

UNIVERSITI SAINS MALAYSIA

Peperiksaan Semester Pertama
Sidang Akademik 1996/97

Oktober/November 1996

EKC 365 - Kejuruteraan Kawalan Pencemaran Udara

Masa: [3 jam]

ARAHAN KEPADA CALON:

Sila pastikan kertas peperiksaan ini mengandungi **EMPAT (4)** mukasurat dan **SEBELAS (11)** lampiran bercetak sebelum anda memulakan peperiksaan.

Kertas peperiksaan ini mengandungi **LIMA (5)** soalan.

Jawab hanya **EMPAT (4)** soalan.

Semua soalan mestilah dijawab dalam Bahasa Malaysia.

Keterangan:

$R = 8.314 \text{ kJ/kg.mole}$

$= 0.08208 \text{ atm. m}^3/\text{kg mol. } ^\circ\text{K}$

1. [a] Apakah definisi popular untuk pencemaran udara?
(5 markah)
- [b] Kepekatan SO_2 di suatu kawasan bandar ialah 0.10 ppm. Seorang jurutera muda kimia yang cerdik mendakwa bahawa beliau telah mereka bentuk proses untuk memulihkan 50% dari sebatian ini dari udara dan menukarkannya ke asid sulfurik. Kirakan hasil di dalam unit kilogram asid per kilometer padu udara. Keadaan atmosfera ialah 300K dan 1 bar.
(10 markah)
- [c] Kirakan peratusan HbCO di dalam darah seorang polis trafik yang terdedah kepada 40 ppm CO selama beberapa jam. Andaikan kandungan HbCO mencapai 60% dari nilai tepu ekuilibriumnya.

$$\frac{Hb\ CO}{Hb\ O_2} = 210 \frac{P_{CO}}{P_{O_2}}$$

(10 markah)

2. [a] Hampir kesemua sistem persampelan pencemaran udara (pengawasan ambien dan persampelan punca) mempunyai beberapa bahagian. Bincang secara terperinci komponen-komponen yang terlibat di dalam pemasangan alatan tersebut.
(8 markah)
- [b] Di dalam persampelan zarah dalam cerobong (stack sampling) dan bukannya gas, aliran isokinetik perlu dikekalkan ke dalam "sampling probe". Bincangkan konsep persampelan secara isokinetik (isokinetic sampling).
(8 markah)
- [c] Gas ekzos dari satu kereta mengandungi 1.5% gas karbon monoksida. Berapakah kepekatan CO dalam unit miligram per meter padu (mg/m^3) pada suhu 25°C dan tekanan 1 atm?

(5 markah)

- [d] Kepekatan ozon didapati berada pada paras $118 \mu\text{g}/\text{m}^3$ di suatu stesen pengawasan. Berapakah kepekatan ozon tersebut dalam ppm?
- (4 markah)
3. [a] Satu stesen janakuasa yang baru dibina bercadang untuk menggunakan arang batu yang haba pembakarannya (heating value) bernilai [a] 10,500 Btu/lb atau [b] 11,500 Btu/lb. Di dalam setiap kes, berapakah peratusan sulfur, mengikut berat, yang boleh dikandungi oleh arang batu tersebut jika emisi piawaian (emission standard) yang ditetapkan ialah $1.2 \text{ lb}/10^6 \text{ Btu}$ dipatuhi tanpa sebarang alatan kawalan SO_2 ?
- (8 markah)
- [b] Sebuah loji pengeluar asid sulfurik beroperasi dengan keadaan 50 tan asid dihasilkan dengan anggaran emisi sebanyak 60 lb titisan asid. Berdasarkan piawaian NSPS (New Source Performance Standard) perlukah alatan kawalan pencemaran dipasang? Jika diperlukan, berapakah kecekapan peratus penyahan (percent removal efficiency).
- (7 markah)
- [c] Kirakan kadar emisi harian (daily emission) zarah, SO_2 , nitrogen oksida dan CO_2 yang dibenarkan oleh NSPS (New Source Performance Standard) untuk stesen janakuasa berkapasiti 300 MW yang menggunakan arang batu sebagai bahan api. Arang batu yang digunakan mengandungi 77% C dan 3% S. Nilai haba pembakaran arang batu tersebut ialah 27,850 kJ/kg. Kecekapan termal stesen janakuasa tersebut ialah 35%.
- (10 markah)
4. [a] EPA telah mengeluarkan satu dokumen penting dipanggil faktor emisi (emission factor) untuk mengurangkan kos di dalam ujian emisi (emission testing) seperti yang ditunjukkan dalam Jadual 4.2 (dalam lampiran). Menggunakan jadual tersebut anggarkan emisi untuk zarah, SO_2 , CO, hidrokarbon, nitrogen oksida dan aldehid dari sebuah janakuasa berkapasiti 500MW yang berjalan sepenuhnya. Arang batu jenis 'Pittsburgh Seam' digunakan sebagai bahan api. Kecekapan termal ialah 35%. Janakuasa tersebut menggunakan dandang jenis 'pulverized general'.
- (9 markah)

- [b] Satu kilang melebur kuprum mempunyai cerobong dengan ketinggian 150 m dan kenaikan plum (plume rise) setinggi 75 m. Sekarang ini kilang tersebut mengeluarkan 1000 g/s SO_2 . Anggarkan kepekatan SO_2 di paras bumi (ground level concentration) di suatu tempat yang jauh 5 km di bawah angin (downwind) dari punca ini. Halaju angin ialah 3 m/s dan kelas stabiliti ialah kelas C. (8 markah)
- [c] Pihak pengurusan kilang melebur kuprum di atas (soalan [4b]) diberitahu bahawa kepekatan yang dikira dua kali lebih tinggi dari paras yang dibenarkan. Mereka bercadang untuk mengatasi masalah ini dengan memasang cerobong (stack) yang lebih tinggi. Berapakah ketinggian cerobong yang diperlukan untuk memastikan kepekatan yang dianggarkan separuh dari nilai dalam masalah 4[b] (kenaikan plum (plume rise) sama seperti dalam soalan [4b]). (8 markah)
5. [a] Berdasarkan kecerunan suhu yang diberikan, kelaskan kestabilan atmosfera samada keadaan tersebut stabil, neutral, atau tidak stabil.
- [i] suhu diparas bumi 25°C , suhu di ketinggian 2000 m ialah 5°C .
- [ii] suhu diparas bumi 30°C , suhu di ketinggian 500 m ialah 20°C .
- [iii] suhu diparas bumi 25°C , suhu di ketinggian 700 m ialah 28°C . (15 markah)
- [b] Andaikan kadar lelap atmosfera (atmospheric lapse rate) untuk satu hari tertentu tetap hingga ketinggian 800m. Pada paras bumi P_0 ialah 1020 mbar dan T_0 ialah 15°C . Satu alat memberi bacaan pada ketinggian z nilai tekanan dan suhu ialah 975 mbar dan 11.5°C masing-masing. Tentukan
- [i] kecerunan suhu atmosfera, $\frac{dT}{dz}$ dalam unit kelvin per meter.
- [ii] nilai z dalam unit meter. (10 markah)

TABLE
Comparison of air quality standards and industrial exposure standards

Substance	Permitted ambient concentrations (NAAQS) ^a	Permitted industrial concentrations (TWA and STEL) ^a
Sulfur dioxide	80 $\mu\text{g}/\text{m}^3$ (0.03 ppm), ^b annual average, 365 $\mu\text{g}/\text{m}^3$ (0.14 ppm), 24-h average. ^c	2 ppm, 8-h average. 5 ppm, 15-min peak.
Ozone	0.12 ppm (235 $\mu\text{g}/\text{m}^3$), 1-h average.	0.1 ppm, 8-h average. 0.3 ppm, 15-min peak.
Nitrogen dioxide (NO ₂)	0.053 ppm (100 $\mu\text{g}/\text{m}^3$), annual average.	3 ppm, 8-h average. 5 ppm, 15-min peak.
Carbon monoxide	9 ppm (10 mg/m ³), 8-h average. 35 ppm (40 mg/m ³), 1-h average.	50 ppm, 8-h average. 400 ppm, 15-min peak.
Total suspended particulates (TSP) ^d	75 $\mu\text{g}/\text{m}^3$, annual average. 260 $\mu\text{g}/\text{m}^3$, 24-h average.	Standards exist for specific kinds of particle, but not for TSP.
Fine particles (PM ₁₀) ^d	50 $\mu\text{g}/\text{m}^3$, annual average. 150 $\mu\text{g}/\text{m}^3$ 24-h average.	Standards exist for specific kinds of particle, but not for PM ₁₀ .
Lead	1.5 $\mu\text{g}/\text{m}^3$, quarterly average.	150 $\mu\text{g}/\text{m}^3$, 8-h average. 450 $\mu\text{g}/\text{m}^3$, 15-min peak.
Asbestos	No NAAQS.	A special standard, in number of fibers per cc, exists.
Benzene	No NAAQS.	10 ppm, 8-h average.
Beryllium	No NAAQS.	2 $\mu\text{g}/\text{m}^3$, 8-h average.
Coke oven emissions	No NAAQS.	No standard for these as a group, standards for individual components.
Inorganic arsenic	No NAAQS.	200 $\mu\text{g}/\text{m}^3$.
Mercury	No NAAQS.	10 $\mu\text{g}/\text{m}^3$, 8-h average plus a lower standard for alkyl mercury compounds.
Radionuclides	No NAAQS.	No comparable standard.
Vinyl chloride	No NAAQS.	5 ppm, 8-h average.

^aThe NAAQS (National Ambient Air Quality Standards) are current EPA values. The TWA (time-weighted average) and STEL (short-term exposure limit) values are current ACGIH (American Conference of Governmental Industrial Hygienists) values.

^bFor gases, the standards can be expressed as ppm or $\mu\text{g}/\text{m}^3$; most tabulations show them both ways (for standard temperature and pressure of the gas). For solids such as TSP, PM₁₀, or asbestos, the molecular weight is generally not known, so representation as ppm by volume or by mol is generally not possible: the standards are expressed as $\mu\text{g}/\text{m}^3$ or its equivalent (again assuming the gas is at standard temperature and pressure).

^cThe short-term NAAQS (24-hour) are not to be exceeded more than once per year. The annual average standards are not to be exceeded in any year.

^dThe particulate standards issued by the EPA in 1971 were for total suspended particulates (TSP). The real definition of TSP is material that is collected by a *hi-vol* sampler. Subsequent investigation showed that *hi-vol* samplers collected too many particles in the size range 10–50 microns. Such particles have no apparent health effect, but in *hi-vol* samplers they often outweighed the smaller particles, which do have health effects. As of July 1, 1987, the EPA revoked the particulate standard for TSP and substituted one for fine particles, which are called PM₁₀ (particulate matter 10 microns or smaller). The real definition of PM₁₀ is that it is the material that is collected by a PM₁₀ sampler, which is like a *hi-vol* sampler, but with an inlet designed to exclude particles larger than 10 microns (see Chapter 4).

Table National Ambient Air Quality Standards (Primary)

Pollutant	Averaging Time	Standard
SO ₂	Annual average	80 µg/m ³
	24 h	365 µg/m ³
NO ₂	Annual average	100 µg/m ³
CO	8 h	10 mg/m ³
	1h	40 mg/m ³
Ozone	1 h	0.12 ppm
Particulate matter (PM ₁₀)	Annual geometric mean	50 µg/m ³
	24 h	150 µg/m ³

Source: 40 CFR (Code of Federal Regulations) 50, 1982.

TABLE
Federal Standards of Performance for New Stationary Sources
(commonly called *new source performance standards* [NSPS])

This list is an excerpt from the 1991 version of 40CFR60. Standards are listed there for 68 industrial categories. New categories are regularly added, and existing ones modified. This excerpt shows the kind of regulations that are contained in that much larger compilation.

1. *Coal-fired power plants* whose construction started after September 18, 1978, may not emit the following to the atmosphere:
 - a. Particulate matter more than 0.03 lb/10⁶ Btu, or 1% of the ash solids in the fuel, whichever is less.
 - b. Sulfur dioxide more than 1.2 lb/10⁶ Btu, or more than 30% of the SO₂ that would be formed if all the sulfur in the coal were converted to SO₂, whichever is less.
 - c. Nitrogen oxides more than 0.6 lb/10⁶ Btu for most coals, or 0.5 lb/10⁶ Btu for sub-bituminous coal.
2. *Large incinerators* shall not emit to the atmosphere gas that contains particulates in concentrations greater than 0.08 grain/dry standard cubic foot, corrected to 12% CO₂.
3. *Portland cement plants* shall not emit to the atmosphere the following:
 - a. Gases from the kiln containing more than 0.30 lb/ton of kiln feed (dry basis).
 - b. Gases from the clinker cooler containing more than 0.10 lb/ton of feed to the kiln (dry basis).
4. *Nitric acid plants* shall not emit gases containing more than 3.0 lb of NO₂ per ton of nitric acid produced.
5. *Sulfuric acid plants* shall not emit gases containing more than 4 lb of SO₂ and/or 0.15 lb of sulfuric acid mist/ton of acid produced (100% basis).

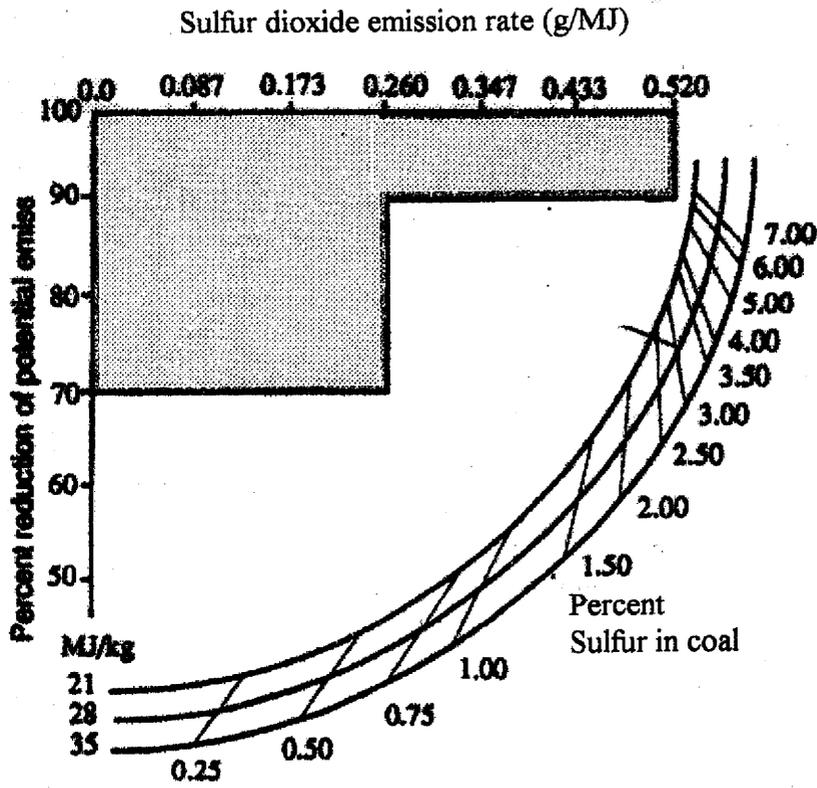
The above regulations also limit the opacity of the plumes from these plants, mostly as a control measure, and have very detailed descriptions of testing and monitoring requirements.

Table Some New Source Performance Standards

Source	Standard
Steam electric power plants	
Particulate matter	13 g/10 ⁶ kJ
NO _x	
Gaseous fuel	86 g/10 ⁶ kJ
Liquid fuel	130 g/10 ⁶ kJ
Coal	260 g/10 ⁶ kJ
SO ₂	
Gas or liquid fuel	86 g/10 ⁶ kJ
Coal	At least 70% removal depending on conditions (see Figure 1.4 for details)
Solid waste incinerators	
Particulate matter	0.18 g/dscm ^a corrected to 12% CO ₂ (3-h average)
Sewage sludge incinerators	
Particulate matter	0.65 g/kg sludge input (dry basis)
Iron and steel plants	
Particulate matter	50 mg/dscm
Primary copper smelters	
Particulate matter	50 mg/dscm
SO ₂	0.065% by volume
Sulfuric acid plants	
SO ₂	2 kg/metric ton of 100% acid
Portland cement plants	
Particulate matter	0.15 kg/metric ton of feed (maximum 2-h average)

^a Dry standard cubic meter.

Source: 40 CFR (Code of Federal Regulations) 60, 1982.



Graphical interpretation of the 1980 NSPS for SO₂ emissions from coal-fired power plants

TABLE
Emission factors for bituminous coal combustion without control equipment; emission factor rating, A

Furnace size, 10 ⁶ Btu/h heat input ^c	Particulates ^b		Sulfur oxides ^d		Carbon monoxide		Hydrocarbons ^e		Nitrogen oxides		Aldehydes	
	lb/ton coal burned	kg/MT coal burned	lb/ton coal burned	kg/MT coal burned	lb/ton coal burned	kg/MT coal burned	lb/ton coal burned	kg/MT coal burned	lb/ton coal burned	kg/MT coal burned	lb/ton coal burned	kg/MT coal burned
Greater than 100 (utility and large industrial boilers)												
Pulverized												
General	16A	8A	38S	19S	1	0.5	0.3	0.15	18	9	0.005	0.0025
Wet bottom	13A ^f	6.5A	38S	19S	1	0.5	0.3	0.15	30	15	0.005	0.0025
Dry bottom	17A	8.5A	38S	19S	1	0.5	0.3	0.15	18	9	0.005	0.0025
Cyclone	2A	1A	38S	19S	1	0.5	0.3	0.15	55	27.5	0.005	0.0025
10 to 100 (large commercial and general industrial boilers)												
Spreader stoker ^f	13A ^f	6.5A	38S	19S	2	1	1	0.5	15	7.5	0.005	0.0025
Less than 10 (commercial and domestic furnaces)												
Spreader stoker	2A	1A	38S	19S	10	5	3	1.5	6	3	0.005	0.0025
Hand-fired units	20	10	38S	19S	90	45	20	10	3	1.5	0.005	0.0025

Source: Table 1-1 of EPA Emissions Factors [7]. The original gives references to the literature on which the values are based.

^a 1 Btu/h = 0.252 kcal/h

^b The letter A on all units other than hand-fired equipment indicates that the weight percentage of ash in the coal should be multiplied by the value given. Example: If the factor is 16 and the ash content is 10 percent, the particulate emissions before the control equipment would be 10 × 16 or 160 lb of particulate per ton of coal (10 × 8 kg, or 80 kg, of particulates per MT of coal).

^c S = sulfur content, which plays the same role as A for the ash content in the preceding footnote.

^d Expressed as methane.

^e Without fly ash reinjection.

^f For all other stokers, use 5A (2.5A) for particulate emission factor.

TABLE
Some values for fuels derived from wood

Material	Ultimate analysis, weight %, dry basis, typical val					
	C	H	O	N	S	Ash
Wood ^b	52.3	6.3	40.5	0.1	<0.1	0.8
Peat ^c	57.0	5.5	31.0	1.5	0.2	4.8
Lignite (also called <i>brown coal</i>) ^d	55.0	4.4	13	1.0	1.7	24.9
Sub-bituminous coal ^e	72.5	6.1	17.2	0.7	0.4	3.1
Bituminous coal ^f	75.8	5.0	7.4	1.5	1.6	8.7
Anthracite coal	82.1	2.3	2.0	0.8	0.6	12.2
U.S. average coal for electric generation, 1991 ^g					1.30	9.7

Notes:

- ^a The values for average U.S. coal, average heating value, and % by weight for electric plants 1991, U.S. Department of Energy Report No. DOE/EIA-0191(91), U.S. Government Printing Office, Washington, DC, 1992.
- ^b The wood values are those for Douglas fir; other kinds of wood are similar but not identical. *Wood Combustion: Principles, Processes and Economics*, Academic Press, New York, p. 43, 1981.
- ^c The peat values are from B. F. Haanel, *Final Report of the Peat Committee*, A. C. Anderson Association, Ottawa, p. 7, 1925.
- ^d The lignite values are for a typical Texas lignite, courtesy of the Texas Mining and Reclamation Association.
- ^e The sub-bituminous values are for a typical Powder River Basin coal, courtesy of the Northern Research Institute.
- ^f The bituminous value is for a "typical Pittsburgh seam coal." Throughout this book it is stated to the contrary.
- ^g In the United States heating values of coal are generally stated as the higher heating value. See the discussion of the difference in Section 10.3.4.1.
- ^h The dry basis heating values are computed from the equation

$$\left(\frac{\text{Higher heating value}}{\text{value, Btu/lb}} \right) = 14.544C + 62.0$$

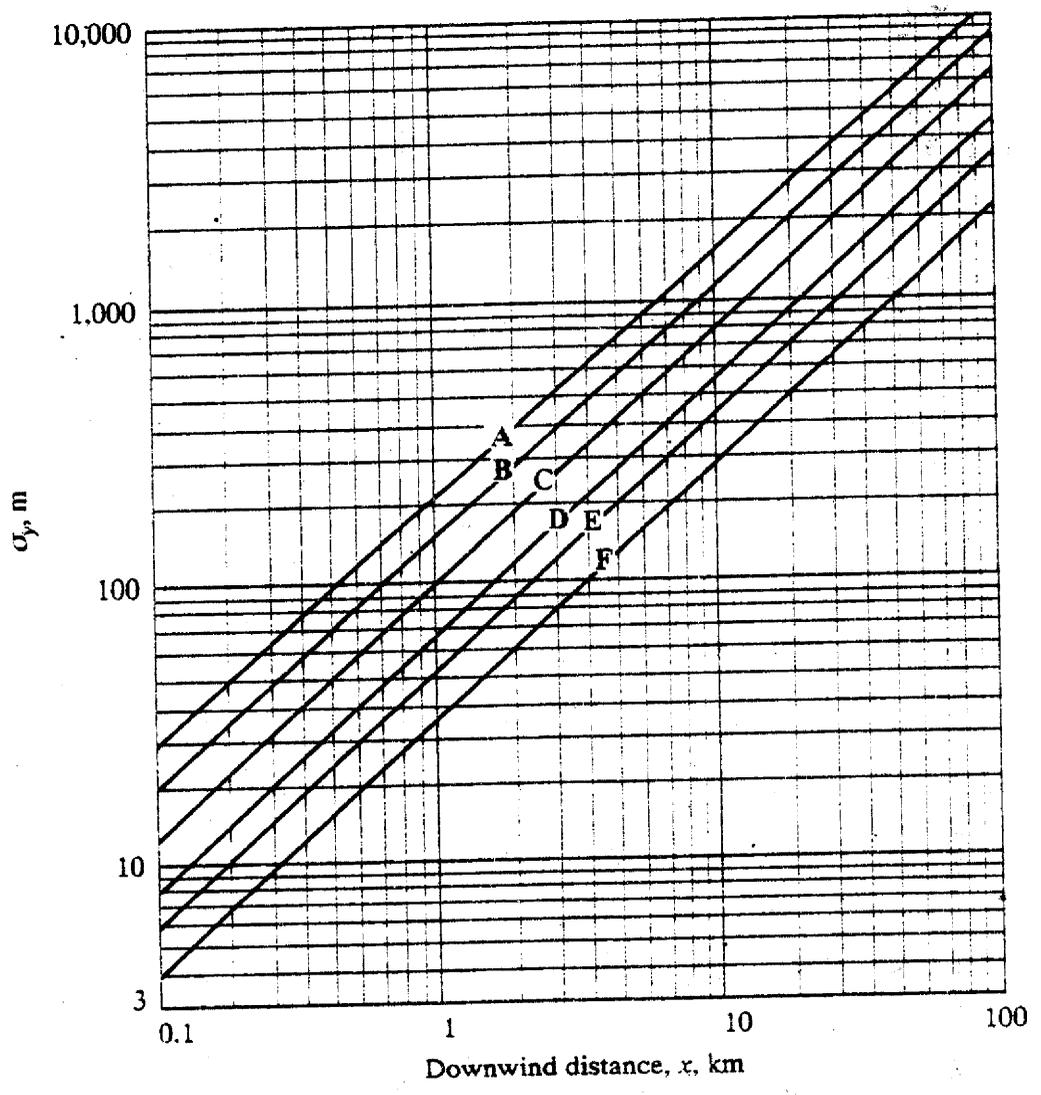
where C, H, O, and S are the weight fractions of carbon, hydrogen, oxygen, and sulfur, respectively. This formula is reported to give values within $\pm 3\%$ of experimental results.

Dry basis ^b	Heating value, Btu/lb ^a		% by weight of U.S. electric generation coal, 1991 ^a
	Average wet basis, as delivered, U.S., 1991 ^a		
9,050			10.2
9,300			31.2
9,727	6,372		58.5
13,006	8,741		0.1
13,600	11,964		
13,258			
	10,387		100.0

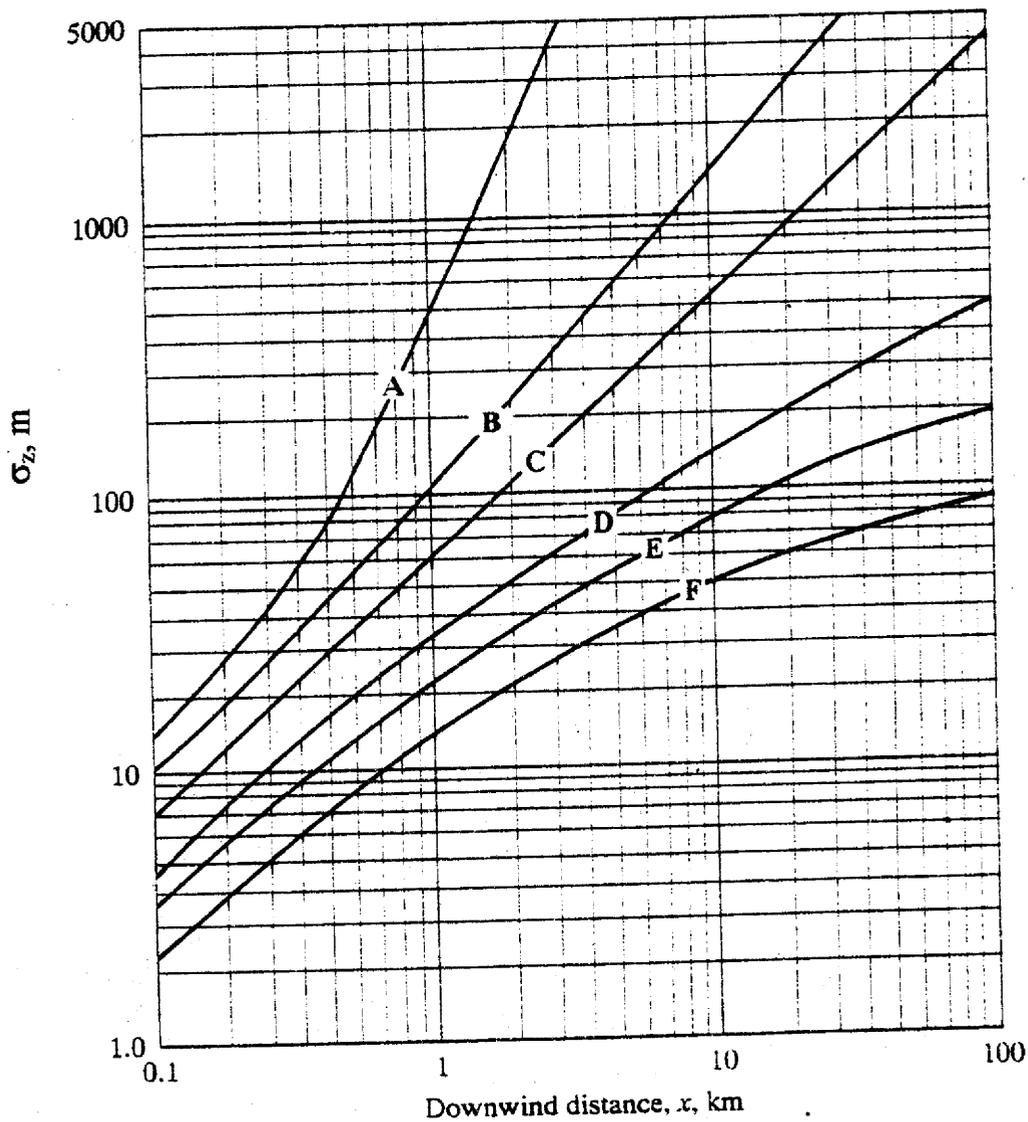
generation are from "Cost and Quality of Fuels for Electric Utility Printing Office, Washington, DC, 1992.
 al. These values are from D. A. Tillman, A. J. Rossi, and W. D. s, p. 43, 1981.
 Ottawa, p. 7, 1925.
 nation Association.
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 mples and problems the values for this coal are used, except when
 , as shown here. In Europe they are generally stated as the lower

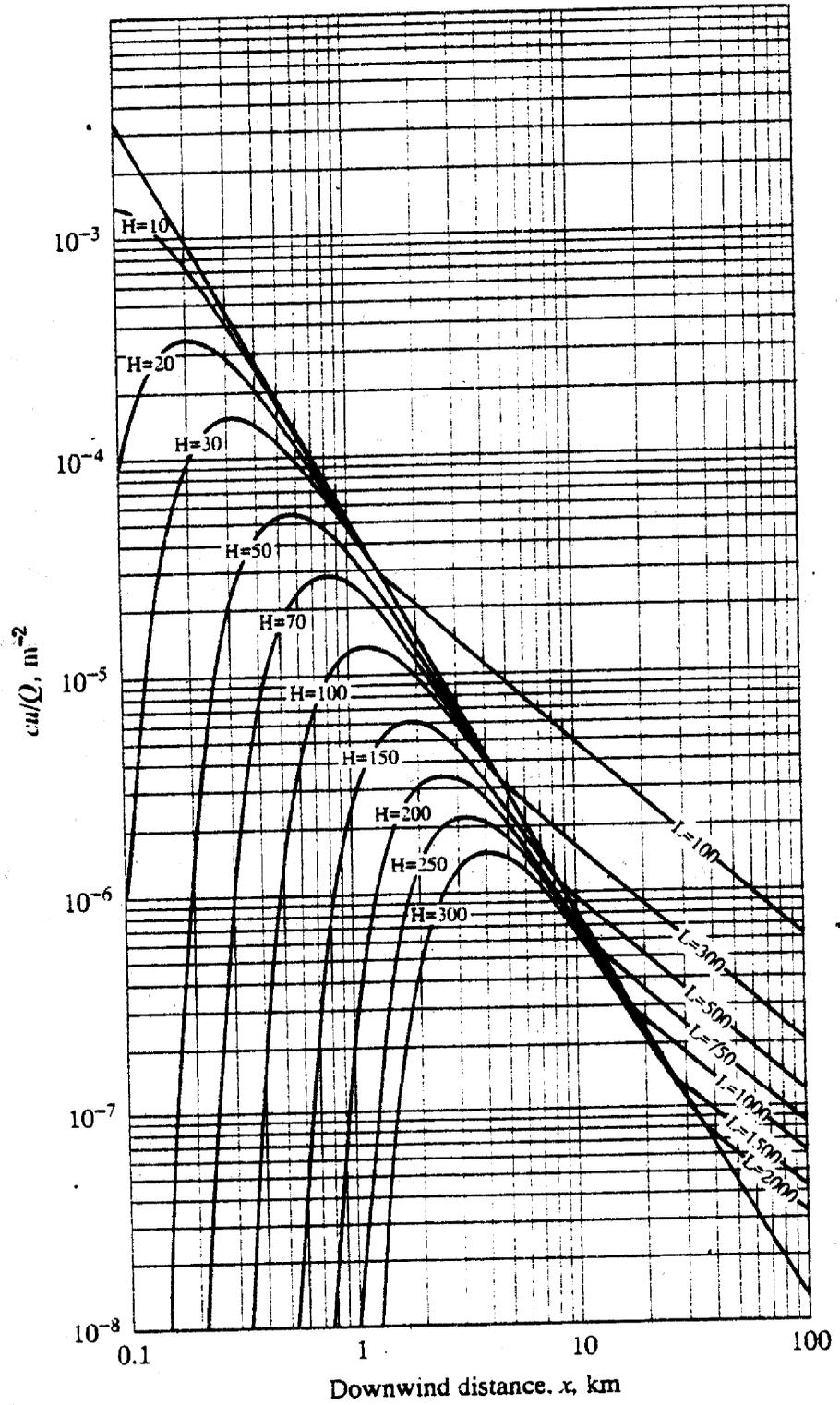
$$\left(\frac{O}{8} \right) + 4050S$$

respectively. This formula is reported to give values within $\pm 3\%$ of



Horizontal dispersion coefficient σ_y , as a function of downwind distance from the source for various stability categories. See Problem 6.16. (From Turner [6].)





$$\sigma_y \sigma_x = \frac{0.117Q}{C_{\max} U}$$

$$U = U_1 \left(\frac{Z}{Z_1} \right)^P \quad P = \frac{n}{2-n} \quad Z_1 = 1m. \quad ; n = 0.27$$

Where U is air velocity at the stack height

$$\sigma_z = 0.717H$$

$$C(x, y, z) = \frac{Q}{\pi u \sigma_y \sigma_z} \exp\left(\frac{-H^2}{2\sigma_z^2}\right) \exp\left(\frac{-y^2}{2\sigma_y^2}\right) \text{ at ground level}$$

$\eta_o = \Sigma(\text{weight fraction})(\eta_d)$ where η_d is the collection efficiency for particle diameter, d