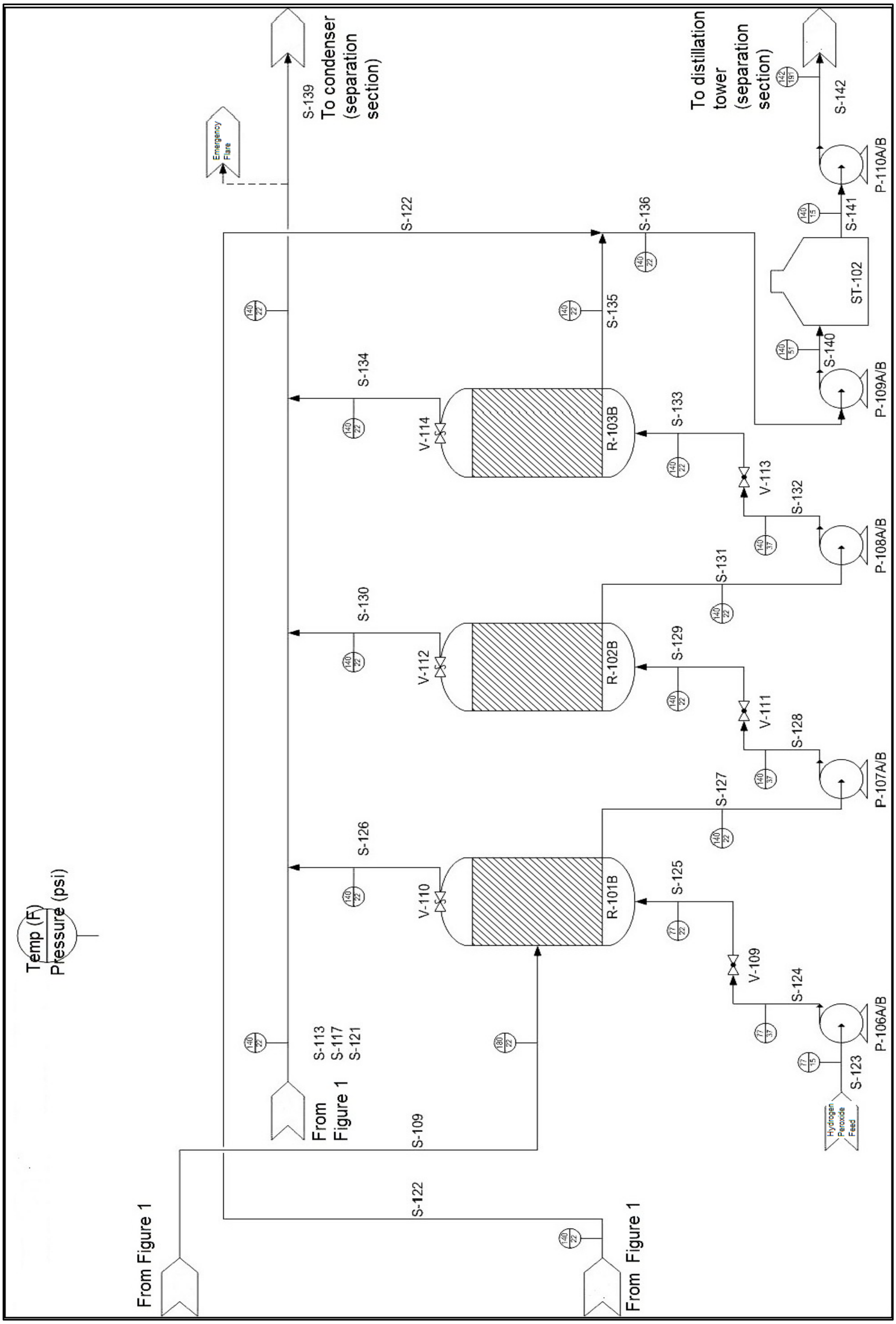


Figure Q.4.2

Rajah S.4.2

[a] Node description: "*line section from S-101 to S-108*"

[i] Low Feed flow

[3 marks]

[ii] Later than Feed flow

[3 marks]

[b] Node description: "*line section from S-109 to S-135*"

[i] High Decomposition of hydrogen peroxide

[3 marks]

[ii] High Pressure in reactor

[3 marks]

[iii] No Methane flow

[3 marks]

[c] Provide two suggestions to improve the safety of the process or operation of reactor with simple schematic sketch, reason for modification and its expected improvement after the modification.

[10 marks]

[a] *Nod keterangan:* "Bahagian saluran paip dari S-101 ke S-108"

[i] *Aliran suapan Rendah*

[3 markah]

[ii] *Terkemudian daripada Aliran suapan*

[3 markah]

[b] *Nod keterangan:* "Bahagian saluran paip S-109 ke S-135"

[i] *Penguraian hidrogen peroksida Tinggi*

[3 markah]

[ii] *Tekanan dalam reaktor Tinggi*

[3 markah]

[iii] *Tiada Aliran metana*

[3 markah]

[c] *Berikan dua cadangan untuk meningkatkan keselamatan proses atau operasi reaktor dengan skema lakaran mudah, sebab bagi pengubahsuaian dan penambahbaikan yang dijangka selepas pengubahsuaian.*

[10 markah]

- oooOooo -

Appendix

Table 1

Probit Correlations for a Variety of Exposures (The causative variable is representative of the magnitude of the exposure.)

Type of injury or damage	Causative variable	Probit parameters k_1	Probit parameters k_2
Fire[1]			
Burn deaths from flash fire	$t_e I_e^{4/3}/10^4$	−14.9	2.56
Burn deaths from pool burning	$tI^{4/3}/10^4$	−14.9	2.56
Explosion[1]			
Deaths from lung hemorrhage	p^o	−77.1	6.91
Eardrum ruptures	p^o	−15.6	1.93
Deaths from impact	J	−46.1	4.82
Injuries from impact	J	−39.1	4.45
Injuries from flying fragments	J	−27.1	4.26
Structural damage	p^o	−23.8	2.92
Glass breakage	p^o	−18.1	2.79
Toxic release[2]			
Ammonia deaths	$\Sigma C^{2.0}T$	−35.9	1.85
Carbon monoxide deaths	$\Sigma C^{1.0}T$	−37.98	3.7
Chlorine deaths	$\Sigma C^{2.0}T$	−8.29	0.92
Ethylene oxide deaths[3]	$\Sigma C^{1.0}T$	−6.19	1.0
Hydrogen chloride deaths	$\Sigma C^{1.0}T$	−16.85	2.0
Nitrogen dioxide deaths	$\Sigma C^{2.0}T$	−13.79	1.4
Phosgene deaths	$\Sigma C^{1.0}T$	−19.27	3.69
Propylene oxide deaths	$\Sigma C^{2.0}T$	−7.42	0.51
Sulfur dioxide deaths	$\Sigma C^{1.0}T$	−15.67	1.0
Toluene	$\Sigma C^{2.5}T$	−6.79	0.41

t_e = effective time duration (s)
I_e = effective radiation intensity (W/m^2)
t = time duration of pool burning (s)
I = radiation intensity from pool burning (W/m^2)
p^o = peak overpressure (N/m^2)
J = impulse (N s/m^2)
C = concentration (ppm)
T = time interval (min)
[1]Selected from Frank P. Lees, *Loss Prevention in the Process Industries* (London: Butterworths, 1986), p. 208.
[2]CCPS, *Guidelines for Consequence Analysis of Chemical Releases* (New York: American Institute of Chemical Engineers, 1999), p. 254.
[3]Richard W. Purgh, "Quantitative Evaluation of Inhalation Toxicity Hazards," in *Proceedings of the 29th Loss Prevention Symposium* (American Institute of Chemical Engineers, July 31, 1995).

Table 2

Transformation from Percentages to Probits[1]

%	0	1	2	3	4	5	6	7	8	9
0	—	2.67	2.95	3.12	3.25	3.36	3.45	3.52	3.59	3.66
10	3.72	3.77	3.82	3.87	3.92	3.96	4.01	4.05	4.08	4.12
20	4.16	4.19	4.23	4.26	4.29	4.33	4.36	4.39	4.42	4.45
30	4.48	4.50	4.53	4.56	4.59	4.61	4.64	4.67	4.69	4.72
40	4.75	4.77	4.80	4.82	4.85	4.87	4.90	4.92	4.95	4.97
50	5.00	5.03	5.05	5.08	5.10	5.13	5.15	5.18	5.20	5.23
60	5.25	5.28	5.31	5.33	5.36	5.39	5.41	5.44	5.47	5.50
70	5.52	5.55	5.58	5.61	5.64	5.67	5.71	5.74	5.77	5.81
80	5.84	5.88	5.92	5.95	5.99	6.04	6.08	6.13	6.18	6.23
90	6.28	6.34	6.41	6.48	6.55	6.64	6.75	6.88	7.05	7.33
%	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
99	7.33	7.37	7.41	7.46	7.51	7.58	7.65	7.75	7.88	8.09

[1] D. J. Finney, *Probit Analysis,* (Cambridge: Cambridge University Press, 1971), p. 25. Reprinted by permission.

Table 3

Roughness Factor ε for Pipes[a]

Pipe material	Condition	Typical ε mm	Typical ε inch
Drawn brass, copper, stainless	New	0.002	0.00008
Commercial steel	New	0.046	0.0018
	Light rust	0.3	0.015
	General rust	2.0	0.08
Iron	Wrought, new	0.045	0.0018
	Cast, new	0.30	0.025
	Galvanized	0.15	0.006
Concrete	Very smooth	0.04	0.0016
	Wood floated, brushed	0.3	0.012
	Rough, visible form marks	2.0	0.08
Glass or plastic	Drawn tubing	0.002[c]	0.0008[c]
Rubber	Smooth tubing	0.01	0.004
	Wire reinforced	1.0	0.04
Fiberglass[b]		0.005	0.0002

[a] Ron Darby, "Fluid Flow," *Albright's Chemical Engineering Handbook*, Lyle F. Albright, ed. (Boca Raton, FL: CRC Press, 2009), p. 421.
[b] William D. Stringfellow, ed., *Fiberglass Pipe Handbook* (Washington, DC: Society of the Plastics Industry, Inc., 1989).
[c] Generally considered smooth pipe with $\varepsilon = 0$.

Table 4

2-K Constants for Loss Coefficients in Fittings and Valves[a]

Fittings	Description of fitting	K_1	K_∞
Elbows	Standard (r/D = 1), threaded	800	0.40
90°	Standard (r/D = 1), flanged/welded	800	0.25
	Long radius (r/D = 1.5), all types	800	0.20
	Mitered (r/D = 1.5): 1 weld (90°)	1000	1.15
	2 welds (45°)	800	0.35
	3 welds (30°)	800	0.30
	4 welds (22.5°)	800	0.27
	5 welds (18°)	800	0.25
45°	Standard (r/D = 1), all types	500	0.20
	Long radius (r/D = 1.5)	500	0.15
	Mitered, 1 weld (45°)	500	0.25
	Mitered, 2 welds (22.5°)	500	0.15
180°	Standard (r/D = 1), threaded	1000	0.60
	Standard (r/D = 1), flanged/welded	1000	0.35
	Long radius (r/D = 1.5), all types	1000	0.30
Tees			
Used as elbows	Standard, threaded	500	0.70
	Long radius, threaded	800	0.40
	Standard, flanged/welded	800	0.80
	Stub-in branch	1000	1.00
Run-through	Threaded	200	0.10
	Flanged/welded	150	0.50
	Stub-in branch	100	0.00
Valves			
Gate, ball or plug	Full line size, $\beta = 1.0$	300	0.10
	Reduced trim, $\beta = 0.9$	500	0.15
	Reduced trim, $\beta = 0.8$	1000	0.25
Globe	Standard	1500	4.00
	Angle or Y-type	1000	2.00
Diaphragm	Dam type	1000	2.00
Butterfly		800	0.25
Check	Lift	2000	10.0
	Swing	1500	1.50
	Tilting disk	1000	0.50

[a] William B. Hooper, *Chemical Engineering* (Aug. 24, 1981), p. 97.

Pipe entrances (normal): K_1 = 160 & K_∞ = 0.50

Pipe exits: K_1 = 0 & K_∞ = 1.0

Table 5

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 6

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

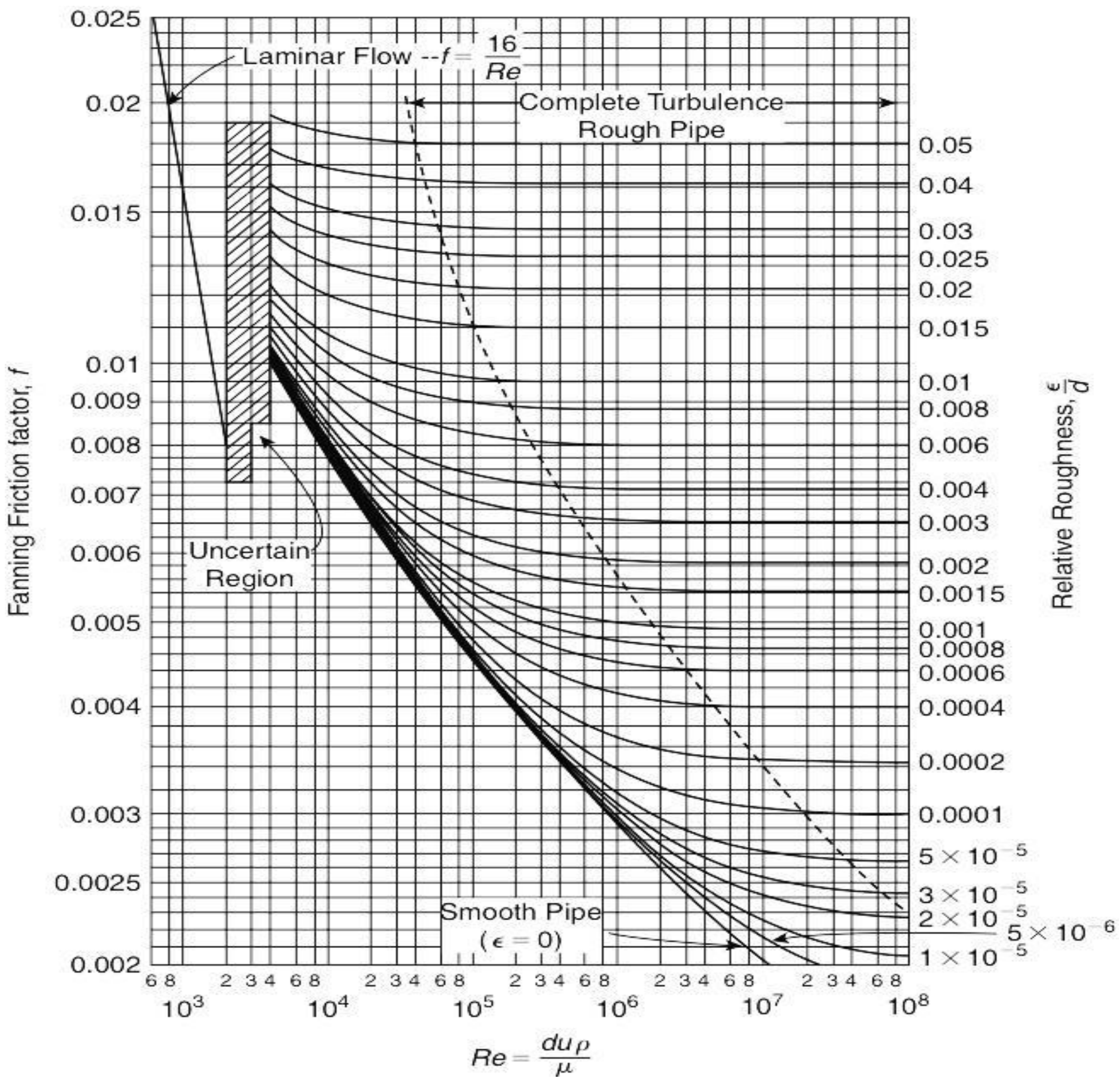
Pasquill-Gifford stability class	σ_y (m)	σ_z (m)
Rural conditions		
A	$0.22x(1 + 0.0001x)^{-1/2}$	$0.20x$
B	$0.16x(1 + 0.0001x)^{-1/2}$	$0.12x$
C	$0.11x(1 + 0.0001x)^{-1/2}$	$0.08x(1 + 0.0002x)^{-1/2}$
D	$0.08x(1 + 0.0001x)^{-1/2}$	$0.06x(1 + 0.0015x)^{-1/2}$
E	$0.06x(1 + 0.0001x)^{-1/2}$	$0.03x(1 + 0.0003x)^{-1}$
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).

Figure 1



Formulae

$$\text{FAR} = \frac{\text{Number of fatalities x } 10^8}{\text{Total hours worked by all employees during period covered}}$$

$$\text{Fatality rate} = \frac{\text{Number of fatalities per year}}{\text{Total number of people in applicable population}}$$

$$Y = k_1 + k_2 \ln V$$

$$P = \frac{1}{(2\pi)^{1/2}} \int_{-\infty}^{Y-5} \exp\left(-\frac{u^2}{2}\right) du$$

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

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

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

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

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

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

$$F = K_f\left(\frac{u^2}{2g_c}\right)$$

$$K_f = \frac{4fL}{d}$$

$$K_f = \frac{K_1}{R_e} + K_\infty\left(1 + \frac{1}{ID_{inches}}\right)$$

$$K_f = \frac{K_1}{R_e} + K_\infty$$

$$R_e = \frac{d\bar{u}\rho}{\mu}$$

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

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

$$Q_m = \dot{m} = \rho\bar{u}A$$

$$\frac{1}{\sqrt{f}} = 4\ log\left(3.7\frac{d}{\varepsilon}\right)$$

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$$\frac{1}{\sqrt{f}} = -4\ log\left(\frac{\varepsilon/d}{3.7065} - \frac{5.0452\ log\ A}{R_e}\right)$$

$$A = \left[\frac{(\varepsilon/d)^{1.1098}}{2.8257} + \frac{5.8506}{{R_e}^{0.8981}}\right]$$

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

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

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

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

$$\langle C\rangle(ut,0,0,t) = \frac{Q_m^*}{\sqrt{2}\,\pi^{3/2}\sigma_x\sigma_y\sigma_z}$$

Conversion & constants

STP (0 °C & 1 atm)
1 atm = 101325 N/m^2 = 101325 Pa = 14.696 psia = 760 mm Hg
1 N = 1 $kg.m/s^2$
1 kW = 1 kJ/s
1 J = 1 N.m = 1 $kg.m^2/s^2$
1 L = 1000 cm^3 = 10^{-3} m^3 = 0.0353 ft^3 = 0.264 gal
1 g = 10^6 μg
1 kg = 2.2046 lbm
1 m = 3.2808 ft = 39.37 in = 100 cm = 10^3 mm
1% = 10^4 ppm
R_g = 82.06 x 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 $lbm.ft/lbf.s^2$
T(°C) = T(K) – 237.15
α = 0.5 (Laminar flow) , α = 1.0 (Plug flow/Turbulent flow)