



Environment
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ENVIRO

Technical

Information for

Problem

Solutions

**SULPHURIC ACID
and OLEUM**

TP
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1984

February 1984

Canada

ENVIRONMENTAL AND TECHNICAL INFORMATION FOR PROBLEM SPILLS MANUALS

Environmental and Technical Information for Problem Spills (EnviroTIPS) manuals provide detailed information on chemical substances. This information is intended to assist the reader in designing countermeasures for spills and to assess their impact on the environment. The manual has been reviewed by the Technical Services Branch, Environmental Protection Service, and approved for publication. Approval does not necessarily signify that the contents reflect the views and policies of the Environmental Protection Service. Mention of trade names or commercial products does not constitute endorsement for use.

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SULPHURIC ACID AND OLEUM

ENVIRONMENTAL AND TECHNICAL INFORMATION FOR PROBLEM SPILLS

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FOREWORD

The Environmental and Technical Information for Problem Spills (EnviroTIPS) manuals were initiated in 1981 to provide comprehensive information on chemicals that are spilled frequently in Canada. The manuals are intended to be used by spill specialists for designing countermeasures for spills and to assess their effects on the environment. The major focus of EnviroTIPS manuals is environmental. The manuals are not intended to be used by first-response personnel because of the length and technical content; a number of manuals intended for first-response use are available. The information presented in this manual was largely obtained from literature review. Efforts were made, both in compilation and in review, to ensure that the information is as correct as possible. Publication of these data does not signify that they are recommended by the Government of Canada, nor by any other group.

ACKNOWLEDGEMENTS

The final version of this manual was prepared by the staff of the Environmental Protection Service who wrote extensive revisions to the text, drafted illustrations and incorporated all comments and additions.

The level of detail present was made possible by the many individuals, organizations and associations who provided technical data and comments throughout the compilation and subsequent review. The Canadian Chemical Producers' Association is especially acknowledged for its review of and input to this manual. The draft of this manual was prepared under contract to Environment Canada by M.M. Dillon Consulting Engineers and Planners, Concord Scientific Corporation, and Waterloo Engineering Limited.

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1 SUMMARY

SULPHURIC ACID (H₂SO₄)

Colourless, odourless oily liquid

SYNONYMS

Battery Acid, Fertilizer Acid, Oil of Vitriol, Hydrogen Sulphate, Sulphuric Acid spent, Acide Sulphurique (Fr.)

IDENTIFICATION NUMBERS

UN No. Acid: 1830, Spent Acid: 1832; CAS No. Acid: 7664-93-9; OHM-TADS No. 7216915; STCC No. Acid: 4930040

GRADES & PURITIES

Commercial Grade (66°Bé): >93.19 percent

Electrolytic - Battery Acid Grade: >93.19 percent

CP (Chemically Pure) Grade: 95.5-96.5 percent

IMMEDIATE CONCERNS

Fire: Not flammable or combustible. Hydrogen gas may be formed on contact with metal

Human Health: Acid mists and liquid are corrosive to tissues, by inhalation and contact

Environment: Harmful to aquatic life in some species, in concentrations as low as 6 mg/L

PHYSICAL PROPERTY DATA

	<u>95.5-96.5%</u>	<u>66°Bé</u>
State (15°C, 1 atm):	liquid	liquid
Boiling Point:	310°C	279.4°C
Melting Point:	3°C	-29.5°C
Flammability:	not flammable	not flammable
Specific Gravity (water=1):	1.8437	1.8354
Solubility (in water):	completely miscible, with evolution of heat	
Behaviour (in water):	sinks and reacts evolving heat	
Odour Threshold and Range:	low concentration is odourless; in fire, high concentration emits SO ₃ with an odour threshold >1 mg/m ³	

ENVIRONMENTAL CONCERNS

Harmful to aquatic life in low concentrations primarily due to its acidity. There is no potential for bioaccumulation or food chain concentration.

HUMAN HEALTH

TLV^o: 1 mg/m³
 IDLH: 80 mg/m³

Exposure Effects

Inhalation: Mists and vapours are corrosive, causing damage to both the upper respiratory tract and the lungs. May cause coughing or sneezing

Contact: Rapidly damaging to all human tissues. Causes severe burns to skin and eyes, depending on concentration

IMMEDIATE ACTIONSpill Control

Restrict access to spill site. Issue warning: "CORROSIVE". Call authorities and notify manufacturer. Stop the flow and contain spill, if safe to do so. Avoid contact with liquid and vapour. Keep contaminated water from entering sewers or watercourses.

Fire Control

Not flammable or combustible, but may form explosive hydrogen gas by reaction with metals. Dry chemical or carbon dioxide may be used to extinguish adjacent fires.

COUNTERMEASURESEmergency Control Procedures in/on

Soil: Construct barriers to contain spill by diking with dry earth, sand, or other available material. Neutralize and remove material with pumps or vacuum equipment

Water: Contain with weirs, damming with gravel, earth, or by diversion. Neutralize and remove sludge

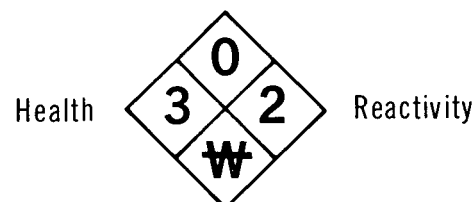
Air: Use water spray to knock down and disperse vapours. Control runoff for later treatment and/or disposal

NAS HAZARD RATING

<u>Category</u>	<u>Rating</u>
Fire	0
Health	
Vapour Irritant	2
Liquid or Solid Irritant	4
Poisons	2
Water Pollution	
Human Toxicity	2
Aquatic Toxicity	3
Aesthetic Effect	2
Reactivity	
Other Chemicals	4
Water	3
Self-reaction	0

NFPA
HAZARD
CLASSIFICATION

Flammability



OLEUM (H₂SO₄+SO₃)

Colourless, oily liquid with a choking odour

SYNONYMS

Fuming Sulphuric Acid, Disulphuric Acid, Dithionic Acid, Pyrosulphuric Acid

IDENTIFICATION NUMBERS

UN No. Acid: 1831; CAS No. 8014-95-7; OHM-TADS No. 7216915; STCC No. 4930030

GRADES & PURITIES

20 to 65 percent of excess SO₃

IMMEDIATE CONCERNS

Fire: Not flammable and not combustible. Hydrogen gas formed by reaction of the acid with metal may accumulate inside tanks regardless of strength. Oleum is very reactive with many substances and reacts violently on contact with water

Human Health: Acid mists and liquid are corrosive to tissues, by inhalation and contact

Environment: Harmful to aquatic life in some species, in concentrations as low as 6 mg/L

PHYSICAL PROPERTY DATA

Oleum by % excess SO₃

	<u>30%</u>	<u>25%</u>	<u>20%</u>
State (15°C, 1 atm):	liquid	liquid	liquid
Boiling Point:	115°C	125°C	138°C
Melting Point:	22°C	14°C	1°C
Flammability:	not flammable	not flammable	not flammable
Specific Gravity (water=1):	1.952	1.935	1.916
Solubility (in water):	completely miscible, with evolution of heat		
Behaviour (in water):	sinks and mixes violently, evolving heat		
Odour Threshold and Range:	>1 mg/m ³		

ENVIRONMENTAL CONCERNS

Harmful to aquatic life in low concentrations, primarily due to its acidity. There is no potential for bioaccumulation or food chain concentration.

HUMAN HEALTH

TLV^o: 1 mg/m³
IDLH: 80 mg/m³

Exposure Effects

Inhalation: Mists and vapours are corrosive, causing damage to both the upper respiratory tract and the lungs. May cause coughing or sneezing

Contact: Rapidly damaging to all human tissue. Causes severe burns to skin and eyes

IMMEDIATE ACTIONSpill Control

Restrict access to spill site. Issue warning: "CORROSIVE". Call authorities and notify manufacturer. Stop the flow and contain spill, if safe to do so. Avoid contact with liquid and vapour; stay upwind of release. Keep contaminated water from entering sewers or watercourses.

Fire Control

Not flammable or combustible, but may form explosive hydrogen gas by reaction with metals. Dry chemical or carbon dioxide may be used to extinguish adjacent fires.

COUNTERMEASURESEmergency Control Procedures in/on

Soil: Construct barriers to contain spill by diking with dry earth, sand, or other available material. Neutralize and remove material with pumps or vacuum equipment

Water: Contain with weirs, damming with gravel, earth, or by diversion. Neutralize and remove sludge

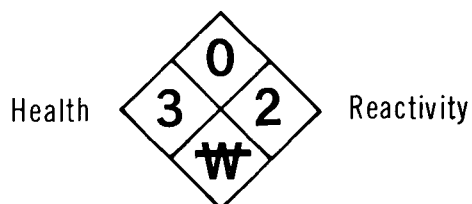
Air: Use water spray to knock down and disperse vapours. Control runoff for later treatment and/or disposal

NAS HAZARD RATING

<u>Category</u>	<u>Rating</u>
Fire	0
Health	
Vapour Irritant	2
Liquid or Solid Irritant	4
Poisons	2
Water Pollution	
Human Toxicity	2
Aquatic Toxicity	3
Aesthetic Effect	2
Reactivity	
Other Chemicals	4
Water	3
Self-reaction	0

NFPA
HAZARD
CLASSIFICATION

Flammability



2 PHYSICAL AND CHEMICAL DATA

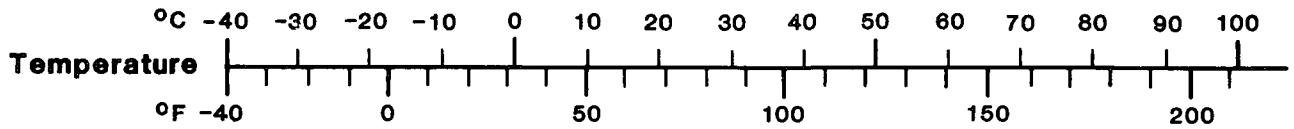
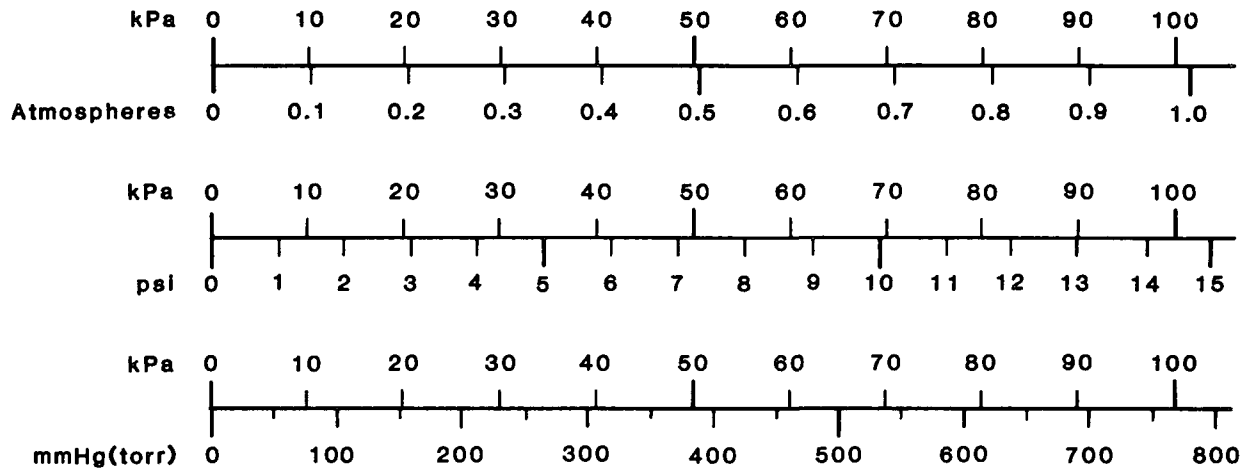
	Sulphuric Acid		Oleum		
	<u>95.5-96.5%</u>	<u>66°Bé</u>	<u>30%</u>	<u>25%</u>	<u>20%</u>
Physical State Properties					
Appearance	Colourless to amber, slightly cloudy, oily liquid (CIL)		Colourless to white, heavy, oily liquid containing sulphur trioxide dissolved in sulphuric acid (CIL)		
Usual shipping state(s)	Liquid (CIL)		Liquid (CIL)		
Physical state at 15°C, 1 atm	Liquid		Liquid		
Freezing point	3.0°C (CRC 1980)	-29.5°C (CIL)	22°C (CIL)	14°C (CIL)	1°C (CIL)
Boiling point	310°C (CIL)	279.4°C (Ashland MSDS 1977)	115°C (Cities MSDS)	125°C (CIL)	138°C (Cities MSDS)
Decomposition temperature	340°C (Merck 1976)				
Densities					
Specific gravity (15°/15°C)	1.8437 (CIL)	1.8354 (CIL)	1.952 (CIL)	1.935 (CIL)	1.916 (CIL)
Fire Properties					
Flammability	Not flammable (NFPA 1978)				
Decomposition temperature	340°C (Merck 1976)				
Decomposition products	Sulphur oxides and water (Merck 1976)				
Other Properties					
Molecular weight of pure substance	98.08 (CRC 1980)				

	Sulphuric Acid		Oleum		
	<u>95.5-96.5%</u>	<u>66°Bé</u>	<u>30%</u>	<u>25%</u>	<u>20%</u>
Constituent components of typical commercial grade	95.5-96.5% H ₂ SO ₄ (CCPA 1982)	93.2% (min) H ₂ SO ₄ (CIL)	28.0 to 32.5% free SO ₃ (CIL)	22.7 to 27.2% free SO ₃ (CIL)	18.0 to 22.2% free SO ₃ (CIL)
Refractive index	1.437 (18°C) (CRC 1980)				
Viscosity (est. 25°C)	21 mPa•s (CIL)	20 mPa•s (CIL)	36 mPa•s (CIL)	33 mPa•s (CIL)	29 mPa•s (CIL)
Liquid interfacial tension with air	55.1 mN/m (20°C) (CRC 1980)				
Liquid interfacial tension with water	75 mN/m (33 wt. % solution 25°C) (CRC 1980)				
Hygroscopicity	Hygroscopic (MCA 1963)				
Latent heat of fusion	9.8 kJ/mole (at melting point) (CRC 1980)				
Latent heat of vaporization	56 kJ/mole (at boiling point) (JANAF 1971)				
Heat of formation	-813.9 kJ/mole (25°C) (JANAF 1971)				
Ionization potential	-		11.0 eV (as SO ₃ ⁺) (Rosenstock 1977)		
Heat of solution	-971 J/g (CHRIS 1978)				
Heat capacity constant pressure (C _p)	138.9 J/mole•°C (25°C) (JANAF 1971)				
Coefficient of thermal expansion	0.558 x 10 ⁻³ /°C (20°C) (Perry 1973)				

	Sulphuric Acid		Oleum		
	<u>95.5-96.5%</u>	<u>66°Bé</u>	<u>30%</u>	<u>25%</u>	<u>20%</u>
Thermal conductivity		3.54 mJ/s·cm·°C (32°C) (Lange's Handbook 1979)	5.2 mJ/s·cm·°C (32°C) (Lange's Handbook 1979)		
Diffusivity		1.97 x 10 ⁻⁵ cm ² /s (in water 25°C) (Perry 1973)			
pH of aqueous solution		0.3 (1 N solution 25°C) (CRC 1980)			
Eutectic compositions		36% aqueous solution (freezing point of -64°C) (CIL)			
Solubility					
In water		Reacts, evolving heat, and mixes slowly with water (CCPA 1982)			

SULPHURIC ACID

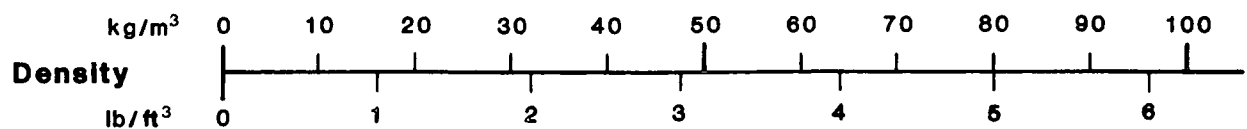
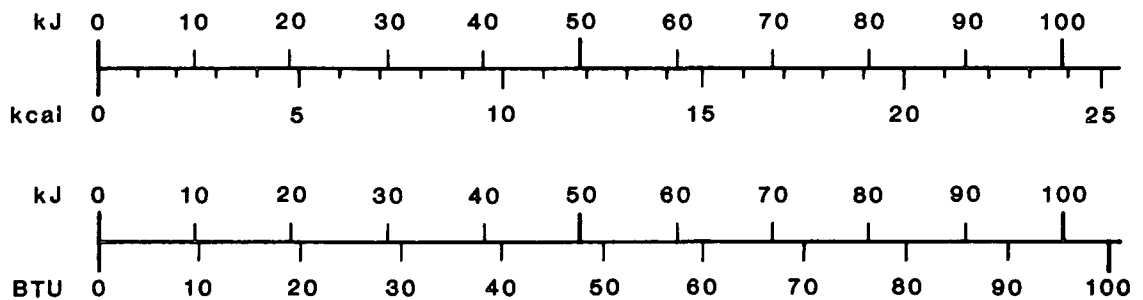
CONVERSION NOMOGRAMS

**Pressure** 1 kPa = 1,000 Pa**Viscosity**

Dynamic 1 Pa·s = 1,000 centipoise (cP)

Kinematic 1 m²/s = 1,000,000 centistokes (cSt)

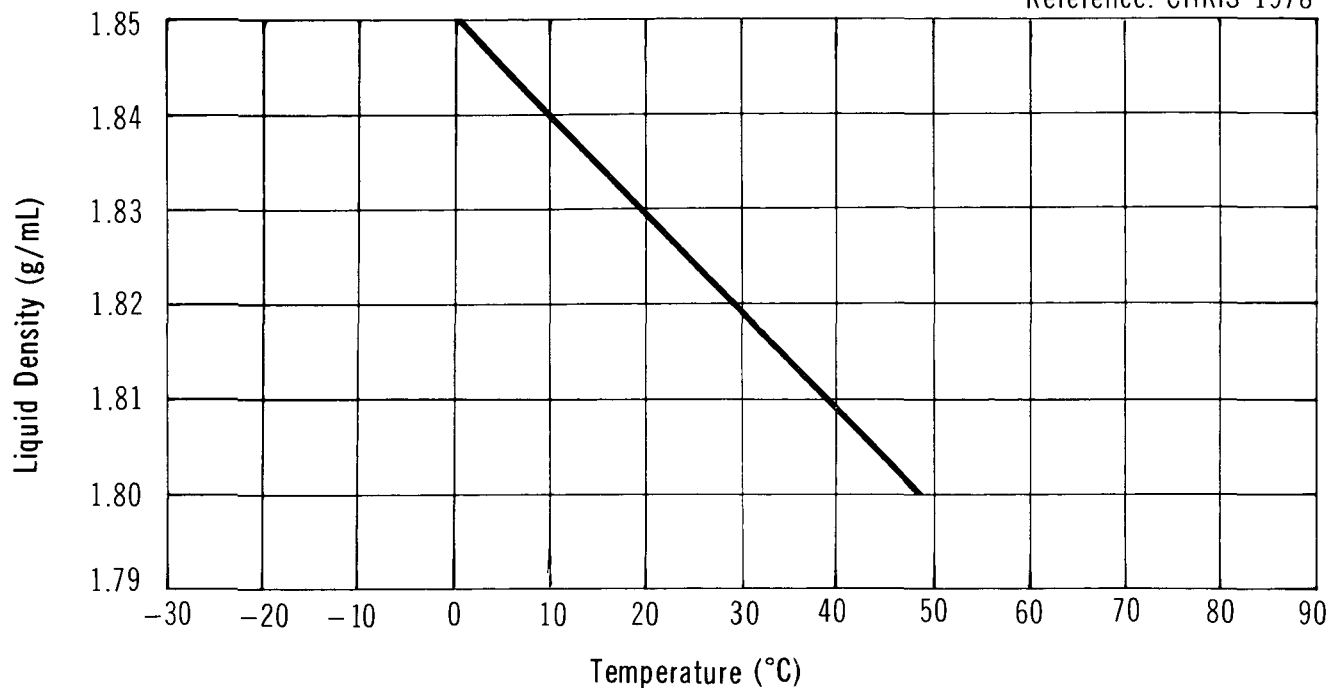
Concentration (in water)

1 ppm \cong 1 mg/L**Energy (heat)** 1 kJ = 1,000 J

SULPHURIC ACID 66° Bé

LIQUID DENSITY vs TEMPERATURE

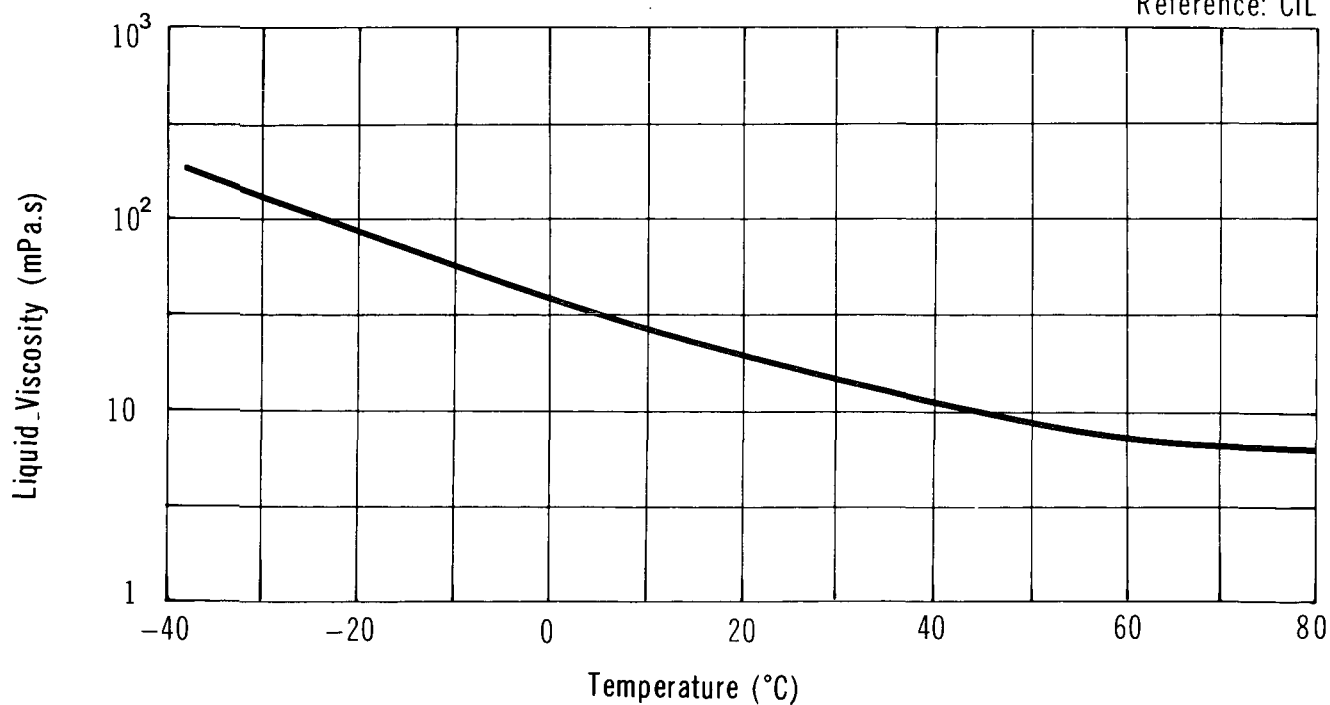
Reference: CHRIS 1978



SULPHURIC ACID 66° Bé

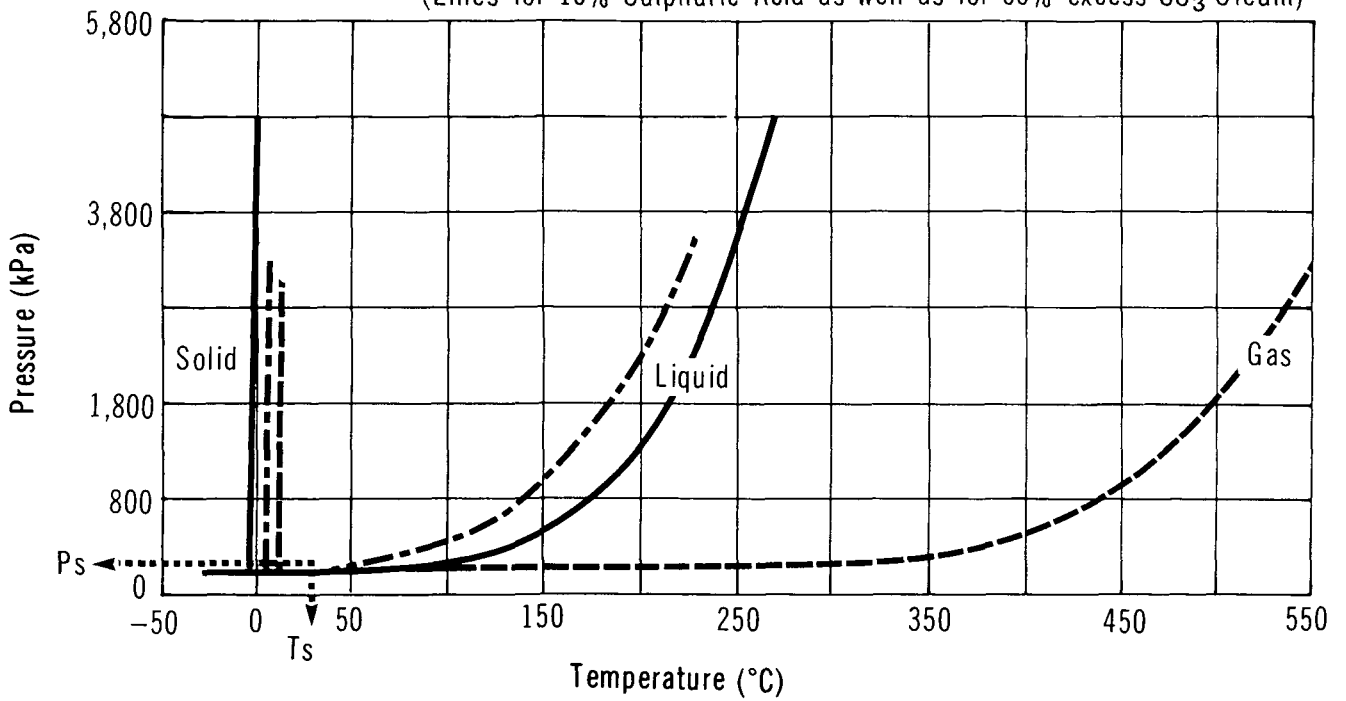
LIQUID VISCOSITY vs TEMPERATURE

Reference: CIL



SULPHURIC ACID

PHASE DIAGRAM

(Lines for 10% Sulphuric Acid as well as for 65% excess SO_3 Oleum)

LEGEND:

- 10% acid
- · - · - · Oleum
- - - - - 100% acid

3 COMMERCE AND PRODUCTION

3.1 Grades, Purities (Corpus 1981; CIL)

3.1.1 Sulphuric Acid. Sulphuric acid is sold in Canada in the following grades:

Grade	Concentration
Commercial (66°Bé)	93.19 percent (min.)
Electrolytic (1.835)	93.19 percent (min.)
Chemically Pure	95.5 to 96.5 percent

3.1.2 **Oleum.** Oleum, or fuming sulphuric acid, is most often shipped in concentrations of 10 and 20 percent excess SO₃ (CCPA 1982).

3.2 Domestic Manufacturers

These are corporate headquarters addresses and are not intended as spill response contacts.

3.2.1 Sulphuric Acid (Corpus 1981; CCR 1978; Scott 1979).

Allied Chemical Canada Ltd.
201 City Centre Drive
Mississauga, Ontario
L5B 2T4
(416) 276-9211

Canadian Electrolytic Zinc
860 boul. Cadieux
Valleyfield, Quebec
J6S 4W2
(514) 373-9144

Border Chemical
155 Carlton
Winnipeg, Manitoba
R3C 3H8
(204) 942-8758

Canadian Industries Limited
45 Sheppard Avenue East
Willowdale, Ontario
M2N 2Z9
(416) 226-6110

Brunswick Mining and Smelting Corp.
Commerce Court West, Suite 4500
P.O. Box 45
Toronto, Ontario
M5L 1B6
(416) 867-7111

Gulf Canada Ltd.
800 Bay Street
Toronto, Ontario
M5S 1Y8
(416) 924-4141

NL Chem Canada Inc.
2140 Sun Life Building
Montreal, Quebec
H3B 2X8
(514) 866-2401, 866-6881

Cominco Ltd.
200 Granville Street
Vancouver, British Columbia
V6C 2R2
(604) 682-0611

DuPont Canada Inc.
Box 2200, Streetsville
Mississauga, Ontario
L5M 2H3

Esso Chemical Canada
2300 Yonge Street
Toronto, Ontario
M5W 1K3
(416) 488-6600

Falconbridge Nickel Mines Ltd.
Commerce Court West
P.O. Box 40
Toronto, Ontario
M5L 1B4

Gaspé Copper Mines
P.O. Box 45
Toronto, Ontario
M5L 1B6
(416) 867-7111

Inco Metals
Inco Ltd.
1 First Canadian Place
P.O. Box 44
Toronto, Ontario
M5X 1C4
(416) 361-7511

Inland Chemicals
Industrial Park
P.O. Box 3180
Fort Saskatchewan, Alberta
T8L 2T2
(403) 998-2225

International Minerals & Chemical
Corp. Canada
701 Evans Avenue, Suite 312
Etobicoke, Ontario
M9C 1A3
(416) 621-9831

Sherritt Gordon Mines Ltd.
P.O. Box 28
Commerce Court West
Toronto, Ontario
M5L 1B1
(416) 363-9241

Sulco Chemicals
60 First Street
Elmira, Ontario
N3B 2Z5
(519) 669-5166

Texasgulf Canada
Commerce Court West
Suite 5000
P.O. Box 175
Toronto, Ontario
M5L 1E7
(416) 869-1200

Western Co-operative Fertilizers Ltd.
111 - 11 Barlow Trail S.E.
P.O. Box 2500
Calgary, Alberta
T2P 2N1
(403) 279-4421

3.2.2 Sulphuric Acid, Fuming (Oleum) (CCR 1978).

Allied Chemical Canada Ltd.
201 City Centre Drive
Mississauga, Ontario
L5B 2T4
(416) 276-9211

Inco Metals (formerly CIL at Copper
Cliff, Ont.)
Inco Ltd.
1 First Canadian Place
P.O. BOX 44
Toronto, Ontario
M5X 1C4
(416) 361-7511

Sulco Chemicals Ltd.
60 First Street
Elmira, Ontario
N3B 2Z5
(519) 669-5166

3.3 Other Suppliers (Corpus 1981)

Noranda Sales Corp. Ltd.
Commerce Court West
P.O. Box 45
Toronto, Ontario
M5L 1B6
(416) 867-7111

3.4 Major Transportation Routes

Current Canadian production of sulphuric acid is very widespread, occurring in seven provinces. 49.2 percent of sulphuric acid is primarily for captive use. The largest production facilities (non-captive) are located near Montreal and the Gaspé Peninsula, Quebec; Sudbury and Timmins, Ontario; near Winnipeg, Manitoba; in Fort Saskatchewan (near Edmonton), Alberta; and in Trail, B.C. (southeast B.C.). Transportation is mainly by rail and tank truck.

3.5 Production Levels (Corpus 1980; CCPA 1982)

Company, Plant Location	Nameplate Capacity kilotonnes/yr (1980)
Allied Chemical Canada, Valleyfield, Que.	113
Border Chemical, Transcona, Man.	150
Brunswick Mining and Smelting, Belledune, N.B.*	180
Canadian Electrolytic Zinc, Valleyfield, Que.	120
CIL, McMaster, Que.	60
NL Chem Canada, Varennes, Que.*	47
Cominco, Trail, B.C.	440
Cominco, Kimberly, B.C.*	280
Esso Chemical Canada, Redwater, Alta.*	515
Falconbridge Nickel, Sudbury, Ont.*	320
Gaspé Copper Mines, Murdochville, Que.	245
Gulf Minerals, Rabbit Lake, Sask.*	45
Inland Chemicals, Ft. Saskatchewan, Alta.	125
Inland Chemicals, Prince George, B.C.	35
INCO, Copper Cliff, Ont.	900
International Minerals and Chemicals, Pt. Maitland, Ont.*	250
Sherritt Gordon Mines, Ft. Saskatchewan, Alta.	190

Company, Plant Location	Nameplate Capacity kilotonnes/yr (1980)
Sulco Chemicals, Elmira, Ont.	35
Texasgulf Canada, Timmins, Ont.	205
Western Co-operative Fertilizers, Calgary, Alta.*	360
Western Co-operative Fertilizers, Medicine Hat, Alta.*	190
TOTAL	4,805
Domestic Production (1980)	4,296.5
Imports (1980)	18
TOTAL	4,314.5

*Primarily for captive use.

3.6 Future Development

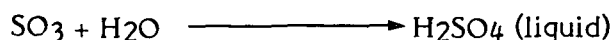
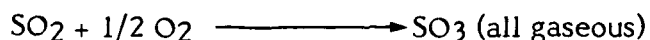
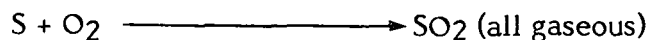
Two plants under construction, Texasgulf in Timmins, Ontario, and Western Co-operative Fertilizers in Medicine Hat, Alberta, will have increased sulphuric acid capacity: 200 kt/yr for Texasgulf and 397 kt/yr for Western Co-operative Fertilizers (existing unit to be replaced) (CCP 1981).

Cominco Ltd. has started to upgrade its acidification plant at Trail, B.C., resulting in a capacity of 380 kt/yr (Eco/Log 1981).

3.7 The Manufacture of Sulphuric Acid and Oleum (Shreve 1977; CCPA 1982)

3.7.1 General. The manufacture of sulphuric acid in Canada is primarily from smelter flue gas (SO₂) recovery.

3.7.2 Manufacturing Process. The process reactions are as follows:



The raw (elemental) sulphur is melted, atomized, and burned in air, resulting in the production of sulphur dioxide. Alternatively, SO₂ is obtained from smelter flue gas recovery. The sulphur dioxide is passed through a converter which contains a catalyst. Sulphur trioxide is emitted from the converter and is then put through an absorbing tower with water and low strength sulphuric acid to form commercial grades.

To produce oleum, concentrated sulphuric acid is mixed with sulphur trioxide. The resulting product is anhydrous sulphuric acid with a certain percentage of free sulphur trioxide.

3.8 Major Uses in Canada (Corpus 1981; CCP 1981)

Sulphuric acid is a widely used chemical in the world and has many applications. Some uses include the production of phosphoric acid, hydrofluoric acid, phosphatic fertilizers, aluminum sulphate, ammonium sulphate, superphosphates, cellulose film, viscose rayon, soaps and detergents, organic chemicals, explosives, and titanium dioxide. It is also used in the following industries: uranium ore processing, mining and smelting, pulp and paper, and petroleum refining.

3.9 Major Buyers in Canada (Corpus 1981; CBG 1980)

Abitibi-Price, Smooth Rock Falls, Ont; Jonquiere, Que.
 Agnew Lake Mines, Agnew Lake, Ont.
 Alcan Smelters & Chemicals, Jonquiere, Que.
 Algoma Steel, Sault Ste. Marie, Ont.
 Allied Chemical Canada, Amherstburg, Ont.
 American Can, Marathon, Ont.
 BP Canada, Oakville, Ont.
 Bate Chemical, Toronto, Ont.
 Bayer (Canada), Mississauga, Ont.
 Benson Chemicals, Freelton, Ont.
 Boise-Cascade, Ft. Frances, Newcastle, N.B.
 British Columbia Forest Products, Crofton, B.C.
 Canada Colours & Chem., Toronto, Ont.
 Canada Wire & Cable, Belledune, N.B.
 Canadian Cellulose, Prince Rupert, B.C.
 Canadian Copper Refiners, Montreal, Que.
 Canadian Forest Products, Pt. Mellon, B.C.
 Canadian International Paper, La Tuque, Que.
 Cariboo Pulp & Paper, Quesnel, B.C.
 Colgate-Palmolive, Toronto, Ont.
 Consolidated-Bathurst, Pontiac Mill, Que.
 Courtaulds Canada, Cornwall, Ont.
 Crestbrook Forest, Skookumchuck, B.C.
 Crown Zellerbach, Campbell River, B.C.
 Denison Mines, Elliot Lake, Ont.
 Dominion Foundries, Hamilton, Ont.
 Domtar, Lac Quevillon, Que.; Cornwall, Ont.
 Donohue St-Felicien, St-Felicien, Que.
 DuPont Canada, Shawinigan, Que.; North Bay, Ont.
 Eddy Forest Products, Espanola, Ont.
 Eurocan Pulp, Kitimat, B.C.
 Great Lakes Forest, Thunder Bay, Dryden, Ont.
 Gulf Canada, Montreal East, Que.
 Gulf Canada, Port Moody, B.C.

Kert Chemical, Toronto, Ont.
Kimberly-Clark of Canada, Terrace Bay, Ont.
Inco, Copper Cliff, Ont.
Intercontinental Paper, Prince George, B.C.
Irving Pulp & Paper, Saint John, N.B.
Lever Detergents, Toronto, Ont.
M & T Chemicals Ltd., Hamilton, Ont.
MacMillan Bloedel, Nanaimo, Pt. Alberni, B.C.
Madawaska Mines, Bancroft, Ont.
NL Chem Canada, Varennes, Que.
Northwood Pulp, Prince George, B.C.
Ontario Paper, Thorold, Ont.
Petrofina, Pte-aux-Trembles, Que.
Price, Kenogami, Que.
Prince Albert Pulp, Prince Albert, Sask.
Prince George Pulp & Paper, Prince George, B.C.
Procter & Gamble, Hamilton, Ont.
Procter & Gamble Cellulose, Grande Prairie, Alta.
Rayonier Canada, Woodfibre, B.C.
Rio Algom, Elliot Lake, Ont.
Ste Anne-Nackawic, Nackawic, N.B.
St. Regis, Hinton, Alta.
Scott Maritimes, Pt. Abercrombie, N.S.
Shefford Chemicals, Granby, Que.
Shell Canada, Oakville, Ont.; Montreal, Que.
Steel Co. of Canada, Hamilton, Ont.
Tahsis, Gold River, B.C.
Texaco Canada, Montreal East, Que.; Nanticoke, Ont.
Thurso Pulp & Paper, Thurso, Que.
Tioxide of Canada, Tracy, Que.
Uba Chemical, Mississauga, Ont.
VanWaters & Rogers, Richmond, B.C.
Weyerhaeuser Canada, Kamloops, B.C.

4 MATERIAL HANDLING AND COMPATIBILITY

4.1 Containers and Transportation Vessels

4.1.1 Bulk Shipment. Sulphuric acid solutions, oleum, and spent acid are shipped bulk in specially designed railway tank cars and tank motor vehicles.

4.1.1.1 Railway tank cars. Railway tank cars used in the transportation of sulphuric acid are classified under the A-1 Class 103, A-3 Class 105A and A-8 Class III CTC tanker specifications. See Table 2 for a description under each specification. Most cars for sulphuric acid service are lined with Heresite resin.

The acid is usually shipped in CTC 103AW and 111A100W2 railway cars, as shown in Figures 4 and 5. Tables 3 and 4 indicate railway tank car details associated with these drawings. Sulphuric acid cars are unloaded through bottom outlets under special CTC permits only. Typically, cars are unloaded from the top using compressed air (MCA 1963). The sulphuric acid is withdrawn through an eduction pipe which extends from the bottom of the tank to the top operating platform where it terminates with a 51 mm (2 in.) unloading connection valve. Air pressure of 207 kPa (30 psi) is applied through the 25 mm (1 in.) air connection valve.

Outside heating coils and fibreglass insulation are required for certain strengths of acid that freeze at common winter temperatures. Occasionally for munition manufacture, nitric acid may be added as an antifreeze agent to sulphuric acid, particularly to oleum (MCA 1963; CCPA 1982).

A safety relief valve set at 518 kPa (75 psi) or a safety vent set at 690 kPa (100 psi) is required on top of the rail car. Rupture disc settings of not more than 100% of tank test pressure on 103AW, 111A100W2 and 111A100W5 are also authorized by the CTC under special permits. A gauging device, either the rod type or the tape type, is optional. The maximum pressure allowable for the CTC 111A100W2 rail cars is 448 kPa (65 psi). When the 111A60W2 cars are used, this maximum pressure would be 276 kPa (40 psi) (TCM 1979). Both these pressures exceed the maximum compressed air pressure of 207 kPa (30 psi) used during unloading. Sulphuric acid is never transported under pressure.

Sulphuric acid cars are filled through a 200 mm (8 in.) opening at the top of the car. As indicated in Figures 4 and 5, a domeless manway or dome option is available depending on the class of car (TCM 1979). When a bottom washout is used, depending again on the class of car selected, a washout plug and "O" ring assembly is

TABLE 2 RAILWAY TANK CAR SPECIFICATIONS

DOT* and CTC**
Specification Number

Sol'n >65% inc. Oleum	Sol'n <51%	Description
103W		Steel fusion-welded tank with dome. Uninsulated or insulated. Bottom outlet or washout optional.
103AW		Steel fusion-welded tank with dome. Uninsulated or insulated. Top unloading arrangement required. Bottom outlet prohibited; bottom washout optional.
	103BW	Steel fusion-welded tank with dome. Uninsulated or insulated. PVC-lined tank. Top unloading arrangement required. Bottom outlet or washout prohibited.
103CW		Alloy (stainless) steel fusion-welded tank with dome. Insulated or uninsulated. 1% dome. Bottom outlet or washout prohibited. Top unloading arrangement required.
111A60W2 (use also for sol'ns >51% and <65% with rubber lining)		Steel fusion-welded tank without dome. Uninsulated or insulated. 2% minimum outage. Gauging device. Top unloading arrangement required. Bottom outlet prohibited; bottom washout optional. Test pressure 414 kPa (60 psi).
111A100W2 (use also for sol'ns >51% and <65% with rubber lining)		Steel fusion-welded tank without dome. Uninsulated or insulated. 2% minimum outage. Gauging device. Top unloading arrangement required. Bottom outlet prohibited; bottom washout optional. Test pressure 690 kPa (100 psi).

TABLE 2 RAILWAY TANK CAR SPECIFICATIONS (cont'd)

DOT* and CTC** Specification Number		
Sol'n >65% inc. Oleum	Sol'n <51%	Description
	111A60W5	Steel fusion-welded tank without dome. Uninsulated or insulated. PVC-lined tank. 2% minimum outage. Gauging device. Top unloading arrangement required. Bottom outlet or washout prohibited. Test pressure 414 kPa (60 psi).
111A100W6		Alloy (stainless) steel fusion-welded tank without dome. Insulated or uninsulated. Gauging device. Top unloading arrangement required. Bottom outlet or washout prohibited. Test pressure 690 kPa (100 psi).
111A100F2		Steel forge-welded tank without dome. Uninsulated or insulated. 2% minimum outage. Gauging device. Top unloading arrangement required. Bottom outlet prohibited; bottom washout optional. Test pressure 690 kPa (100 psi).

* Department of Transportation (U.S.)

** Canadian Transport Commission

required in conjunction with a separate nozzle flange and blind flange gasket. A tell-tale plug between both assemblies is required (TCM 1979).

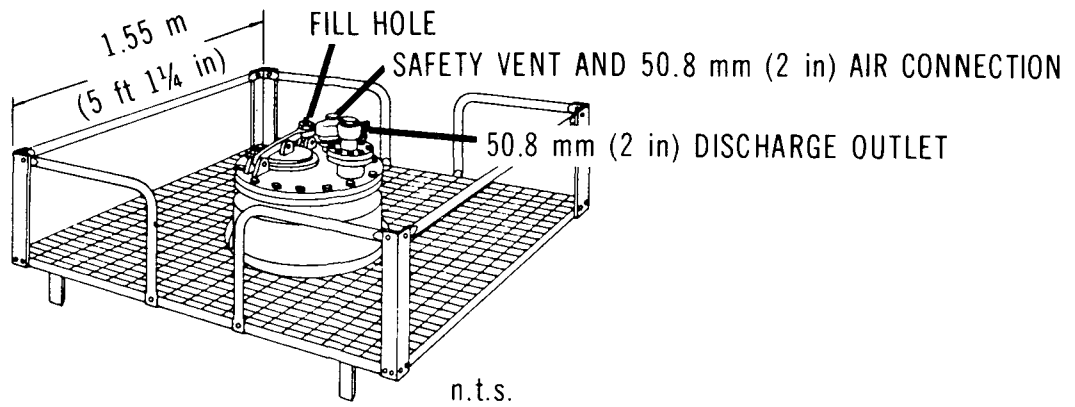
4.1.1.2 Tank motor vehicles. The capacities of tank trucks transporting sulphuric acid range from 15 to 28 tonnes, with 22 tonnes being most common.

Similar to railway tank cars, these highway tankers are unloaded from the top. Compressed air is used for unloading. The air inlet is usually a 25 mm (1 in.) diameter male threaded connection located at the top of the trailer through which air pressure not

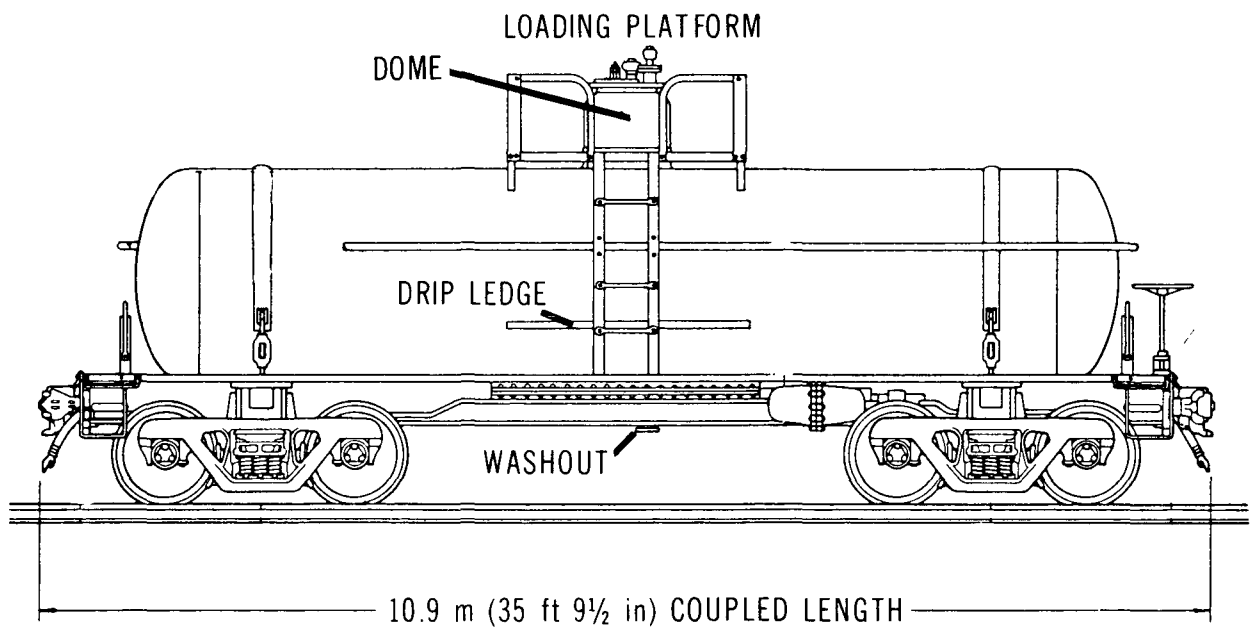
SULPHURIC ACID

RAILWAY TANK CAR - CLASS 103 AW

(Reference - TCM 1979; AAR 1982; RTDCR 1974)



Detail of loading platform



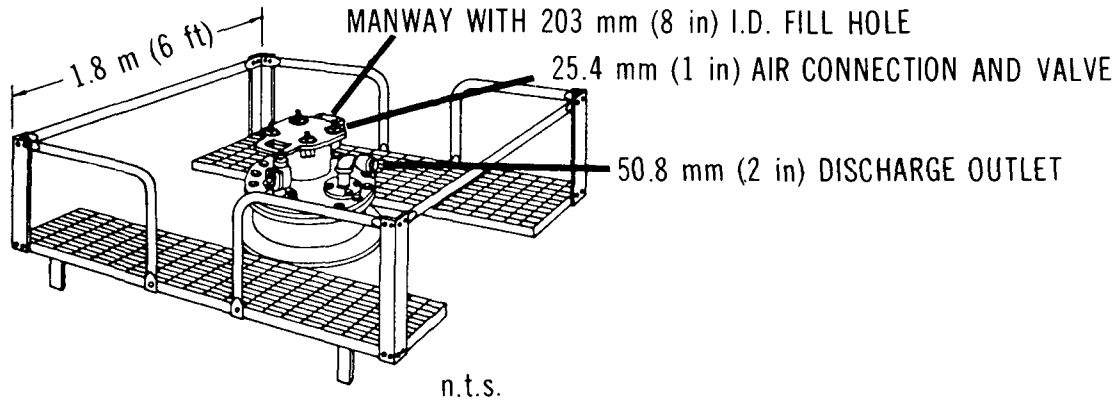
Approximate Scale

Illustration of train car layout

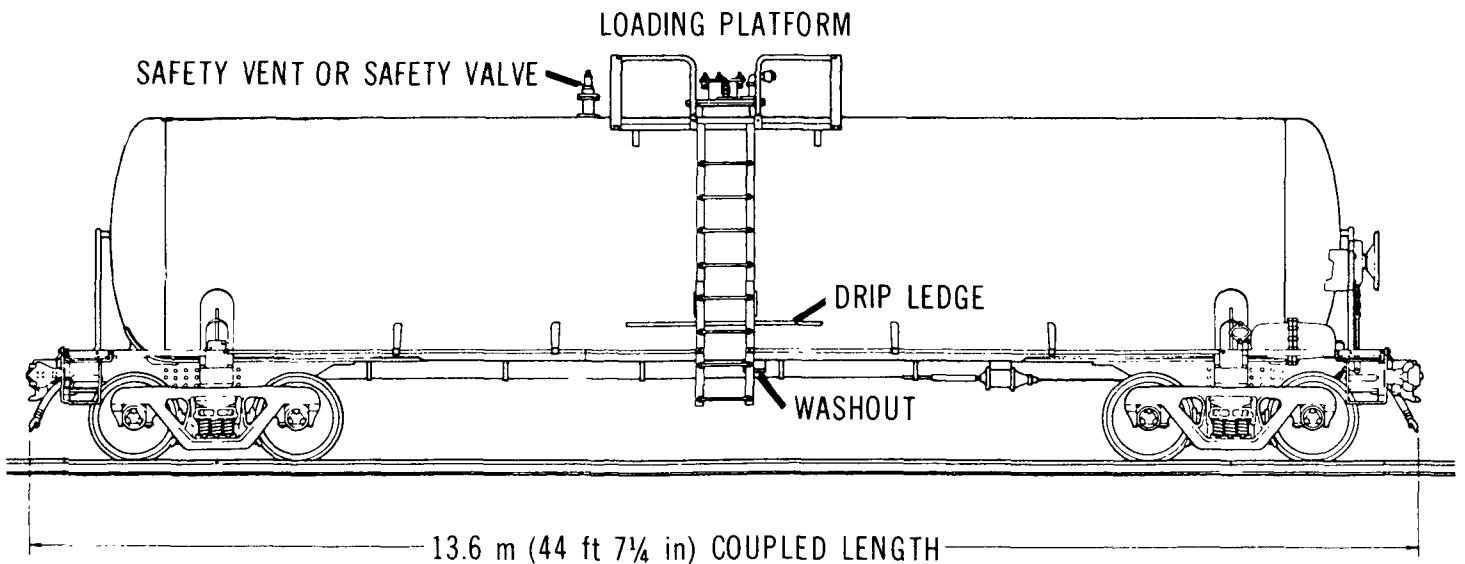
SULPHURIC ACID

RAILWAY TANK CAR - CLASS 111A100W2

(Reference - TCM 1979; AAR 1982, RTDCR 1974)



Detail of loading platform



Approximate Scale 1 : 72

Illustration of train car layout

TABLE 3 RAILWAY TANK CAR DETAILS - CLASS 103AW (TCM 1979; AAR 1982; RTDCR 1974)

	Description	Dimension	Notes
Overall	Nominal capacity Car weight-empty Car weight-full	26,500 L (5,800 gal.) 19,200 kg (42,400 lb.) 80,300 kg (117,000 lb.)	
Tank	Material Thickness Inside diameter Test pressure Burst pressure	 14.3 mm (9/16 in.) 1.95 m (77 in.) 414 kPa (60 psi) 1,650 kPa (240 psi)	Steel
Typical Dimensions	Coupled length Length over strikers Length of truck centers Height to top of grating Overall height Overall width (over grabs) Coupler height over rail Length of grating Width of grating	10.9 m (35 ft 9 1/2 in.) 10.1 m (33 ft 2 in.) 6.77 m (22 ft 2 1/2 in.) 3.08 m (10 ft 1 1/4 in.) 4.20 m (13 ft 9 3/8 in.) 3.10 m (10 ft 2 in.) 0.88 m (2 ft 10 1/2 in.) 2.25 m (7 ft 4 5/8 in.) 1.86 m (6 ft 1 1/8 in.)	
Loading/ Unloading Fixtures	Unloading connection Fill hole Air connection Bottom outlet Bottom washout	51 mm (2 in.) 152-203 mm (6-8 in.) 51 mm (2 in.) 152-203 mm (6-8 in.)	quick-opening type prohibited, CTC approval required for bottom unloading
Safety Devices	Safety vent		required, may be equipped with frangible disc with 3 mm (1/8 in.) vent hole except for oleum service
Dome			required, provides 1% expansion capacity
Insulation			Optional

TABLE 4 RAILWAY TANK CAR DETAILS - CLASS 111A100W2 (TCM 1979; AAR 1982; RTDCR 1974)

	Description	Dimension	Notes
Overall	Nominal capacity Car weight-empty Car weight-full	50,500 L (11,100 gal.) 25,200 kg (55,600 lb.) 119,300 kg (263,000 lb.)	
Tank	Material Thickness Inside diameter Test pressure Burst pressure	 14.3 mm (9/16 in.) 2.40 m (94 1/2 in.) 690 kPa (100 psi) 3,450 kPa (500 psi)	Aluminum Alloy
Typical Dimensions	Coupled length Length over strikers Length of truck centers Height to top of grating Overall height Overall width (over grabs) Coupler height over rail Length of grating Width of grating	13.6 m (44 ft 7 1/4 in.) 12.8 m (41 ft 11 3/4 in.) 9.46 m (31 ft 0 1/4 in.) 3.48 m (11 ft 5 13/16 in.) 4.26 m (13 ft 11 13/16 in.) 3.21 m (10 ft 6 1/2 in.) 0.88 m (2 ft 10 1/2 in.) 2.44 m (8 ft 0 1/8 in.) 1.83 m (6 ft)	
Loading/ Unloading Fixtures	Unloading connection Fill hole Air connection Bottom outlet Bottom washout	51 mm (2 in.) 203 mm (8 in.) 25 mm (1 in.) 152-203 mm (6-8 in.)	prohibited, CTC approval required for bottom unloading
Safety Devices	Safety vent		required, may be equipped with frangible disc with 3 mm (1/8 in.) vent hole except for oleum service
Insulation			Optional
Dome			None

exceeding 207 kPa (30 psi) may be applied. Tanks may be insulated and heated depending on the acid strength and freezing point (CSA 1976).

Tank motor vehicles must conform to Transport Canada specification TC312, covering MC310, MC311, MC312 as outlined in Table 5 (TDGC 1980). Sulphuric acid solutions are not transported under pressure. Highway tankers must be pressure tested at 311 kPa (45 psi) minimum to allow for the compressed air pressure of 207 kPa (30 psi) used during top unloading (CSA 1976). The maximum working pressure of the tanker is in effect 207 kPa (30 psi).

TABLE 5 TANK MOTOR VEHICLE SPECIFICATIONS

TC* Specification Number	Description
TC312	<p>Steel butt-welded tank.</p> <p>Design and construct in accordance with ASME code when unloading by pressure in excess of 103 kPa (15 psi).</p> <p>Gauging device not required.</p> <p>Top and/or bottom discharge outlet.</p> <p>Bottom discharge outlet must have remotely operated handles.</p> <p>Minimum one pressure relief device per compartment as required by ASME code.</p> <p>One minimum 380 mm (15 in.) diameter manhole per compartment.</p> <p>Bottom washout optional.</p>

* Transport Canada

4.1.2 Packaging. In addition to bulk shipments, sulphuric acid is also transported in drums, although again this practice is infrequent in Canada. Drums fabricated from a variety of construction materials are permitted. Tables 6 and 7 listing drum types and descriptions for oleum and for sulphuric and spent acid are included (TDGC 1980).

Glass carboys, boxed or in expanded polyethylene containers, are also used to transport oleum and sulphuric acid (MCA 1963).

4.2 Off-loading

4.2.1 Off-loading Equipment and Procedures for Railway Tank Cars. The following procedures are derived from literature sources and are included to provide information which may be of use in spill events. Readers are advised to consult with experts from industry in the event that this information is required.

Prior to off-loading, certain precautions must be taken (MCA 1963):

- The vented storage tank must be checked to make sure that it will hold the contents of the car.
- For night-time unloading, lights must have an explosion-proof rating.
- Personnel must not enter the car under any circumstances.
- Brakes must be set, wheels chocked, derails placed and caution placards displayed.
- A safe operating platform must be provided at the unloading point.

Proceed with off-loading as follows (MCA 1963):

- In cold weather for certain strengths of acid, connect steam coil connection valves to live steam.
- Connect the 51 mm (2 in.) unloading line to the discharge outlet and connect the 25 mm (1 in.) air line. Air pressure must be reduced to 207 kPa (30 psi) for unloading. A safety relief valve must be installed in the air line to release at 242 kPa (35 psi).
- After opening the air supply valve, the unloading connection valve can then be opened to unload the car.
- Once the car is empty, the air supply valve must be closed and the vent valve in the air line opened to allow the line pressure to equalize to atmospheric pressure.
- Reverse the above procedure to close up the car.

4.2.2 Off-loading Equipment and Procedures for Tank Motor Vehicles. The unloading of sulphuric acid tank trailers is similar to that of railway tank cars. The general procedures for tank cars apply equally well to tank trailers.

TABLE 6 DRUMS FOR OLEUM

Type of Drum	Designation	Description	Figure No. (if any)
Steel	1A1	Nonremovable head, reusable	6
	1A1A	1A1 with reinforced chime	6
	1A1B	1A1 with welded closure flange	6
	1A1C	1A1 with lead coating	6
	1A1D	1A1 with coating (other than lead)	6
	1A2	Removable head, reusable	6
Monel*	TC5M		6
Nickel	TC5K	Similar to monel drum, only nickel	6

*See Section 4.3 of this report.

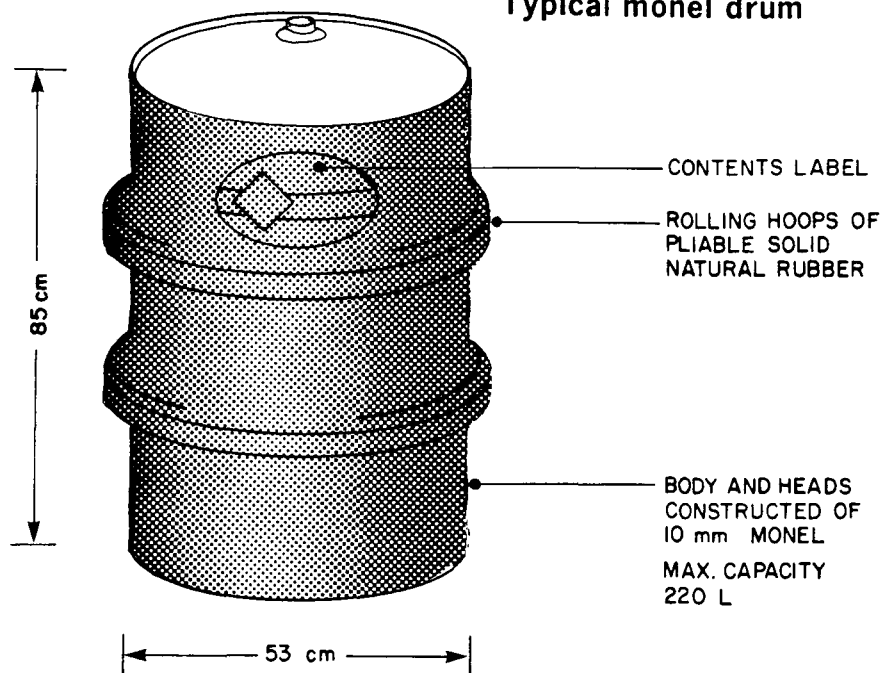
TABLE 7 DRUMS FOR SULPHURIC ACID AND SPENT ACID

Type of Drum	Designation	Description	Figure No. (if any)
Steel	1A1	Nonremovable head, reusable	6
	1A1A	1A1 with reinforced chime	6
	1A1B	1A1 with welded closure flange	6
	1A1C	1A1 with lead coating	6
	1A1D	1A1 with coating (other than lead)	6
	1A3	Nonremovable head, single use only	6
Plastic	1H1	Nonremovable head. Maximum capacity 250 L. Maximum net mass 400 kg	
Steel Drums with inner plastic receptacles	6HA1	Outer steel sheet in the shape of drum. Inner plastic receptacle. Maximum capacity 225 L	

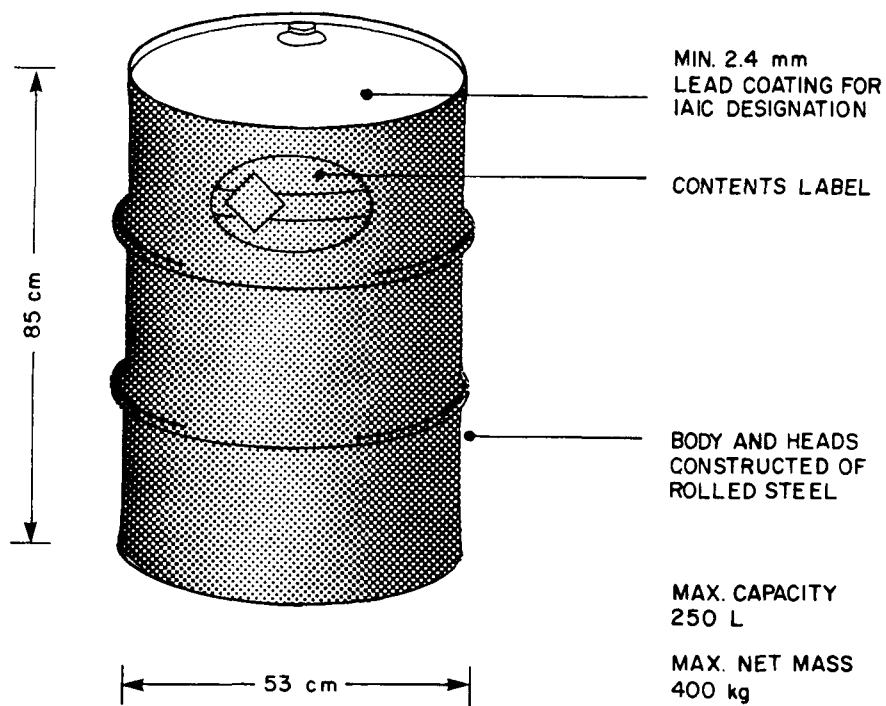
SULPHURIC ACID

TYPICAL DRUM CONTAINERS

Typical monel drum



Typical steel drum



4.2.3 Specifications and Materials for Off-loading Equipment. The materials of construction for off-loading system components discussed in this section along with specifications refer to those generally used in sulphuric acid service. The components of a typical off-loading system include pipes and fittings, flexible connections, valves, gaskets, pumps and storage tanks.

Schedule 80 seamless ASTM A106 carbon steel or Schedule 40 stainless steel 316 pipes and welding fittings are recommended for oleum and commercial sulphuric acid (MCA 1963). Flanged joints should be used and these should be welded, because threaded pipes and fittings tend to leak. Stress relief at the weld will also lengthen the serviceability of the pipe. The pipe line should be tested with air at pressures from 345 to 518 kPa (50 to 75 psi) and all leaks carefully stopped. If leaks develop in service, the only satisfactory way to repair them is to chip out the bad weld and reweld, or to replace the section of pipe.

The unloading line should be 51 mm (2 in.) pipe because this is the standard fitting on sulphuric acid tank cars; however, process pipe may be almost any size. Pipe under 25 mm (1 in.), however, is not recommended.

Outdoor lines must be self-draining and may be insulated depending upon acid strength. These can be steam traced with 9 mm to 13 mm (3/8 to 1/2 in.) copper tubing or steel pipe located inside the insulation (CSA 1976).

Steel or stainless steel pipe and swivel joints may be used for flexible sections when handling oleum. Either the ball bearing type swivel joint or the simple stuffing box type will give adequate service with proper maintenance. Flexible acid hose is normally used to handle oleum and sulphuric acid. Chemiflex 951 gives satisfactory service for all strengths of sulphuric acid up to 98/99 percent. Teflon-lined Chemiflex 976 is suitable for oleum up to 30 percent strength (CSA 1976).

For valving, quick acting ball or plug valves in "20" alloy will serve adequately in all sulphuric acid and oleum applications (ASA 1978).

Teflon gaskets can be used as a gasket material in all sulphuric acid strengths (DCRG 1978).

A single suction centrifugal pump with "20" alloy shaft and impeller and a high silicon cast iron casing is recommended for pumping. Teflon again is a good packing material (CSA 1976).

Welded heavy wall carbon steel or stainless steel storage tanks are commonly used. Fibre-reinforced plastic or PVC lined steel is commonly used for solutions up to 70 percent sulphuric acid (CSA 1976).

4.3 Compatibility with Materials of Construction

The compatibility of sulphuric acid with materials of construction is shown in Table 8. The unbracketed abbreviations are described in Table 9.

The rating system used in Table 8 is briefly described below.

- Recommended: This material will perform satisfactorily in the given application.
- Conditional: Material will show deterioration in the given application; however, it may be suitable for intermittent or short-term service.
- Not Recommended: Material will be severely affected in this application and should not be used.

TABLE 8 COMPATIBILITY WITH MATERIALS OF CONSTRUCTION

Application	Chemical		Material of Construction		
	Conc.	Temp. (°C)	Recommended	Conditional	Not Recommended
1. Pipes and Fittings	54-60°Bé		CS, Sch. 80 and 150 lb. Welding Flanges		
	66°Bé-100%		CI and 250 lb. Welding Flanges (DSA)		
	Electrolyte and Other Grades up to 60°Bé		Lead, with 6% Antimony 125 lb. Flanges or Lap Joint Flanges		
			High Silicon Cast Iron		
			Rigid Normal Impact uPVC, Sch. 80 (DSA)		
	Electrolyte		Lead, with 6% Antimony Lead 125 lb.		

TABLE 8 COMPATIBILITY WITH MATERIALS OF CONSTRUCTION (Cont'd)

Application	Chemical		Material of Construction		
	Conc.	Temp. (°C)	Recommended	Conditional	Not Recommended
	66°Bé		Flanges or Lap Joint Flanges		
			High Silicon Cast Iron (DSA)		
	Chemically Pure 95.5 to 96.5%		Pyrex Glass		
			PTFE Plastic Lined Hose (DSA)		
	Oleum, All Strengths		CS, Sch. 80 and 150 lb. Welding Flanges (DSA)		CI, High Silicon Cast Iron (DSA)
	10-75%	23	PE		ABS (DPPED 1967)
			PVC I PVC II (DPPED 1967)		
	10-75%	49			PE (DPPED 1967)
	10-75%	60	PVC I		PVC II (DPPED 1967)
	75-90%	23	PVC I		PE ABS PVC II (DPPED 1967)
	75-90%	60		PVC I (DPPED 1967)	
	16%	121	PVDF Chlorinated Polyether (DCRG 1978)		

TABLE 8 COMPATIBILITY WITH MATERIALS OF CONSTRUCTION (Cont'd)

Application	Chemical		Material of Construction		
	Conc.	Temp. (°C)	Recommended	Conditional	Not Recommended
	16%	93	PP (DCRG 1978)		
	16%	52	PVDC (DCRG 1978)		
	60%	121	Chlorinated Polyether (DCRG 1978)		
	60%	121	PVDF (DCRG 1978)		PVDC (DCRG 1978)
	60%	107	PVDF (DCRG 1978)		PVDC (DCRG 1978)
	60%	93	PP (DCRG 1978)		PVDC (DCRG 1978)
	93%	79	PVDF		PVDC (DCRG 1978)
			PP (DCRG 1978)		
	93%	66	Chlorinated Polyether		PVDC (DCRG 1978)
	98%	66	PVDF (DCRG 1978)		PVDC (DCRG 1978)
	98%	52	PP (DCRG 1978)		PVDC (DCRG 1978)
2. Valves	54-60°Bé 66°Bé - 100%		"20" Alloy With PTFE Plastic Packing and 150 lb. Flanges		
			Plug-type, "20", PTFE Plastic Sleeve and 150 lb. Flanges (DSA)		

TABLE 8 COMPATIBILITY WITH MATERIALS OF CONSTRUCTION (Cont'd)

Application	Chemical		Material of Construction		
	Conc.	Temp. (°C)	Recommended	Conditional	Not Recommended
	Electro-lyte and Other Grades up to 60°Bé		"20" Alloy or High Silicon Cast Iron with PTFE Plastic Packing and 150 lb. Flanges		
			6% Antimony Lead with PTFE Plastic Packing and 125 lb. Flanges		
			Plug-type, "20" Alloy, PTFE Plastic Sleeve and 150 lb. Flanges (DSA)		
	Electro-lyte 66°Bé		"20" Alloy or High Silicon Iron with PTFE Plastic Packing and 150 lb. Flanges		
			6% Antimony Lead with PTFE Plastic Packing and 125 lb. Flanges		
			Plug-type, "20" Alloy, PTFE Plastic Sleeve and 150 lb. Flanges (DSA)		
	Chemically		Porcelain "Y" Valves		

TABLE 8 COMPATIBILITY WITH MATERIALS OF CONSTRUCTION (Cont'd)

Application	Chemical		Material of Construction		
	Conc.	Temp. (°C)	Recommended	Conditional	Not Recommended
	Pure 95.5 to 96.5%		with PTFE Plastic Discs and 150 lb. Flanges (DSA)		
	Oleum All Strengths		"20" Alloy with PTFE Plastic Packing and 150 lb. Flanges		
			Plug-type, "20" Alloy, PTFE Plastic Sleeve and 150 lb. Flanges (DSA)		
	50% (41°Bé)	21	SS 316 (JSSV 1979)		
	50% (41°Bé)	Boiling			SS 316 (JSSV 1979)
	Concen- trated (66°Bé)	21	SS 316 (JSSV 1979)		
	Concen- trated (66°Bé)	Boiling		SS 316 (JSSV 1979)	
3. Pumps	>77%	Cold	All Iron High Silicon Cast Iron (HIS 1969)		
	65- 93%	>79	High Silicon Cast Iron (HIS 1969)		
	65- 93%	<79	High Silicon Cast Iron (HIS 1969)		

TABLE 8 COMPATIBILITY WITH MATERIALS OF CONSTRUCTION (Cont'd)

Application	Chemical		Material of Construction		
	Conc.	Temp. (°C)	Recommended	Conditional	Not Recommended
	10-65%		High Silicon Cast Iron (HIS 1969)		
	54°-60°Bé		Centrifugal Type "20" Alloy		
	60°Bé - 100%		CI with "20" Alloy Impeller		
			High Silicon Cast Iron (DSA)		
	Electro-lyte and Other Grades up to 60°Bé		Centrifugal type "20" Alloy High Silicon Cast Iron (DSA)		
	Electro-lyte 66°Bé		Centrifugal type "20" Alloy High Silicon Cast Iron (DSA)		
	Chemi- cally Pure 95.5 to 96.5%		Centrifugal type, Glass Lined Diaphragm type with PTFE Plastic Diaphragm (DSA)		
	Oleum - All Strengths		Centrifugal type, "20" Alloy (DSA)		

TABLE 8 COMPATIBILITY WITH MATERIALS OF CONSTRUCTION (Cont'd)

Application	Chemical		Material of Construction		
	Conc.	Temp. (°C)	Recommended	Conditional	Not Recommended
4. Storage	54° - 60°Bé		Heavy Steel (DSA)		
	93 to 100%				
	Electro- lyte and Other Grades up to 60°Bé		Steel or Wood with Chemical Lead Lining (DSA)		
	Electro- lyte 66°Bé		Steel or Wood with Chemical Lead Lining		
			Steel with Baked Phenolic Lining (i.e. Heresite P-403) (DSA)		
	Chemi- cally Pure 95.5 to 96.5%		Glass Lined Steel (DSA)		
	Oleum All Strengths		Heavy Steel (DSA)		
5. Others	10%	60	PVC (TPS 1978)		
	10%	100	CPVC (TPS 1978)		
	10%	82	PP (TPS 1978)		
	10%		NR SBR CR NBR IIR		

TABLE 8 COMPATIBILITY WITH MATERIALS OF CONSTRUCTION (Cont'd)

Application	Chemical		Material of Construction		
	Conc.	Temp. (°C)	Recommended	Conditional	Not Recommended
			CSM Si EPDM (GPP)		
	15%	20	SS 316 (ASS)		SS 302 SS 304 SS 410 SS 430 (ASS)
	15%	60			SS 302 SS 304 SS 316 SS 410 SS 430 (ASS)
	Up to 40%	40	uPVC PE PP NR NBR IIR EPDM CR FPM CSM (GF)		POM (GF)
	Up to 40%	60	PE PP IIR EPDM CR FPM CSM (GF)	uPVC NR (GF)	POM NBR (GF)
	50%	49	PP (TPS 1978)		
	50%	60	PVC (TPS 1978)		
	50%	66		PP (TPS 1978)	
	50%	85	CPVC (TPS 1978)		

TABLE 8 COMPATIBILITY WITH MATERIALS OF CONSTRUCTION (Cont'd)

Application	Chemical		Material of Construction		
	Conc.	Temp. (°C)	Recommended	Conditional	Not Recommended
	50%	100		CPVC (TPS 1978)	
	50%	20		SS 316 (ASS)	SS 302 SS 304 SS 410 SS 430 (ASS)
	50%	Boiling			SS 302 SS 304 SS 316 SS 410 SS 430 (ASS)
	50%		CSM (GPP)		NR SBR CR NBR IIR EPDM (GPP)
	96%	20	uPVC (GF)	PE PP FPM (GF)	POM NR NBR IIR EPDM CR CSM (GF)
	96%	60		uPVC PE (GF)	PP POM NR NBR IIR EPDM CR FPM CSM (GF)
	98%	22			PVC CPVC

TABLE 8 COMPATIBILITY WITH MATERIALS OF CONSTRUCTION (Cont'd)

Application	Chemical		Material of Construction		
	Conc.	Temp. (°C)	Recommended	Conditional	Not Recommended
					(TPS 1978)
	98%	49		PP (TPS 1978)	
	98%	66	PVDF (TPS 1978)		PP (TPS 1978)
	98%	121			PVDF (TPS 1978)
	100%	22			PVC CPVC (TPS 1978)
	100%	23		PP (TPS 1978)	
	100%	49			PP (TPS 1978)
	Concen- trated				NR SBR CR NBR IIR CSM Si EPDM (GPP)
	Concen- trated	20	SS 302 SS 304 SS 316 SS 410 SS 430 (ASS)		
	Concen- trated	40	SS 316 (ASS)	SS 302 SS 304 (ASS)	SS 410 SS 430 (ASS)
	Concen- trated	60		SS 302 SS 304 SS 316 (ASS)	SS 410 SS 430 (ASS)
	Concen- trated	100			SS 302 SS 304 SS 316 (ASS)

TABLE 8 COMPATIBILITY WITH MATERIALS OF CONSTRUCTION (Cont'd)

Application	Chemical		Material of Construction		
	Conc.	Temp. (°C)	Recommended	Conditional	Not Recommended
	Oleum (100%)	24 to 260	Glass (CDS 1967)		

TABLE 9 MATERIALS OF CONSTRUCTION

Abbreviation	Material of Construction
ABS	Acrylonitrile Butadiene Styrene Aluminum
CFE	Polychlorotrifluoroethylene (Plaskon, CTFE, KEL-F, Florothene)
CI	Cast Iron, Austenitic Cast Iron, High Silicone Chlorinated Polyether
CPVC	Chlorinated Polyvinyl Chloride
CR	Polychloroprene (Neoprene)
CS	Carbon Steel
CSM	Chlorosulphonated Polyethylene (Hypalon)
EPDM	Ethylene Propylene Rubber
FPM	Fluorine Rubber (Viton) Glass Iron
IIR	Isobutylene/Isoprene Rubber (Butyl) Lead
NBR	Acrylonitrile/Butadiene Rubber (Nitrile, Buna N)
NR	Natural Rubber Nickel Nickel-Copper Alloy (Monel)
PE	Polyethylene
POM	Polyoxymethylene

TABLE 9 MATERIALS OF CONSTRUCTION (Cont'd)

Abbreviation	Material of Construction
PP	Polypropylene Porcelain
PTFE	Polytetrafluoroethylene (Teflon)
PVC (Followed by grade, if any)	Polyvinyl Chloride
PVDC	Polyvinylidene Chloride (Saran)
PVDF	Polyvinylidene Fluoride
Si	Silicone
SBR	Styrene/Butadiene (GR-5, Buna S)
SS (Followed by grade)	Stainless Steel "20" Alloy (Durimet 20, Carpenter 20)
uPVC	Unplasticised Polyvinyl Chloride Wood

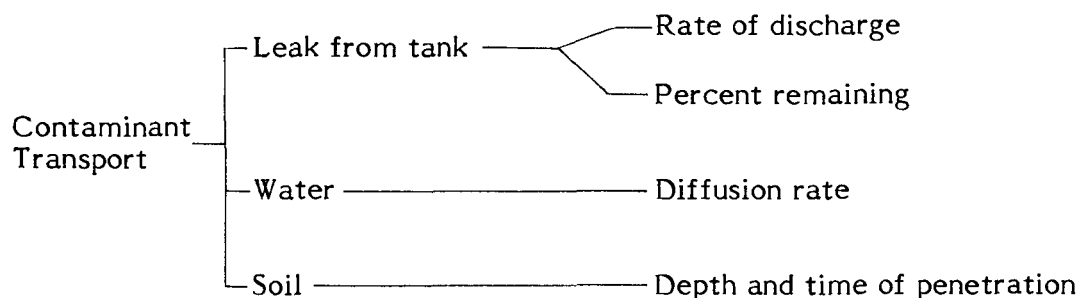
5 CONTAMINANT TRANSPORT

5.1 General Summary

Sulphuric acid is commonly transported in tank cars as a liquid. When spilled in water, it will mix slowly; oleum or concentrated acid solutions react violently. When spilled on soil, the liquid will spread on the surface and penetrate into the soil at a rate dependent on the soil type and its water content. Downward transport of the liquid toward the groundwater table may cause environmental concerns.

Because sulphuric acid is essentially nonvolatile, dispersion in air is not a problem.

The following factors are considered for the transport of a spill in water and soil:



It is important to note that, because of the approximate nature of the contaminant transport calculations, the approach adopted throughout has been to use conservative estimates of critical parameters so that predictions are approaching worst case scenarios for each medium. This may require that the assumptions made for each medium be quite different and, to some extent, inconsistent. As well as producing worst case scenarios, this approach allows comparison of the behaviours of different chemicals under consistent assumptions.

5.2 Leak Nomograms

5.2.1 Introduction. Sulphuric acid is commonly transported in railway tank cars as a nonpressurized liquid. While the capacities of the tank cars vary widely, one tank car size has been chosen for development of the leak nomograms. It is approximately 2.75 m in diameter and 13.4 m long, with a carrying capacity of about 80,000 L.

If a tank car loaded with sulphuric acid is punctured on the bottom, all of the contents will drain out by gravity. The aim of the nomograms is to provide a simple means to obtain the time history of the conditions in the tank car and the discharge rate

of the liquid. Because of the relatively low volatility of sulphuric acid and the fact that the tank cars are not pressurized, no leak nomograms have been prepared for vapour release from a puncture in the top of the tank.

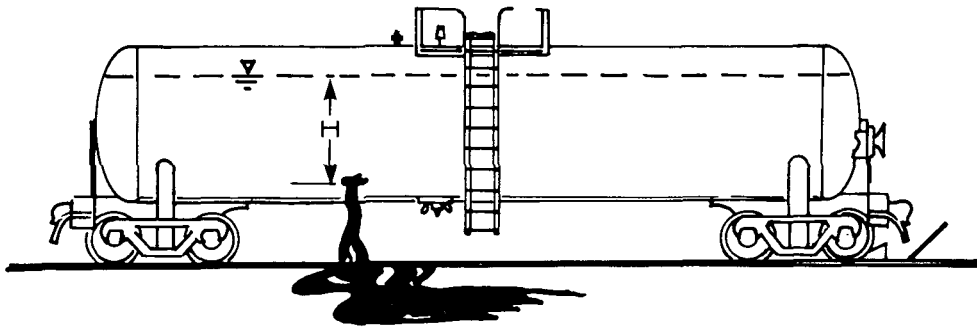


FIGURE 7 TANK CAR WITH PUNCTURE HOLE IN BOTTOM

The rate of outflow (q) from a puncture hole in the bottom of the tank car is defined by the standard orifice equation (Streeter 1971). It is a function of the hole size (A) and shape, the height of the fluid above the puncture hole (H) and a coefficient of discharge (C_d).

As the gravitational force predominates over viscous and other forces for a wide range of fluid conditions, the rate of discharge is relatively independent of fluid temperature and viscosity. Consequently, it is reasonable to assume a constant discharge coefficient for sulphuric acid for a wide range of temperature and viscosity. For the purposes of nomogram preparation, a constant discharge coefficient of 0.8 has been assumed.

5.2.2 Nomograms.

5.2.2.1 Figure 8: Percent remaining versus time. Figure 8 provides a means of estimating the percent of liquid remaining in the standard tank car after the time of rupture, for a number of different hole diameters. The hole diameter is actually an equivalent diameter and can be applied to a noncircular puncture.

The standard tank car (2.75 m ϕ x 13.4 m long) is assumed to be initially full (at $t=0$) with a volume of about 80,000 L of sulphuric acid. The amount remaining at any time (t) is not only a function of the discharge rate over time, but also of the size and shape of the tank car.

FIGURE 8

SULPHURIC ACID

PERCENT REMAINING
VS TIME

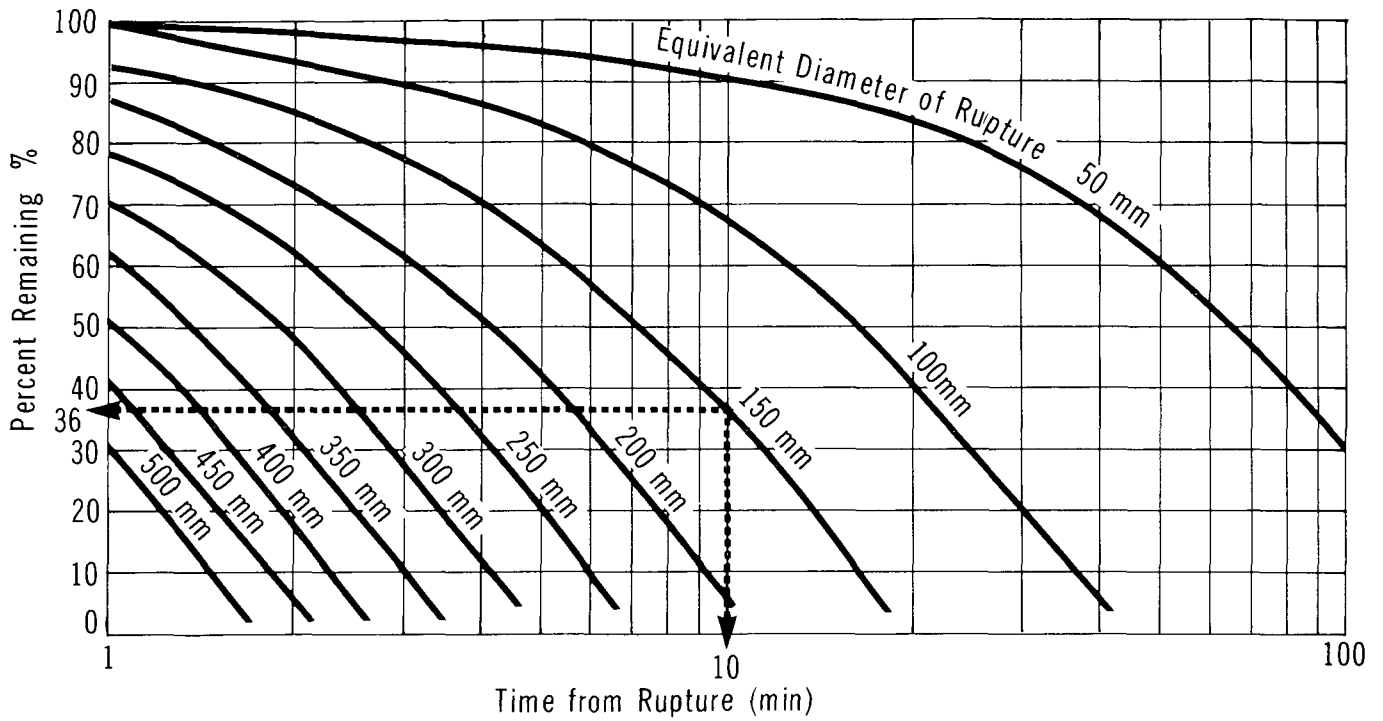
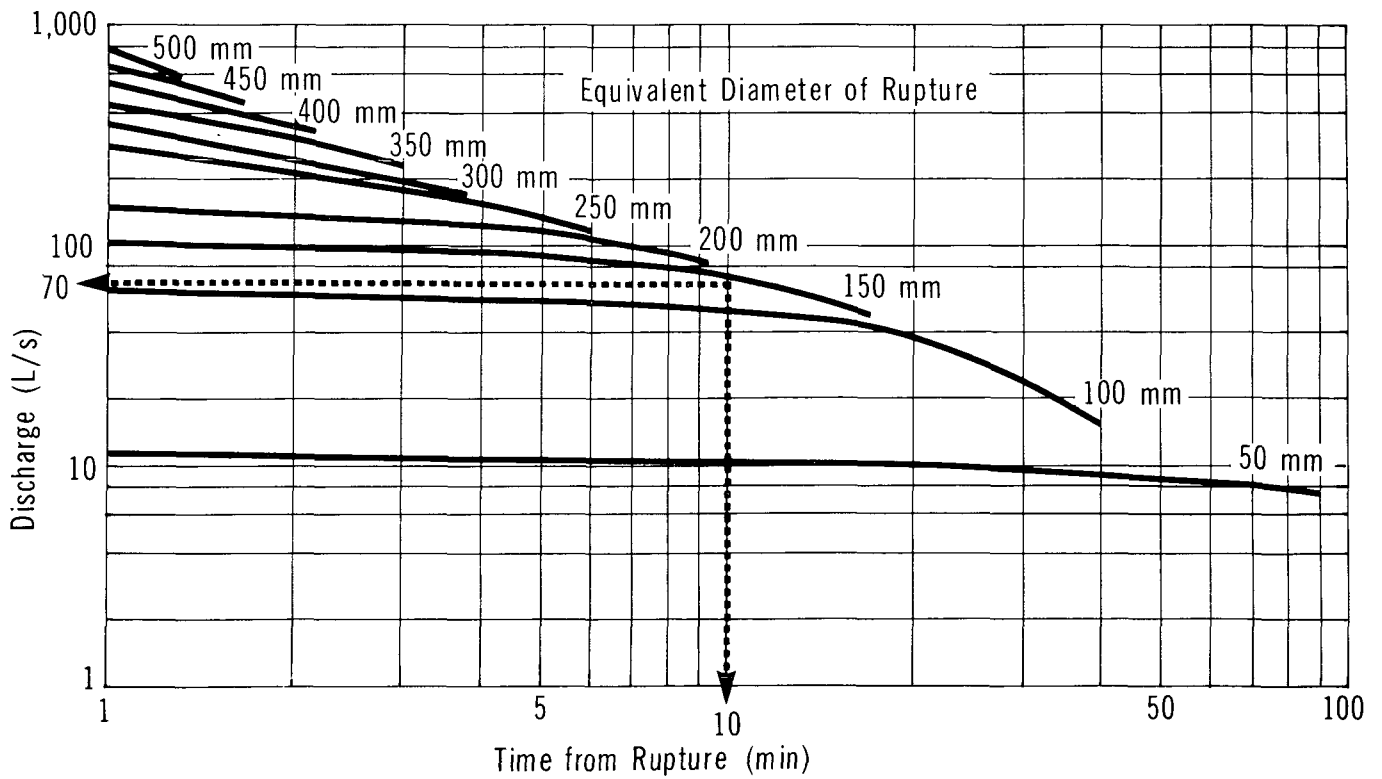


FIGURE 9

SULPHURIC ACID

DISCHARGE RATE
VS TIME



5.2.2.2 Figure 9: Discharge rate versus time. Figure 9 provides a means of estimating the instantaneous discharge rate (L/s) at any time (t) after the time of rupture for a number of equivalent hole diameters. The nomogram is only applicable to the standard tank car size with an initial volume of 80,000 L.

5.2.3 Sample Calculations.

i) Problem A

The standard tank car (2.75 m ϕ x 13.4 m long) filled with sulphuric acid has been punctured on the bottom. The equivalent diameter of the hole is 150 mm. What percent of the initial 80,000 L remains after 10 minutes?

Solution to Problem A

- . Use Figure 8
- . With $t=10$ min and $d=150$ mm, the amount remaining is about 36 percent or 28,800 L

ii) Problem B

With the same conditions as Problem A, what is the instantaneous discharge rate from the tank 10 minutes after the accident?

Solution to Problem B

- . Use Figure 9
- . With $t=10$ min and $d=150$ mm, the instantaneous discharge rate (q) = 70 L/s

5.3 Dispersion in the Air

5.3.1 Introduction. Since sulphuric acid is a nonvolatile liquid, direct venting of the vapour to the atmosphere from a hole in a ruptured vessel does not constitute a significant hazard downwind. However, oleum (30% or more excess SO_3) will release SO_3 vapour from a liquid pool spilled on a ground or water surface; therefore, this situation is treated here.

To estimate the vapour concentrations downwind of the accident site for the determination of the flammability or toxicity hazard zone, the atmospheric transport and dispersion of the contaminant vapour must be modelled. The models used here are based on Gaussian formulations and are the ones most widely used in practice for contaminant concentration predictions. The model details are contained in the Introduction Manual.

Figure 10 depicts schematically the contaminant plume configuration from a continuous surface release. The dispersion model represents the liquid pool area source as a virtual point source (with the same vapour emission rate, Q) located 10 equivalent pool radii upwind.

When oleum (30% or more excess SO_3) is instantaneously spilled on land or water, SO_3 vapour will be released to the atmosphere. The SO_3 vapour released will react quickly with atmospheric water vapour to form sulphuric acid which will then nucleate and grow into an acid mist. The air dispersion nomograms presented here apply to dispersion of vapour releases and are not applicable to dispersion of mists, unless the particle size distribution of the mist is such that the mist is easily transported downwind. This would occur if all particles were less than 20 μm in diameter.

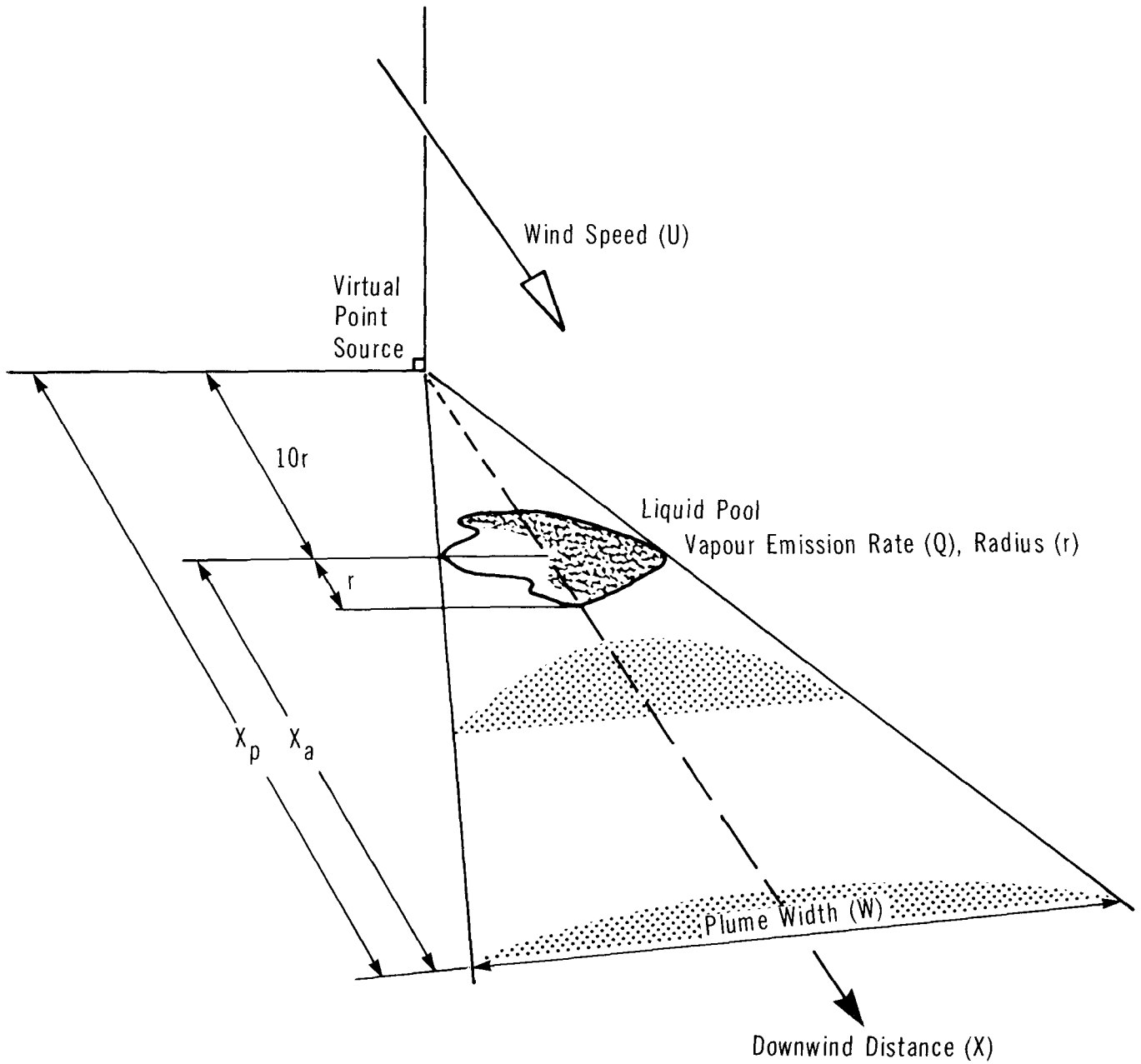
For spills on water, small-scale laboratory experiments have shown that sulphuric acid mist particles generated as a result of a spill of oleum (20% excess SO_3) were all less than 10 μm in diameter (Tang et al. 1982) and therefore can be easily transported downwind. However, due to dilution of the oleum with the water, it was conservatively estimated that no more than 0.1 percent of the spilled oleum would become airborne to form an acid mist under most spill conditions on water. On land, however, dilution with water may not occur and considerably more SO_3 vapour would be released to the atmosphere. Therefore, for conservative purposes it will be assumed that all of the free SO_3 content from a spill of oleum (30% or more excess SO_3) will form sulphuric acid mist that will behave as a vapour. This will result in conservative estimations for spills on land; however, for spills on water, grossly over-estimated results will be obtained.

5.3.2 Vapour Dispersion Nomograms and Tables. The aim of the air dispersion nomograms is to define the hazard zone due to toxicity or flammability of a vapour cloud. The following nomograms and data tables are contained in this section (to be used in order given):

- Figure 12: vapour emission rate from a liquid pool as a function of maximum pool radius for various temperatures
- Table 10: weather conditions
- Figure 13: normalized vapour concentration as a function of downwind distance and weather conditions
- Table 11: maximum plume hazard half-widths
- Figure 14: vapour plume travel distance as a function of time elapsed since the spill and wind speed

SULPHURIC ACID

SCHEMATIC OF CONTAMINANT PLUME



The flow chart given in Figure 11 outlines the steps necessary to make vapour dispersion calculations and identifies the nomograms or tables to be used. This section deals only with the portion contained within the dashed box. Data on "total liquid discharged" are contained in Section 5.2. A description of each vapour dispersion nomogram and its use follows.

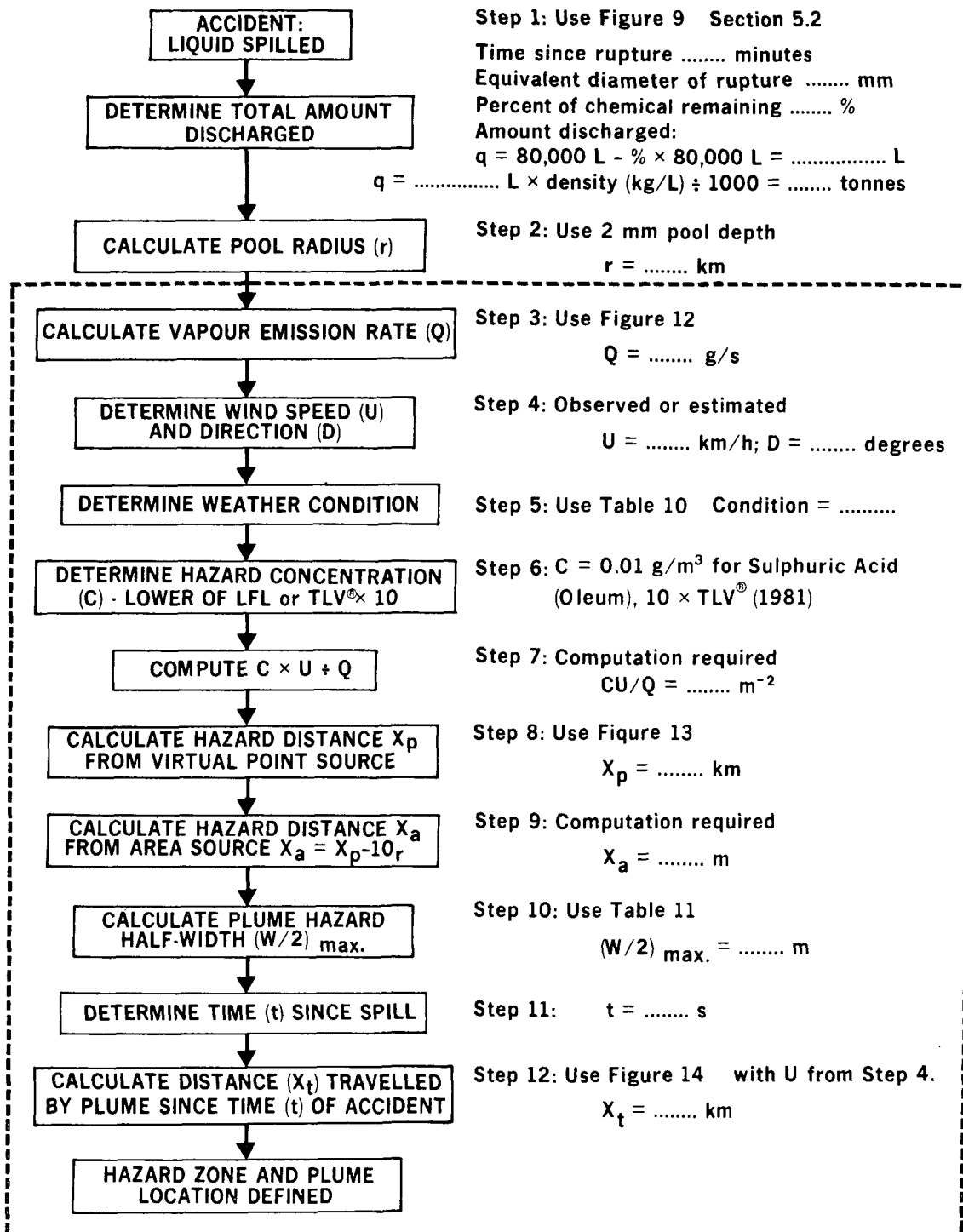
5.3.2.1 Figure 12: Vapour emission rate versus liquid pool radius for various temperatures. An evaporation rate for sulphuric acid (as SO_3 vapour from oleum) has been calculated employing the evaporation rate equations contained in the Introduction Manual. The computed evaporation rate for oleum at 20°C and a wind speed of 4.5 m/s (16.1 km/h) is $0.26\text{ g/m}^2\text{s}$. Evaporation rates at other temperatures have been calculated using the evaporation rate equation which, at a given wind speed, is dependent on ambient temperature and the vapour pressure (CRC 1980) of oleum at that temperature. For example, evaporation rates of $0.053\text{ g/m}^2\text{s}$ at 0°C and $0.56\text{ g/m}^2\text{s}$ at 30°C were calculated for a wind speed of 4.5 m/s . Note that in an actual spill situation, SO_3 vapour released from a liquid pool will lower the concentration of free SO_3 in the liquid phase and result in lower SO_3 evaporation rates with time. The use of the value at the initial free SO_3 concentration will therefore be the worst case situation.

Using a 2 mm pool depth, the maximum spill radius corresponding to various spill amounts of oleum may be determined. The resultant spill areas and the oleum evaporation rates provide the basis for preparation of the vapour release rate versus spill radius nomogram in Figure 12.

Use: For a pool of oleum of known radius, the rate (Q) at which oleum vapour is released to the atmosphere at a given temperature can then be estimated from Figure 12. The solid portions of the curves represent spills of 0.1 to 156 tonnes, the latter representing about one standard $80,000\text{ L}$ ($17,600\text{ Imp. gal.}$) rail car load of oleum. It should be noted that Figure 12 is valid for a wind speed of 4.5 m/s (16.1 km/h) and therefore can only be used to provide an approximation of oleum vapour emission rates at other wind speeds. The Introduction Manual contains the appropriate equation to convert the evaporation rate at 4.5 m/s to an evaporation rate at another wind speed should it be desired.

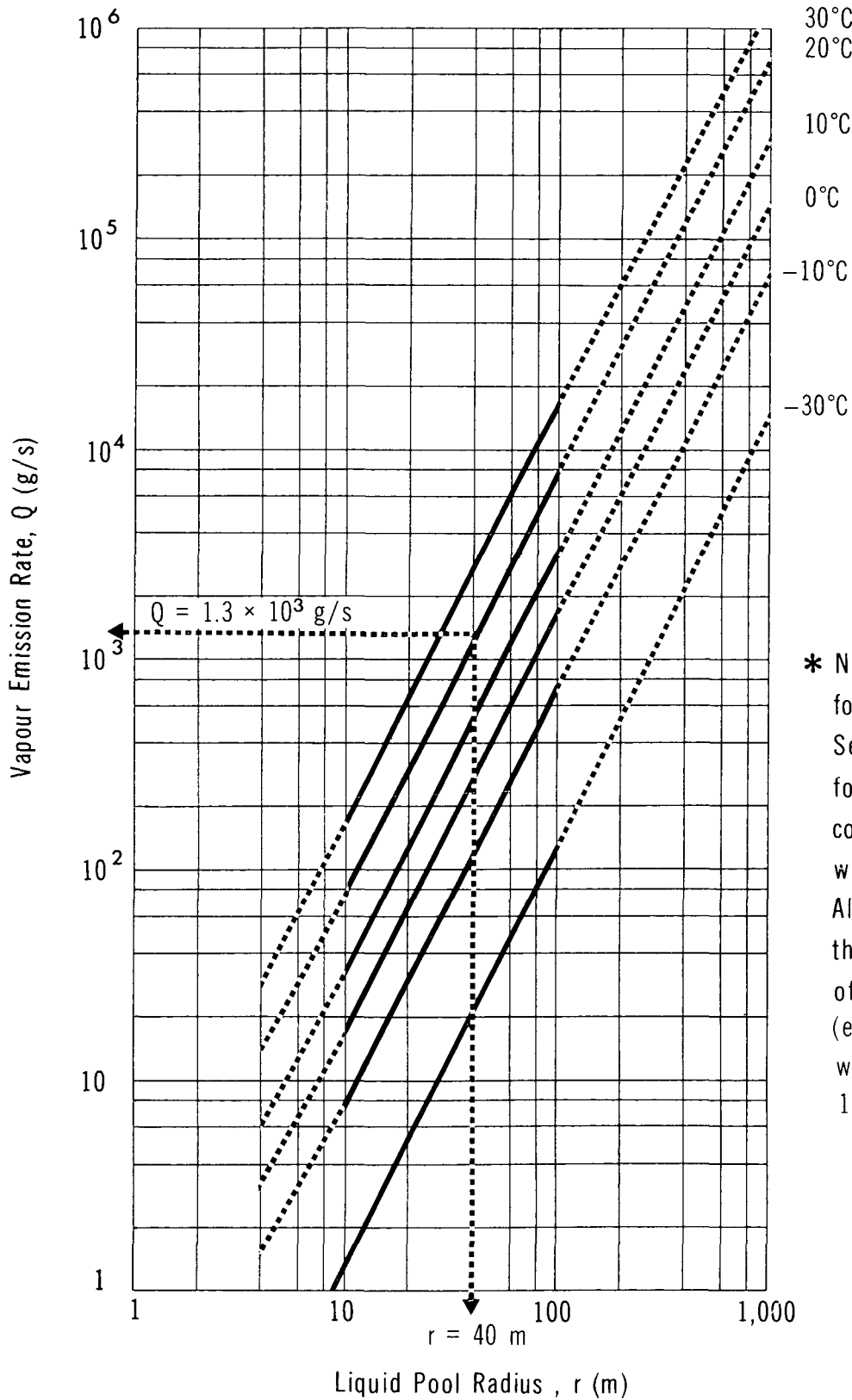
It should also be noted that the determination of the emission rate is based on an arbitrary spill radius on flat land. The spill radius for any given spill amount was calculated assuming a 2 mm depth of spill value and assuming symmetrical spreading of the spilled liquid. The resultant spill radius is considered to provide the maximum value,

**FLOW CHART TO DETERMINE
VAPOUR HAZARD ZONE**



SULPHURIC ACID

VAPOUR EMISSION RATE VS LIQUID POOL RADIUS FOR VARIOUS TEMPERATURES



* Note: Nomogram applies for wind speed of 4.5 m/s. See Introduction Manual for relationships to compute values for other wind speeds, if necessary. Also, the solid portions of the curves represent spills of 0.1 to 156 tonnes. (except -30°C and -10°C , where lower limit is 1 tonne)

since the type of ground surface that would normally be encountered in a spill situation (namely, irregular and porous) would likely cause a smaller observed spill radius.

5.3.2.2 Figure 13: Vapour concentration versus downwind distance. Figure 13 shows the relationship between the vapour concentration and the downwind distance for weather conditions D and F. The nomograms were developed using the dispersion models described in the Introduction Manual. The vapour concentration is represented by the normalized, ground-level concentration (CU/Q) at the centreline of the contaminant plume. Weather condition F is the poorest for dispersing a vapour cloud and condition D is the most common in most parts of Canada. Before using Figure 13, the weather condition must be determined from Table 10.

TABLE 10 WEATHER CONDITIONS

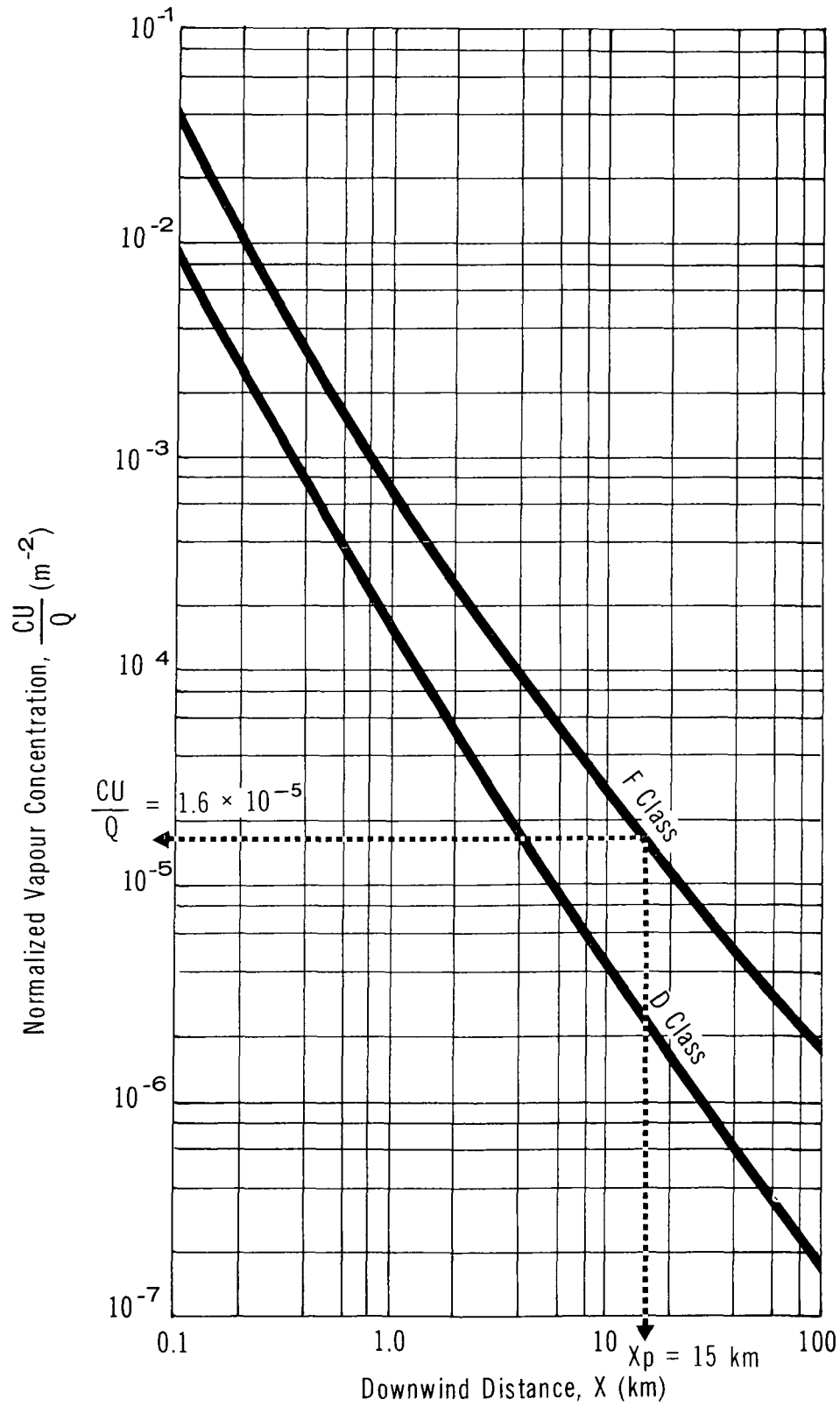
Weather Condition F	Weather Condition D
Wind speed <11 km/h (< 3 m/s) and one of the following: - overcast day - night time - severe temperature inversion	Most other weather conditions

Use: The maximum hazard distance, X_p , downwind of the spill can be calculated from Figure 13 knowing:

- Q, the vapour emission rate (g/s)
- U, the wind speed (m/s)
- the weather condition
- the hazard concentration limit, C, which is the lower value of 10 times the Threshold Limit Value® (TLV in g/m³), or the Lower Flammability Limit (LFL in g/m³), which for nonflammable vapour will be 10 x TLV®. Note that the TLV® for sulphuric acid (oleum) is provided only in g/m³ and is not pertinent in ppm. Therefore, a conversion nomogram (from ppm to g/m³) is not provided.

A hazard concentration limit of 10 times the TLV® has been arbitrarily chosen as it represents a more realistic level at which there would be concern for human health on the short term (i.e. on the order of 30 minutes). The TLV® is a workplace standard for

SULPHURIC ACID

NORMALIZED VAPOUR CONCENTRATION
VS DOWNWIND DISTANCE

long-term exposure and use of this value as the hazard limit would result in unrealistically large hazard zones.

5.3.2.3 Table 11: Maximum plume hazard half-widths. This table presents data on the maximum plume hazard half-width, $(W/2)_{\max}$, for a range of Q/U values under weather conditions D and F. These data were computed using the dispersion modelling techniques given in the Introduction Manual for a value of 10 times the oleum Threshold Limit Value (TLV[®]) of 0.001 g/m³, or 0.01 g/m³. The maximum plume hazard half-width represents the maximum half-width of the oleum vapour cloud, downwind of the spill site, corresponding to a hazard concentration limit of 10 x TLV[®]. Table 11 is therefore only applicable for an oleum hazard concentration limit of 10 x TLV[®] or 0.01 g/m³. Also, data are provided up to a maximum hazard distance downwind of 100 km.

TABLE 11 MAXIMUM PLUME HAZARD HALF-WIDTHS (FOR SULPHURIC ACID (OLEUM) AT 20°C)

Weather Condition D		Weather Condition F	
Q/U (g/m)	$(W/2)_{\max}$ (m)	Q/U (g/m)	$(W/2)_{\max}$ (m)
70,000	3,430 (99.5 km*)	6,000	1,430 (99.5 km*)
60,000	3,115	5,000	1,250
50,000	2,785	4,000	1,060
40,000	2,425	3,000	855
30,000	2,030	2,000	630
25,000	1,815	1,000	380
20,000	1,580	750	310
15,000	1,320	500	240
10,000	1,030	250	155
7,500	860	100	85
5,000	670	50	55
2,500	450	25	35
1,000	260	10	25
750	220		
500	175		
250	115		
100	70		
50	45		
10	20		

Q/U = 619 →

→ $(W/2)_{\max} = 275$ m

*Data are provided up to a maximum downwind hazard distance of 100 km.

Example: A spill releasing oleum vapour at the rate of $Q = 1.3 \times 10^3$ g/s under weather condition F and a wind speed $U = 2.1$ m/s means $Q/U = 619$ g/m which results in a maximum plume hazard half-width $(W/2)_{\max} = 275$ m.

Note: Above table is valid only for an oleum concentration of 10 x TLV[®], or 0.01 g/m³.

Under weather condition D, the wind speed (U) range applicable is 1 to 30 m/s. The range of vapour emission rates (Q) used was 300 to 70,000 g/s, corresponding to oleum spills in the range of about 5 to 1,100 tonnes, respectively. If the entire contents of an 80,000 L (17,600 Imp. gal.) tank car spill, the mass spilled would be 156,000 kg or approximately 156 tonnes. Therefore, under class D of Table 11, data are provided for up to 7 times this amount.

Under weather condition F, the wind speed (U) range applicable is up to 3 m/s. The range of vapour emission rates (Q) used was 30 to 6,000 g/s, corresponding to oleum spills in the range of about 0.05 to 90 tonnes, respectively. Therefore, under class F of Table 11, data are provided for only up to about 60 percent of a standard rail car load.

Use: Knowing the weather condition, Q and U, compute Q/U. Choose the closest Q/U value in the table and the corresponding $(W/2)_{\max}$, the maximum plume hazard half-width, in metres. (For a slightly more accurate number, interpolate Q/U and $(W/2)_{\max}$ values.) Also refer to the example at the bottom of Table 11.

5.3.2.4 Figure 14: Plume travel time versus travel distance. Figure 14 presents plots of plume travel time (t) versus plume travel distance (X_t) as a function of different wind speeds (U). This is simply the graphical presentation of the relationship $X_t = Ut$ for a range of typical wind speeds.

Use: Knowing the time (t) since the spill occurred and the wind speed (U), the distance (X_t), which indicates how far downwind the plume has travelled, can be determined.

5.3.3 Sample Calculation. The sample calculation given below is intended to outline the steps required to estimate the downwind hazard zone which could result from a spill of liquid oleum. The user is cautioned to take note of the limitations in the calculation procedures described herein and in the Introduction Manual. The estimates provided here apply only for conditions given. It is recommended that the user employ known or observational estimates (i.e. of the spill radius) in a particular spill situation if possible.

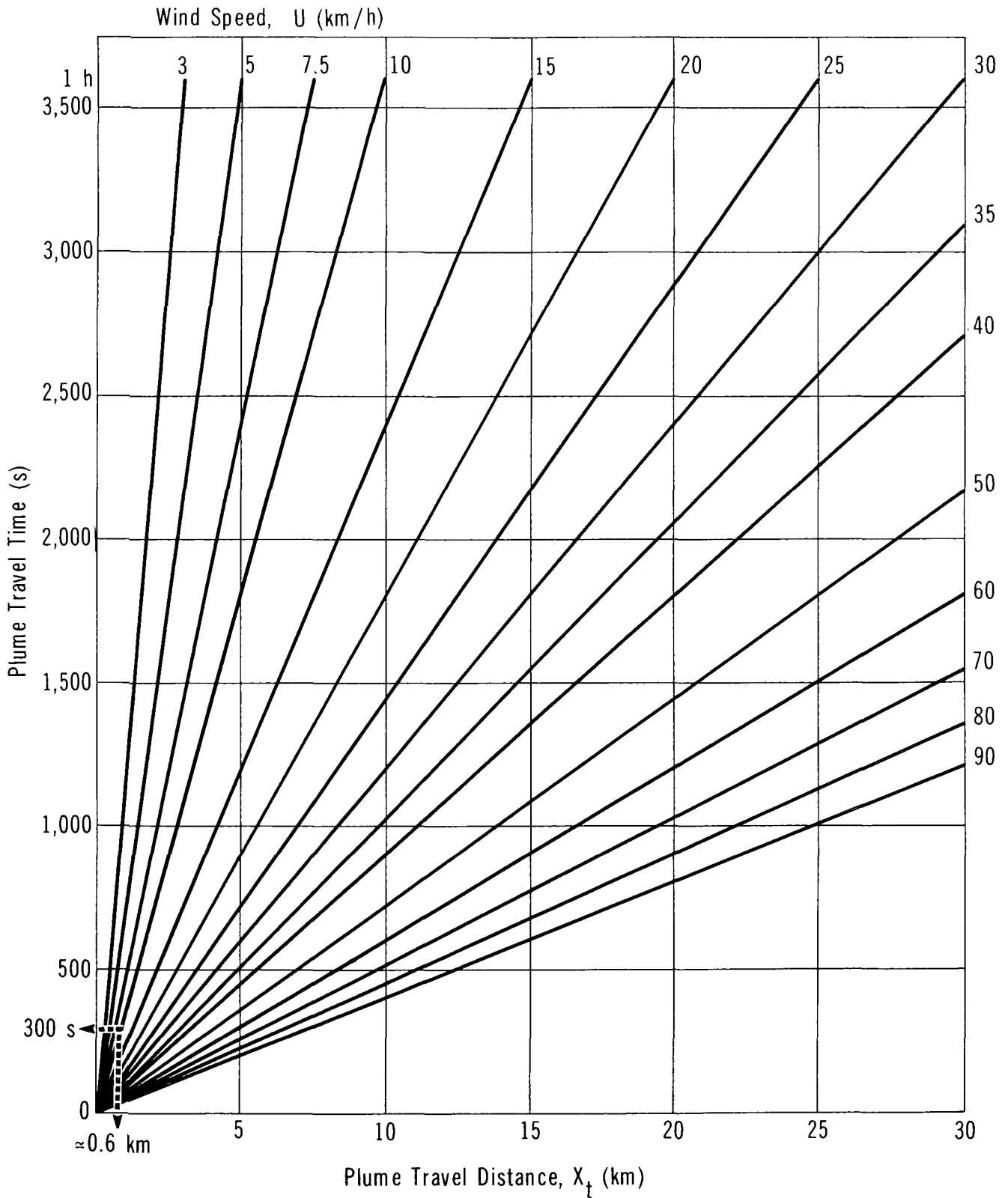
Problem:

During the night, at about 2:00 a.m., 20 tonnes of oleum were spilled on a flat ground surface. It is now 2:05 a.m. The temperature is 20°C and the wind is from the NW at 7.5 km/h. Determine the extent of the vapour hazard zone.

Solution

Step 1: Quantity spilled is given, 20 tonnes

SULPHURIC ACID

PLUME TRAVEL TIME
VS TRAVEL DISTANCE

- Step 2: Determine pool radius (r) for spill of 20 tonnes
- Use observed (measured) pool radius if possible. If not, use a 2 mm pool depth: $r(\text{m}) = \sqrt{\text{Volume}/\pi \text{ depth}}$
 - Radius (r) = 40 m \div 1,000 = 0.04 km, here $r(\text{m}) = \sqrt{\frac{V(\text{tonnes})}{0.012}}$
- Step 3: Calculate vapour emission rate (Q) at T = 20°C
- From Figure 12, r = 40 m and T = 20°C
 - $Q = 1.3 \times 10^3 \text{ g/s}$
- Step 4: Determine wind speed (U) and direction (D)
- Use available weather information, preferably on-site observations
 - Given:
 - $U = 7.5 \text{ km/h}$, then $U = 7.5 \div 3.6 = 2.1 \text{ m/s}$
 - $D = \text{NW or } 315^\circ$ (D = Direction from which wind is blowing)
- Step 5: Determine weather condition
- From Table 10, weather condition = F since U is less than 11 km/h and it is night
- Step 6: Determine hazard concentration limit (C)
- This is the lower of 10 times the TLV^{*}, or the LFL; since oleum vapours are not flammable, this is 10 x TLV^{*}
 - $C = 0.01 \text{ g/m}^3$ (TLV^{*} = 0.001 g/m³; no LFL)
- Step 7: Compute CU/Q
- $$CU/Q = \frac{0.01 \times 2.1}{1.3 \times 10^3} = 1.6 \times 10^{-5} \text{ m}^{-2}$$
- Step 8: Calculate downwind distance (X_p) from the virtual point source
- From Figure 13 with $CU/Q = 1.6 \times 10^{-5} \text{ m}^{-2}$ and weather condition F, $X_p \approx 15 \text{ km}$
- Step 9: Calculate hazard distance (X_a) downwind of the area source
- With $X_p = 15 \text{ km}$ and $r = 0.04 \text{ km}$ then
 - $X_a = X_p - 10 r = 15 \text{ km} - 10 (0.04 \text{ km}) = 14.6 \text{ km}$
- Step 10: Calculate plume hazard half-width (W/2)_{max}
- Use Table 11

- With $Q = 1.3 \times 10^3$ g/s and $U = 2.1$ m/s
then $Q/U = \frac{1.3 \times 10^3}{2.1} = 619$ g/m
- Then for weather condition F the closest Q/U value is between 500 and 750 g/m which gives $(W/2)_{\max} \approx 275$ m

Step 11: Determine the time since spill

- $t = 5 \text{ min} \times 60 = 300$ s

Step 12: Calculate distance travelled (X_t) by vapour plume since time of accident

- Using Figure 14 with $t = 300$ s and $U = 7.5$ km/h, then $X_t = 0.6$ km (more accurately from $Ut = 2.1 \text{ m/s} \times 300 \text{ s} = 630 \text{ m} = 0.63 \text{ km}$).

Step 13: Map the hazard zone.

- This is done by drawing a rectangular area with dimensions of twice the maximum plume hazard half-width (275 m) by the maximum hazard distance downwind of the area source (14.6 km) along the direction of the wind, as shown in Figure 15
- If the wind is reported to be fluctuating by 20° about 315° (or from $315^\circ \pm 10^\circ$), the hazard zone is defined as shown in Figure 16
- Note that the plume has only travelled 0.63 km in the 5 minutes since the spill. At a wind speed of 7.5 km/h there remain 112 minutes before the plume reaches the maximum downwind hazard distance of 14.6 km

5.4 Behaviour in Water

5.4.1 Introduction. When spilled on water, sulphuric acid has often been observed to sink and slowly mix with the water. For purposes of this section, it will be presumed that sulphuric acid has already dissolved or mixed with the water. This mixing can generally be described by classical diffusion equations with one or more diffusion coefficients. In rivers, the principal mixing agent is stream turbulence, while in calm water mixing takes place by molecular diffusion.

To estimate pollutant concentration in a river downstream from a spill, the turbulent diffusion has been modelled. The model employed is strictly applicable to neutrally buoyant liquids and solids that dissolve in water. As sulphuric acid is denser than water, the maximum concentration would be expected near the bottom.

The one-dimensional model uses an idealized rectangular channel section and assumes a uniform concentration of the pollutant throughout the section. Obviously, this

SULPHURIC ACID

HAZARD AREA FOR STEADY WINDS, EXAMPLE PROBLEM

Wind U = 7.5 km/h from 315° (NW)

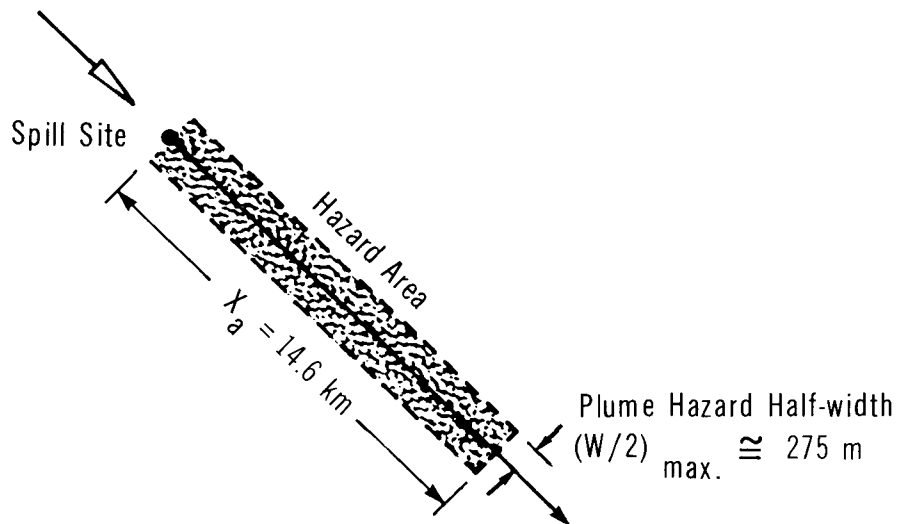
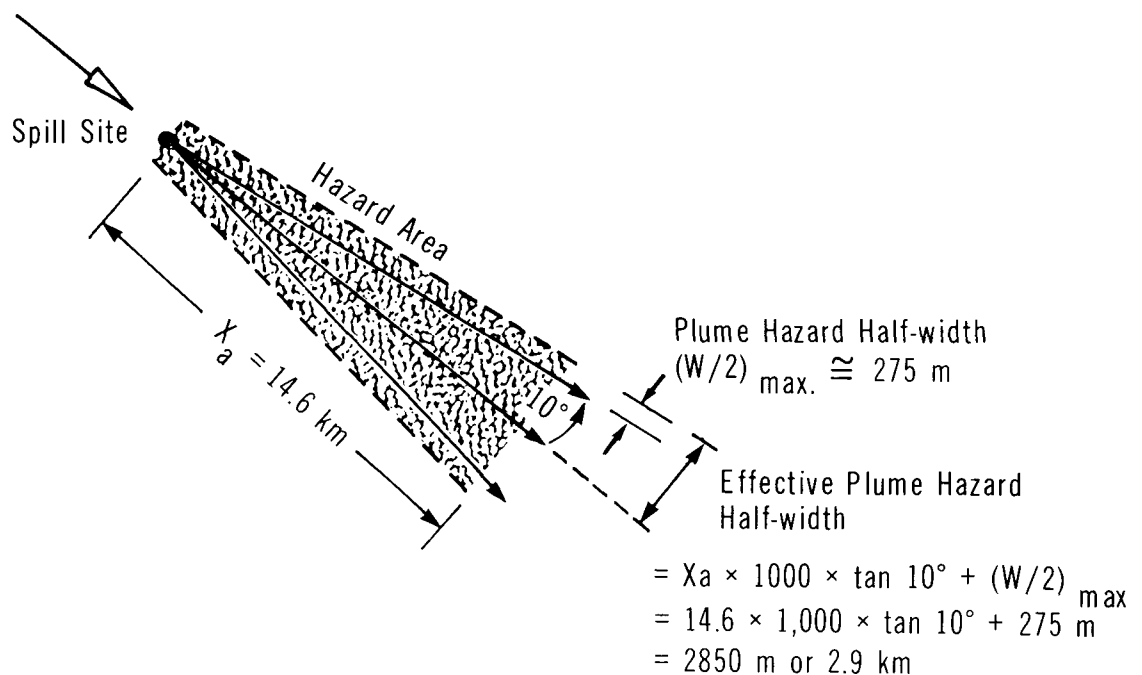


FIGURE 16

SULPHURIC ACID

HAZARD AREA FOR UNSTEADY WINDS, EXAMPLE PROBLEM

Wind U = 7.5 km/h from $315^\circ \pm 10^\circ$ 

applies only to points sufficiently far downstream of the spill where mixing and dilution have distributed the pollutant across the entire river channel. The model is applicable to rivers where the ratio of width to depth is less than 100 ($W/d < 100$) and assumes a Manning's roughness coefficient of 0.03. Details of the model are outlined in the Introduction Manual.

No modelling has been carried out for molecular diffusion in still water. Rather, nomograms have been prepared to define the hazard zone and the average concentration within the hazard zone as a function of spill size, but independent of time.

5.4.2 Nomograms. The following nomograms are presented to calculate pollutant concentrations in non-tidal rivers and in lakes (still water).

Non-tidal Rivers

- Figure 18: time versus distance for a range of average stream velocities
- Figure 19: hydraulic radius versus channel width for a range of stream depths
- Figure 20: diffusion coefficient versus hydraulic radius for a range of average stream velocities
- Figure 21: α^* versus diffusion coefficient for various time intervals
- Figure 22: α versus δ^* for a range of spill sizes
- Figure 23: maximum concentration versus δ for a range of river cross-sectional areas

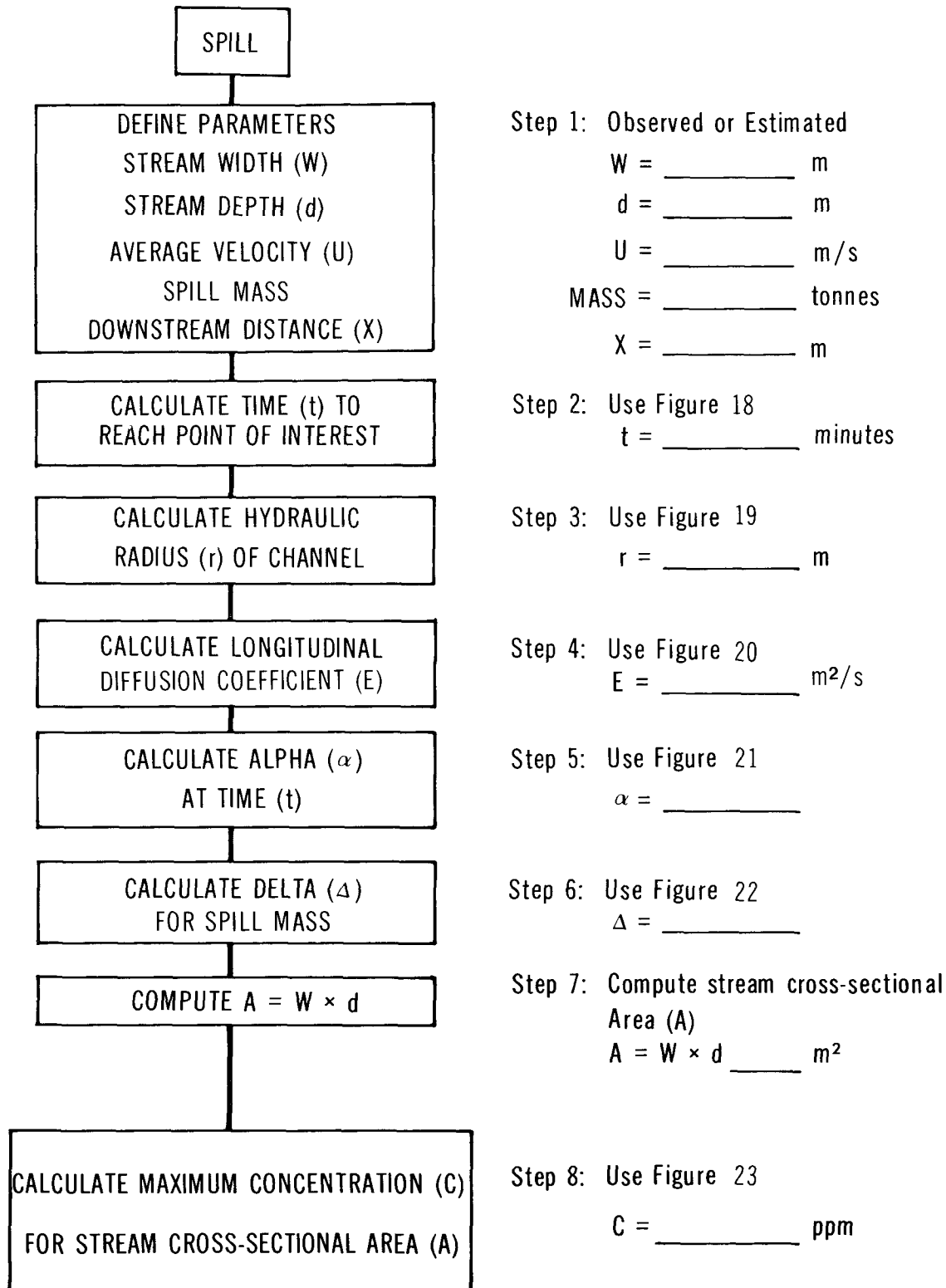
Lakes or Still Water Bodies

- Figure 24: volume versus radius for the hazard zone for a range of lake depths
- Figure 25: average concentration versus volume for the hazard zone for a range of spill sizes

The flow chart in Figure 17 outlines the steps required to estimate downriver concentration after a spill and identifies the nomograms to be used. These nomograms (Figures 18 through 23) are described in the following sub-sections.

*Alpha and delta are conversion factors only and are of no significance other than to facilitate calculation of downstream concentrations.

SULPHURIC ACID

FLOW CHART TO DETERMINE POLLUTANT CONCENTRATION IN NON-TIDAL RIVERS

5.4.2.1 Nomograms for non-tidal rivers.

Figure 18: Time versus distance. Figure 18 presents a simple relationship between average stream velocity, time and distance. Using an estimate of average stream velocity (U), the time (t) to reach any point of interest at some distance (X) downstream of the spill can be readily obtained from Figure 18.

Figure 19: Hydraulic radius versus channel width. The model used to estimate downstream pollutant concentration is based on an idealized rectangular channel of width (W) and depth (d).

The hydraulic radius (r) for the channel is required in order to estimate the turbulent diffusion coefficient (E). The hydraulic radius (r) is defined as the stream cross-sectional area (A) divided by the wetted perimeter (P). Figure 19 is a nomogram for computation of the hydraulic radius (r) using the width and depth of the idealized river cross-section.

Figure 20: Diffusion coefficient versus hydraulic radius. Figure 20 permits calculation of the diffusion coefficient (E), knowing the hydraulic radius (r) from Figure 19 and the average stream velocity (U).

Figure 21: Alpha versus diffusion coefficient. Figure 21 is used to estimate a conversion factor alpha (α), which is a function of the diffusion coefficient (E) and the time (t) to reach the point of interest downstream of the spill.

Figure 22: Alpha versus delta. A second conversion factor, delta (Δ), must be estimated from Figure 22 to allow determination of pollutant concentration at the point of interest. Delta (Δ) is a function of alpha (α) and the spill mass.

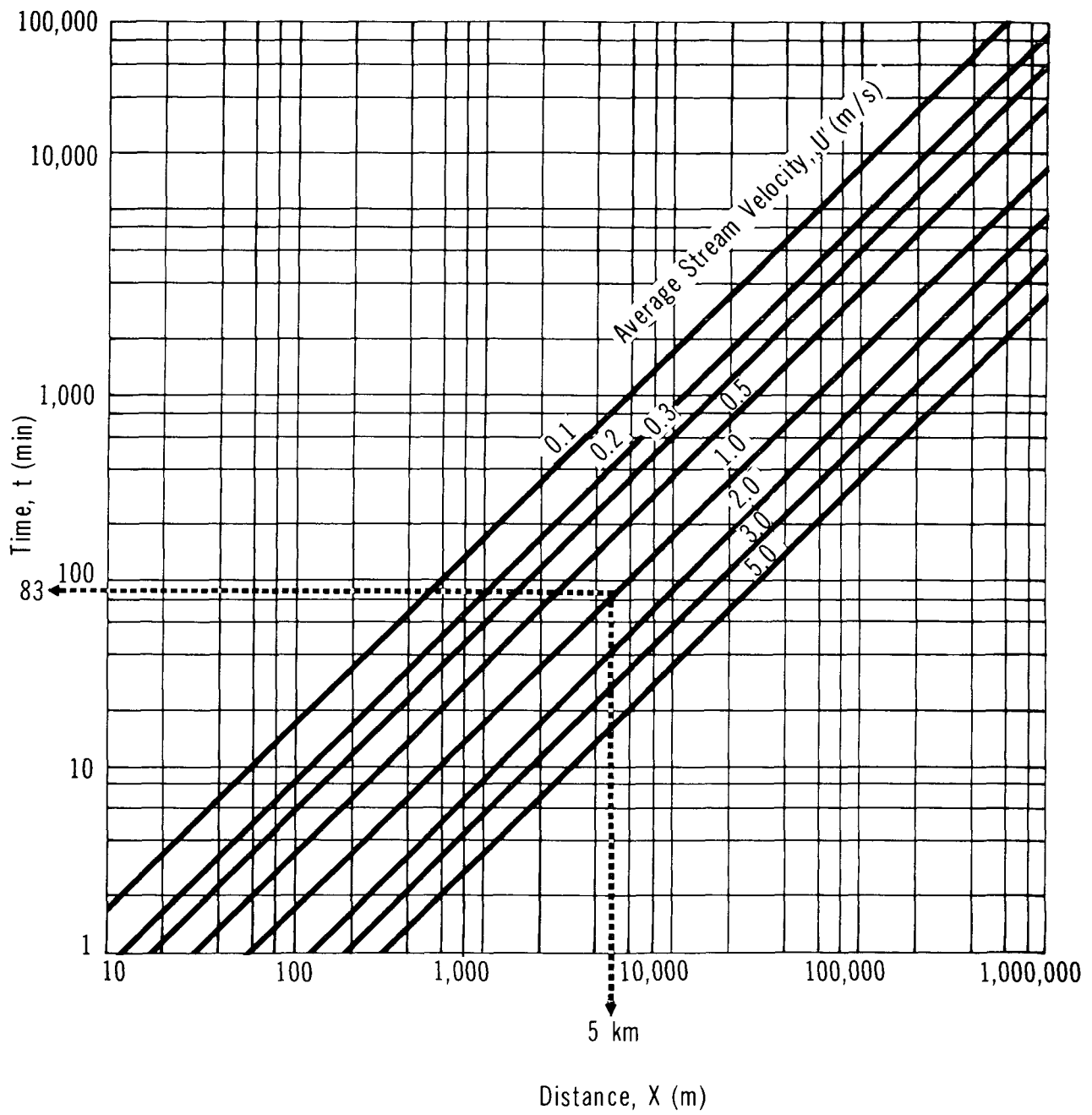
Figure 23: Maximum concentration versus delta. Figure 23 represents the final step for calculation of the maximum downstream pollutant concentration (C) at the point of interest. Using the factor delta (Δ) and knowing the stream cross-sectional area (A), the concentration (C) is readily obtained from the nomogram. The value obtained from Figure 23 applies to neutrally buoyant liquids or solids and will vary somewhat for other pollutants which are heavier or lighter than water.

5.4.2.2 Nomograms for lakes or still water bodies.

Figure 24: Volume versus radius. The spill of a neutrally buoyant liquid in a lake in the absence of wind and current has been idealized as a cylinder of radius (r) and length (d), equivalent to the depth of the lake at the point of spill. The volume of water

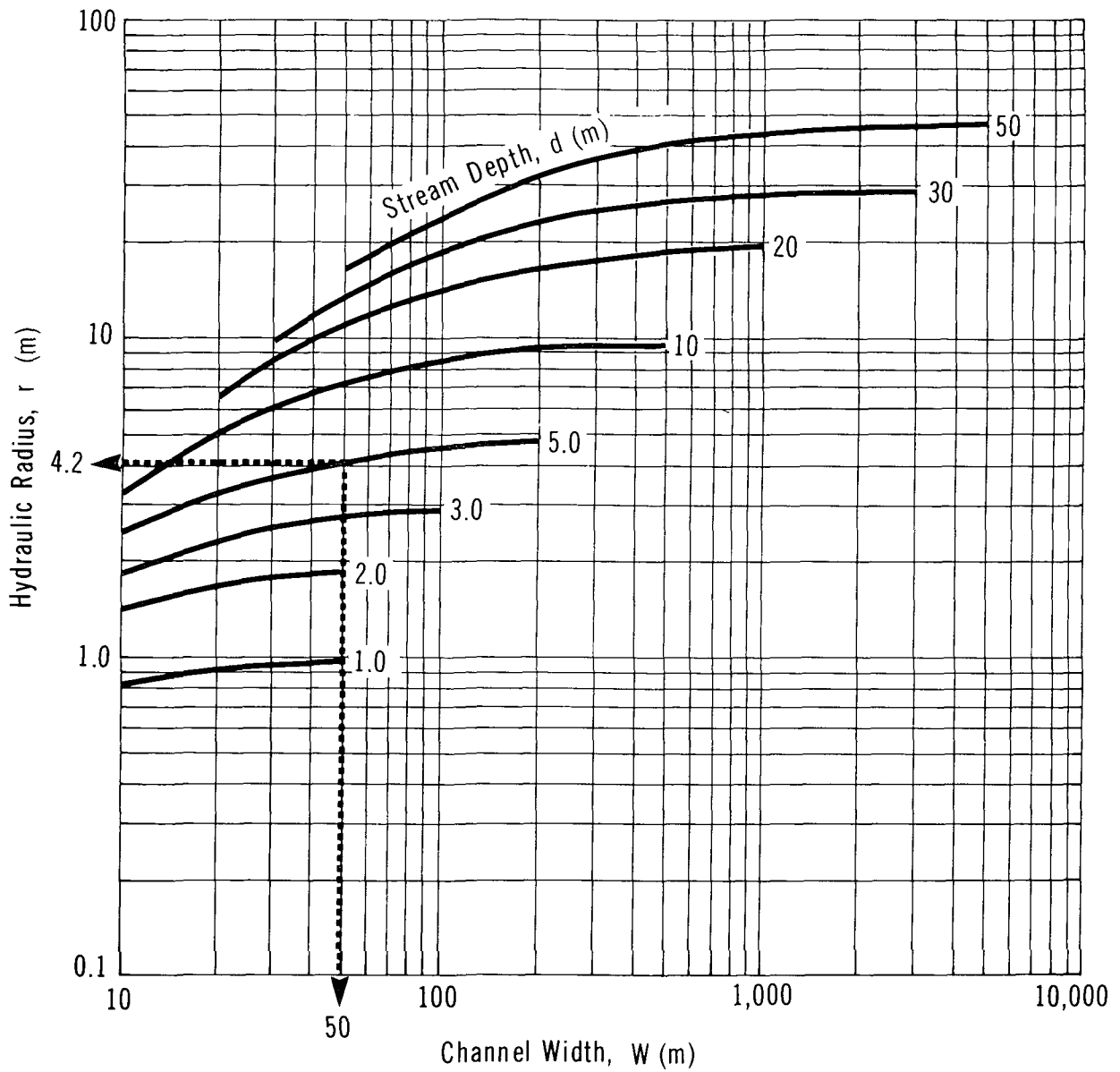
SULPHURIC ACID

TIME vs DISTANCE



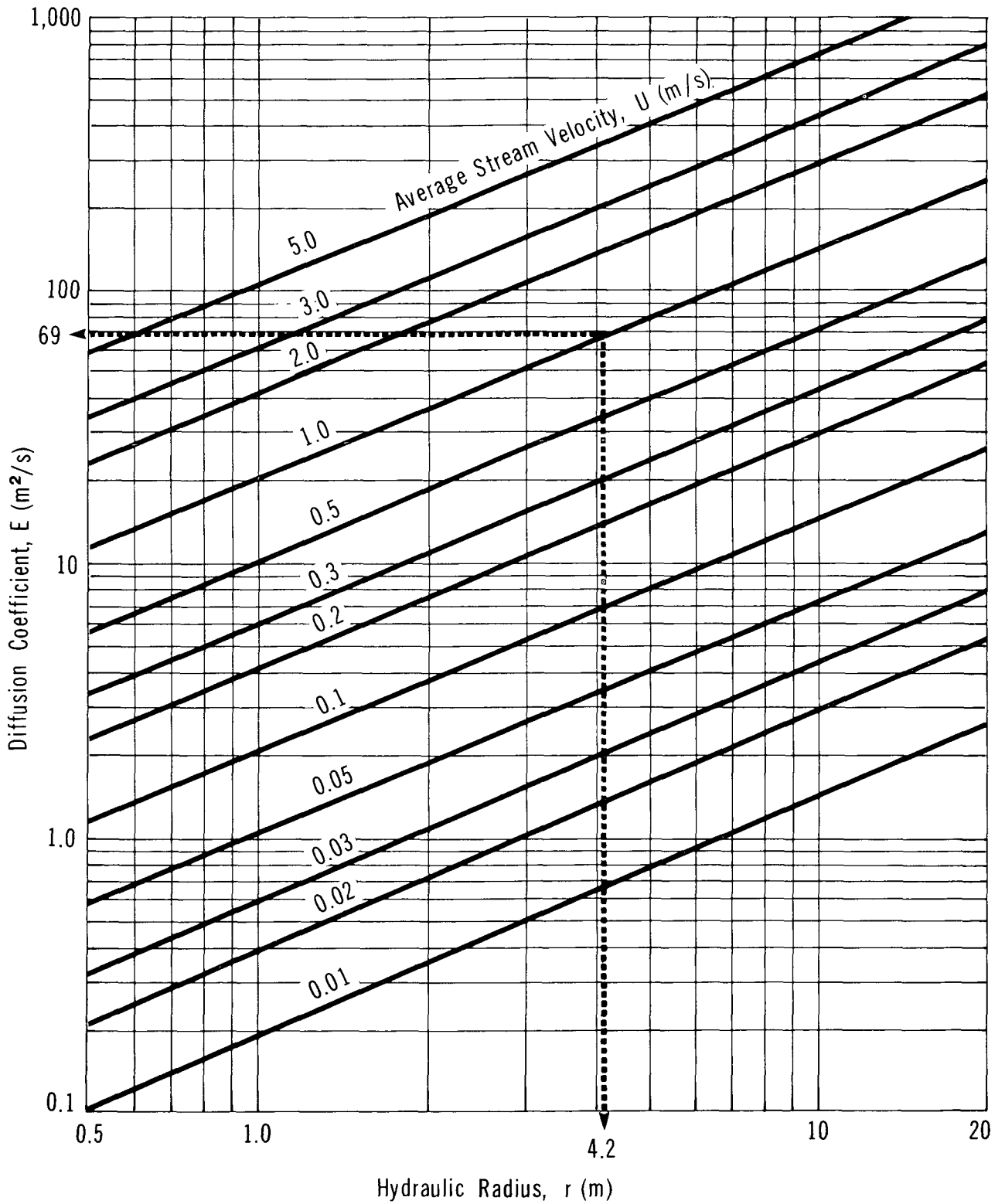
SULPHURIC ACID

HYDRAULIC RADIUS VS CHANNEL WIDTH



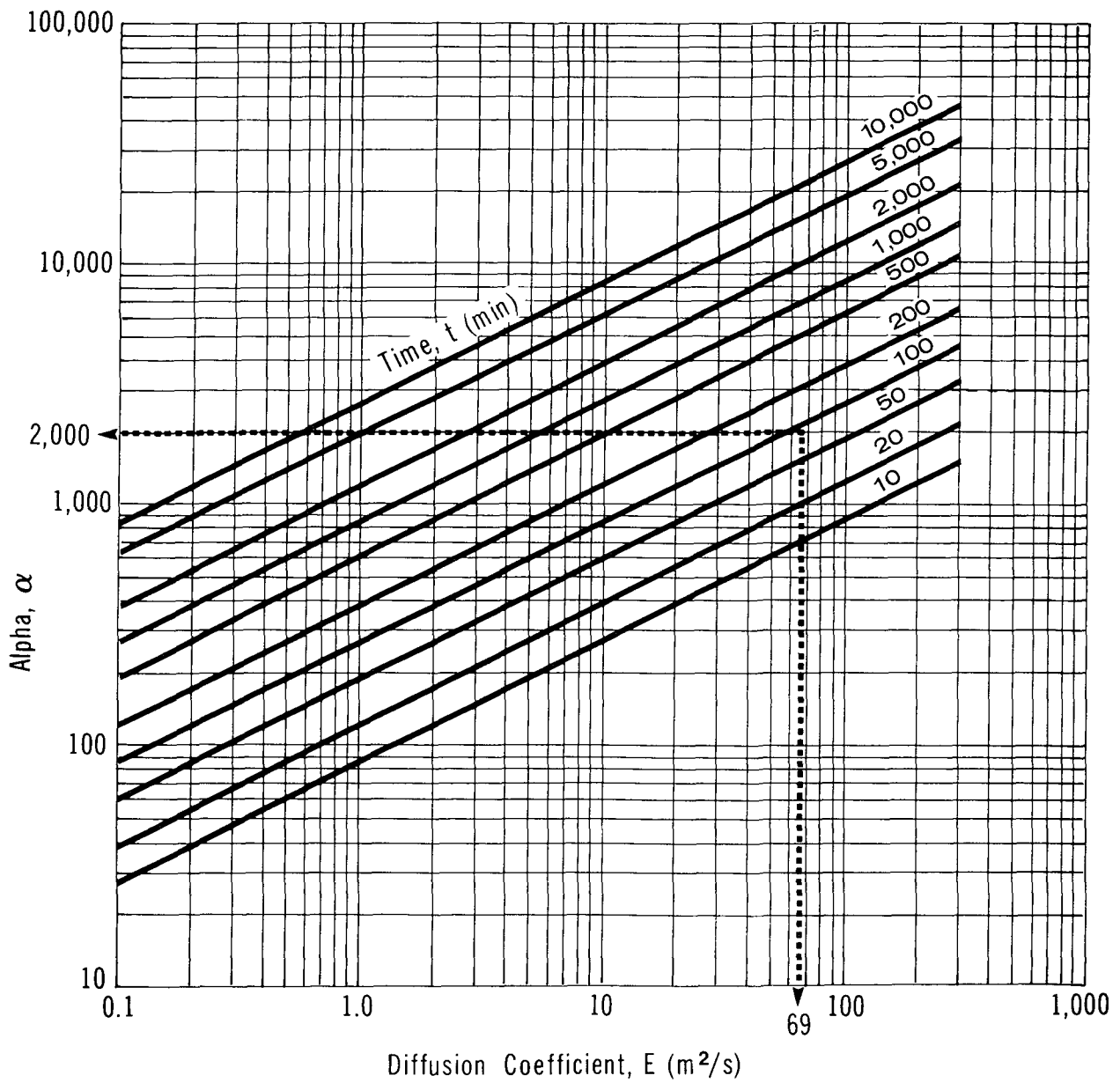
SULPHURIC ACID

DIFFUSION COEFFICIENT
VS HYDRAULIC RADIUS



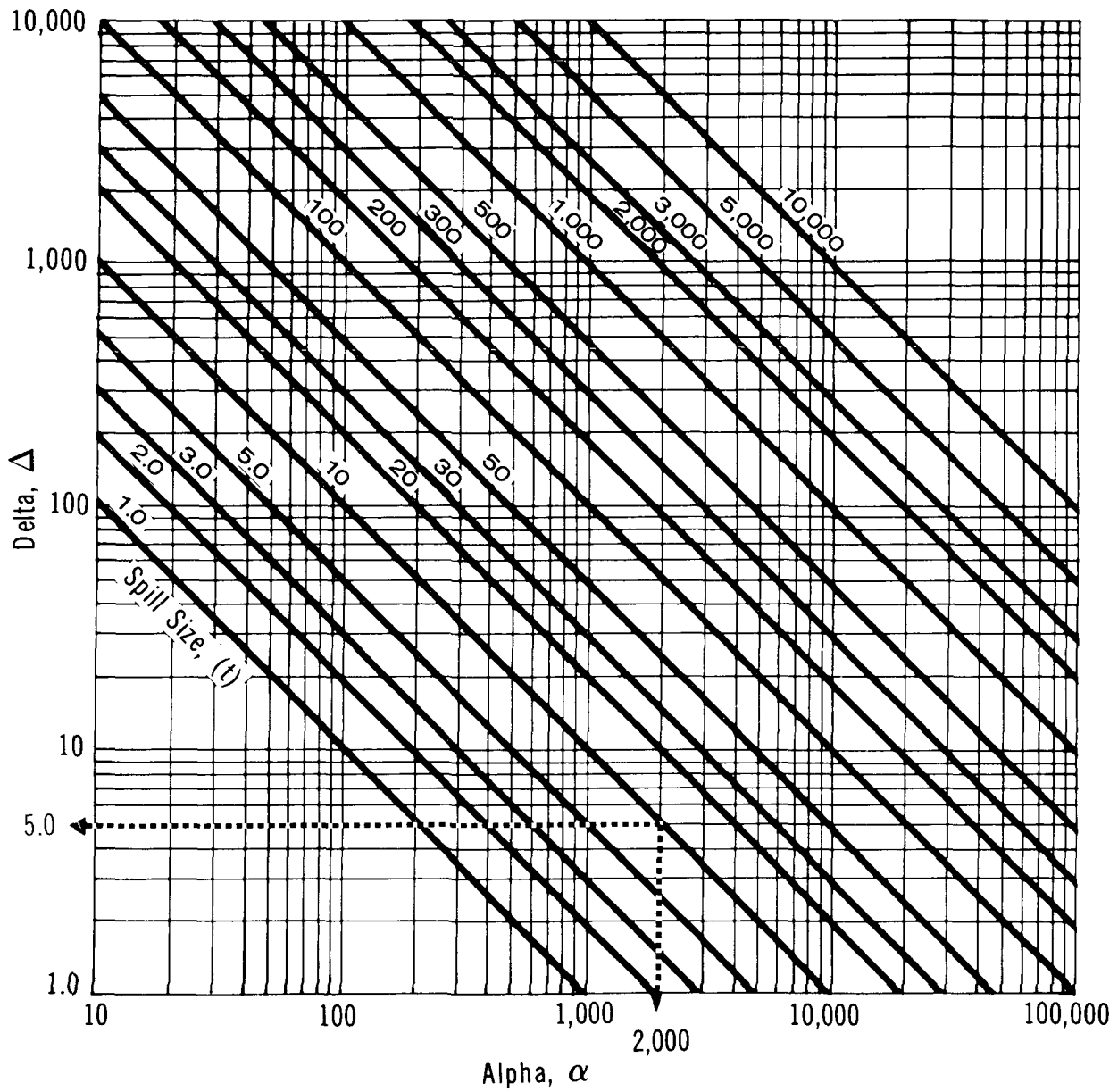
SULPHURIC ACID

ALPHA vs DIFFUSION COEFFICIENT



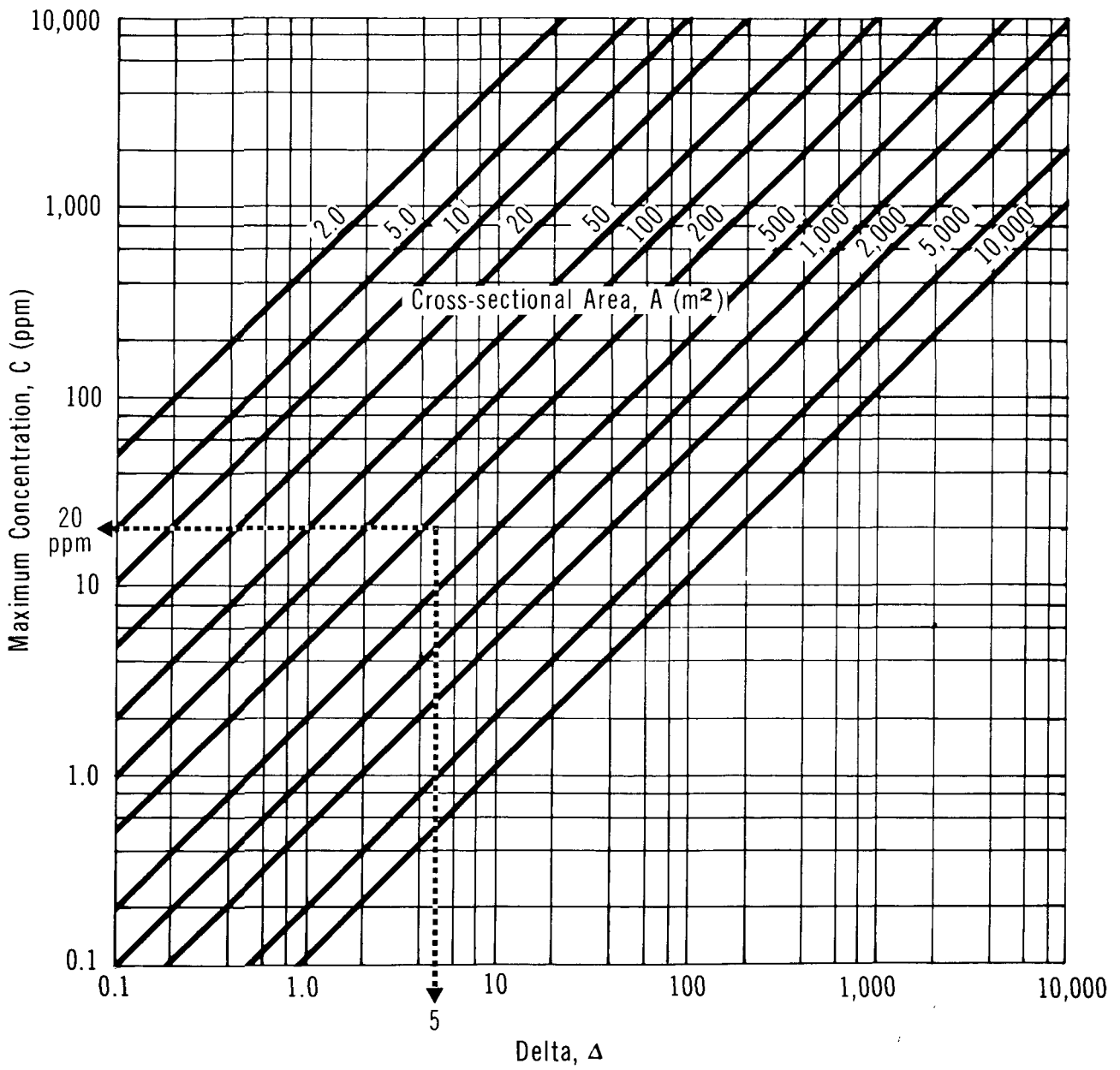
SULPHURIC ACID

ALPHA vs DELTA



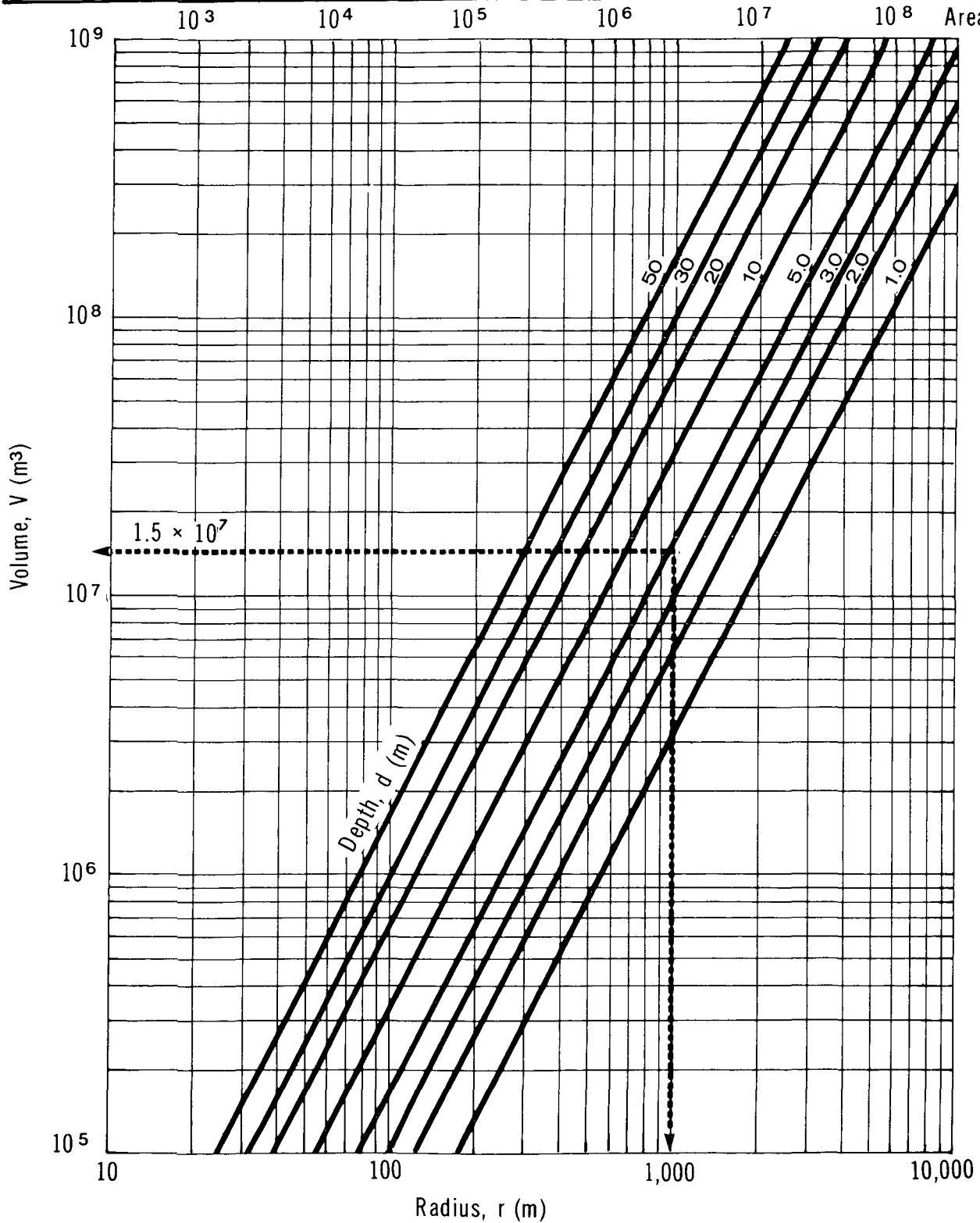
SULPHURIC ACID

MAXIMUM CONCENTRATION vs DELTA



SULPHURIC ACID

VOLUME vs RADIUS



in the cylinder can be obtained from Figure 24. The radius (r) represents the distance from the spill to the point of interest.

Figure 25: Average concentration versus volume. For a known volume of water (within the idealized cylinder of radius (r) and length (d)), the average concentration of pollutant (C) can be obtained from Figure 25 for a known mass of spill. This assumes the pollutant is spread evenly throughout the cylinder. For pollutants that are more or less dense than water, the actual concentration at the bottom would be higher or lower, respectively.

5.4.3 Sample Calculations.

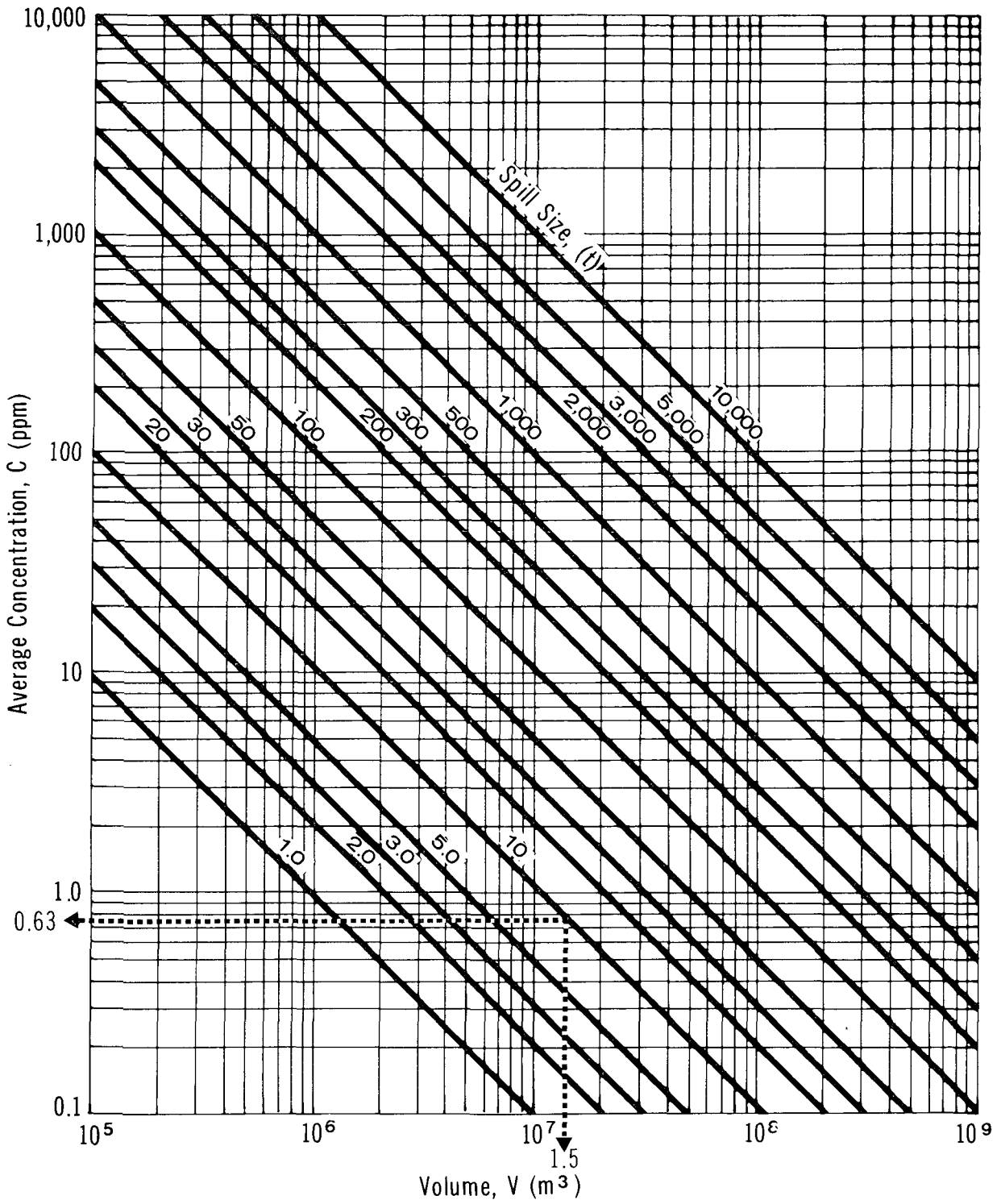
5.4.3.1 Pollutant concentration in non-tidal rivers. A 20 tonne spill of 50 percent sulphuric acid solution has occurred in a river. The stream width is 50 m and the stream depth is 5 m. The average stream velocity is estimated at 1 m/s. What is the maximum concentration expected at a water intake located 5 km downstream?

Solution

- Step 1: Define parameters
- . $W = 50$ m
 - . $d = 5$ m
 - . $U = 1$ m/s
 - . mass = 20 tonnes of 50 percent solution, equivalent to 10 tonnes of 100 percent sulphuric acid
 - . $X = 5,000$ m
- Step 2: Calculate time to reach point of interest
- . Use Figure 18
 - . With $X = 5,000$ m and $U = 1$ m/s, $t = 83$ min
- Step 3: Calculate hydraulic radius (r)
- . Use Figure 19
 - . With $W = 50$ m and $d = 5$ m, $r = 4.2$ m
- Step 4: Calculate longitudinal diffusion coefficient (E)
- . Use Figure 20
 - . With $r = 4.2$ m and $U = 1$ m/s, $E = 69$ m²/s
- Step 5: Calculate alpha (α)
- . Use Figure 21
 - . With $E = 69$ m²/s and $t = 83$ min, $\alpha = 2,000$

SULPHURIC ACID

AVERAGE CONCENTRATION vs VOLUME



- Step 6: Calculate delta (Δ)
- . Use Figure 22
 - . With alpha (α) = 2,000 and mass = 10 tonnes, delta (Δ) = 5
- Step 7: Compute stream cross-sectional area (A)
- . $A = W \times d = 50 \times 5 = 250 \text{ m}^2$
- Step 8: Calculate maximum concentration (C) at point of interest
- . Use Figure 23
 - . With $\Delta = 5$ and $A = 250 \text{ m}^2$, $C = 20 \text{ ppm}$

5.4.3.2 Average pollutant concentration in lakes or still water bodies. A 20 tonne spill of 50 percent sulphuric acid solution has occurred in a lake. The point of interest is located on the shore approximately 1,000 m from the spill. The average depth between the spill site and the point of interest is 5 m. What is the average concentration which could be expected?

Solution

- Step 1: Define parameters
- . $d = 5 \text{ m}$
 - . $r = 1,000 \text{ m}$
 - . mass = 10 tonnes (equivalent 100 percent sulphuric acid)
- Step 2: Determine the volume of water available for dilution
- . Use Figure 24
 - . With $r = 1,000 \text{ m}$, $d = 5 \text{ m}$, the volume is approximately $1.6 \times 10^7 \text{ m}^3$
- Step 3: Determine the average concentration
- . Use Figure 25
 - . With $V = 1.6 \times 10^7 \text{ m}^3$ and mass = 10 tonnes, the average concentration is 0.63 ppm

5.5 Subsurface Behaviour: Penetration into Soil

5.5.1 Mechanisms. Concentrated sulphuric acid has a boiling point of 310°C at a pressure of 1 atmosphere. Consequently, when it is spilled onto soil only limited evaporation will occur below this temperature.

Since sulphuric acid is miscible with water, the presence of water in the soil or falling as precipitation at the time of the spill will influence the rate of chemical

movement in the soil. Concentrated sulphuric acid reacts violently with water producing much heat. Dilution through mixture with water will decrease the viscosity more than the mass density. This will have the net effect of increasing the velocity of downward movement in the soil.

If the soil surface is saturated with moisture at the time of the spill, as might be the case after a rainfall, the spilled chemical will run off or remain ponded.

For this work, the soils have been assumed to be at field capacity. This situation provides very little interstitial water to dilute the chemical during transport or to impede its downward movement and thus represents a typical case.

During transport through the soil, sulphuric acid can dissolve some of the soil material, in particular carbonate-based materials. The acid will be neutralized to some degree. However, significant amounts of acid are expected to remain for transport down toward the groundwater table. The analysis used here neglects these retarding factors.

Upon reaching the groundwater table, the acid will continue to move in the direction of groundwater flow and downward since its mass density exceeds that of water. A contaminated plume will be produced, with diffusion and dispersion serving to reduce the acid concentration somewhat. This is shown schematically in Figure 26.

5.5.2 Equations Describing Sulphuric Acid Movement into Soil. The equations and assumptions used to describe contaminant movement downward through the unsaturated soil zone toward the groundwater table have been described in the Introduction Manual. Transport velocities have been based on Darcy's Law assuming saturated piston flow.

5.5.3 Saturated Hydraulic Conductivity of Sulphuric Acid in Soil. The saturated hydraulic conductivity (K_0), in m/s, is given by:

$$K_0 = \frac{(\rho g)k}{\mu}$$

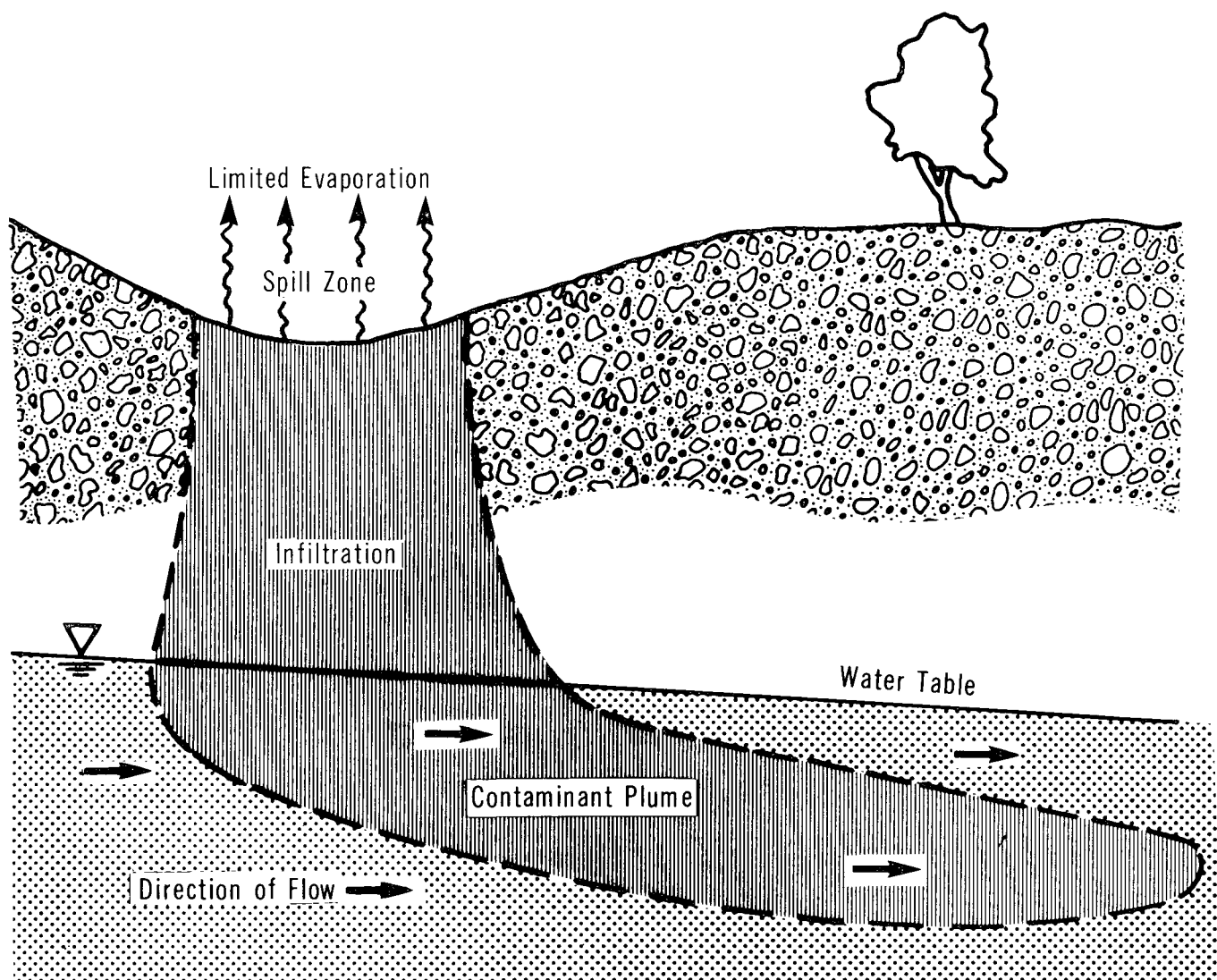
where:

- k = intrinsic permeability of the soil (m^2)
- ρ = mass density of the fluid (kg/m^3)
- μ = absolute viscosity of the fluid ($Pa \cdot s$)
- g = acceleration due to gravity = 9.81 m/s^2

The fluids involved are sulphuric acid (60% by weight and concentrated) and water. The water calculations represent the extreme as sulphuric acid is diluted.

SULPHURIC ACID

SCHEMATIC SOIL TRANSPORT



Soil: Coarse Sand

-Porosity (n) = 0.35-Intrinsic Permeability (k) = 10^{-9} m^2 -Field Capacity (θ_{fc}) = 0.075

Property	Sulphuric Acid			Water 20°C
	Concentrated	60% by Weight		
	20°C	20°C	4°C	
Mass density (ρ), kg/m ³	1,830	1,500	1,510	1,000
Absolute viscosity (μ), Pa•s	25.4×10^{-3}	6.4×10^{-3}	8.8×10^{-3}	1.0×10^{-3}
Saturated hydraulic conductivity (K_0), m/s	$(0.07 \times 10^7)k$	$(0.23 \times 10^7)k$	$(0.17 \times 10^7)k$	$(0.98 \times 10^7)k$

5.5.4 Soils. The Introduction Manual describes the three soils selected for this work. Their relevant properties are:

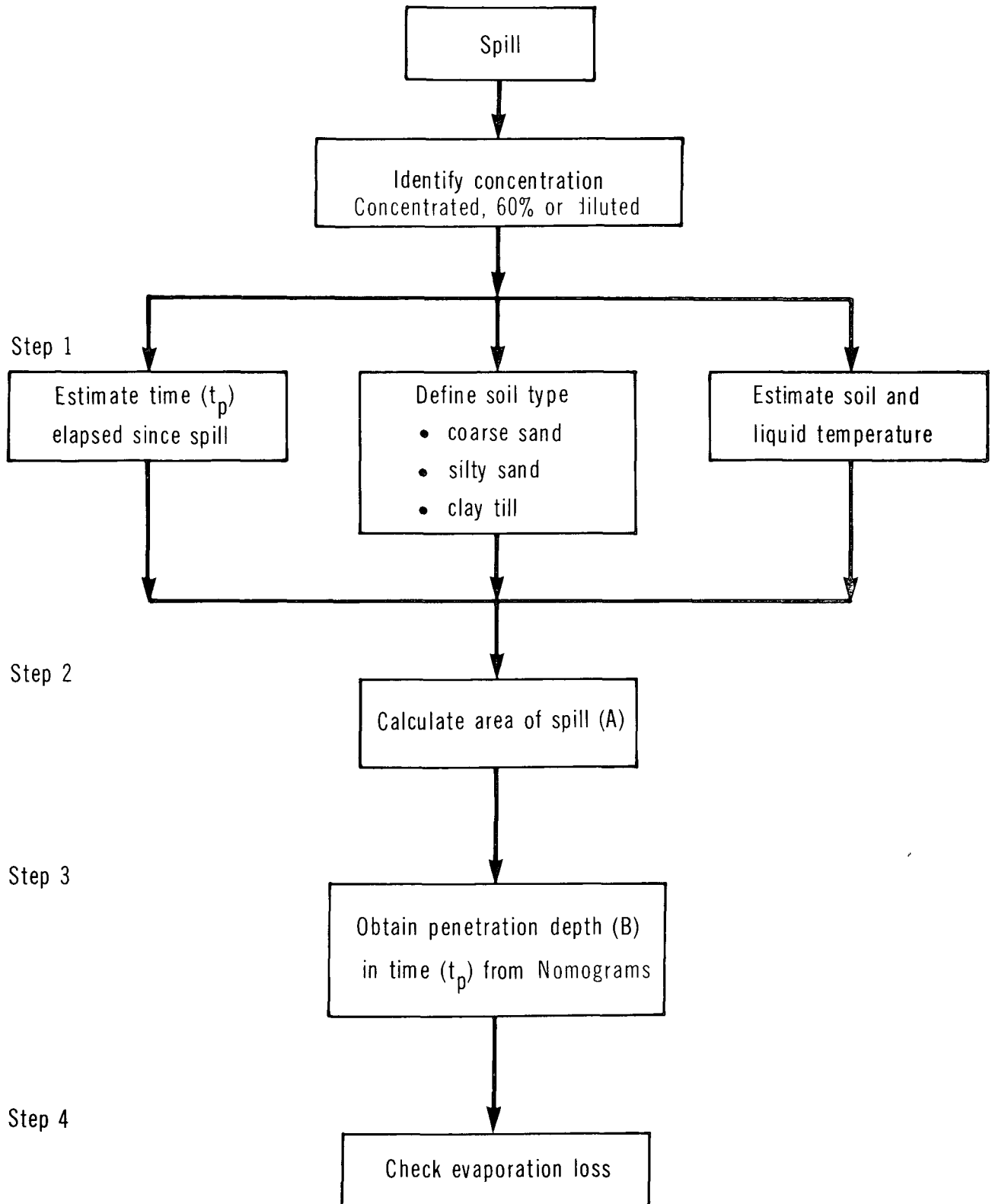
Property	Soil Type		
	Coarse Sand	Silty Sand	Clay Till
Porosity (n), m ³ /m ³	0.35	0.45	0.55
Intrinsic permeability (k), m ²	10^{-9}	10^{-12}	10^{-15}
Field capacity (θ_{fc}), m ³ /m ³	0.075	0.3	0.45

5.5.5 Penetration Nomograms. Nomograms for the penetration of sulphuric acid into the unsaturated zone above the groundwater table were prepared for each soil. They present penetration time (t_p) plotted against depth of penetration (B). Because of the methods and assumptions used, the penetration depth should be considered as a maximum depth, in time t_p .

A flowchart for the use of the nomograms is presented in Figure 27. The nomograms are presented in Figures 28, 29 and 30. The water line on the nomograms represents the maximum penetration of water at 20°C, in time t_p . It is a limiting condition as sulphuric acid becomes highly diluted with water.

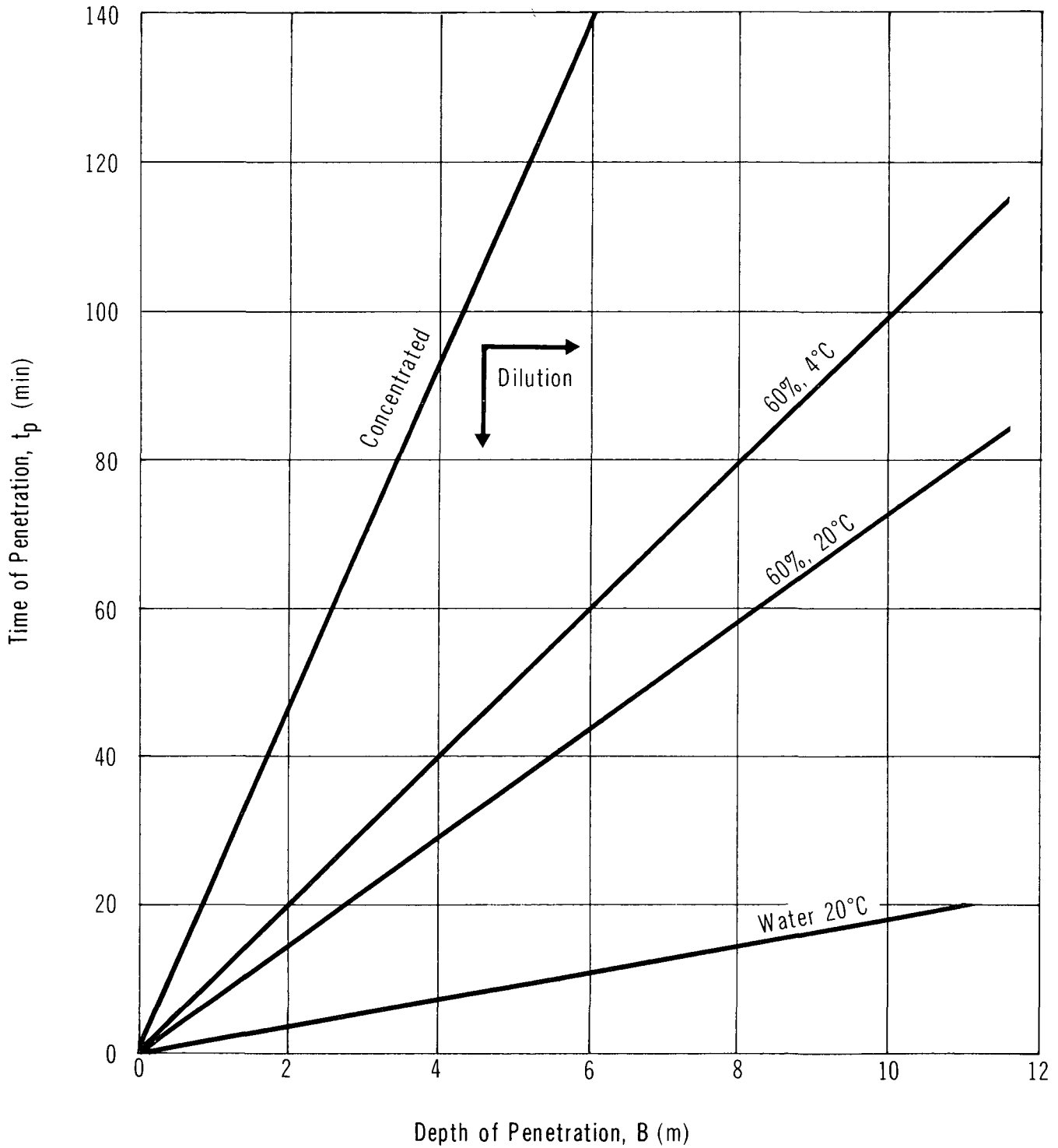
SULPHURIC ACID

FLOWCHART FOR NOMOGRAM USE



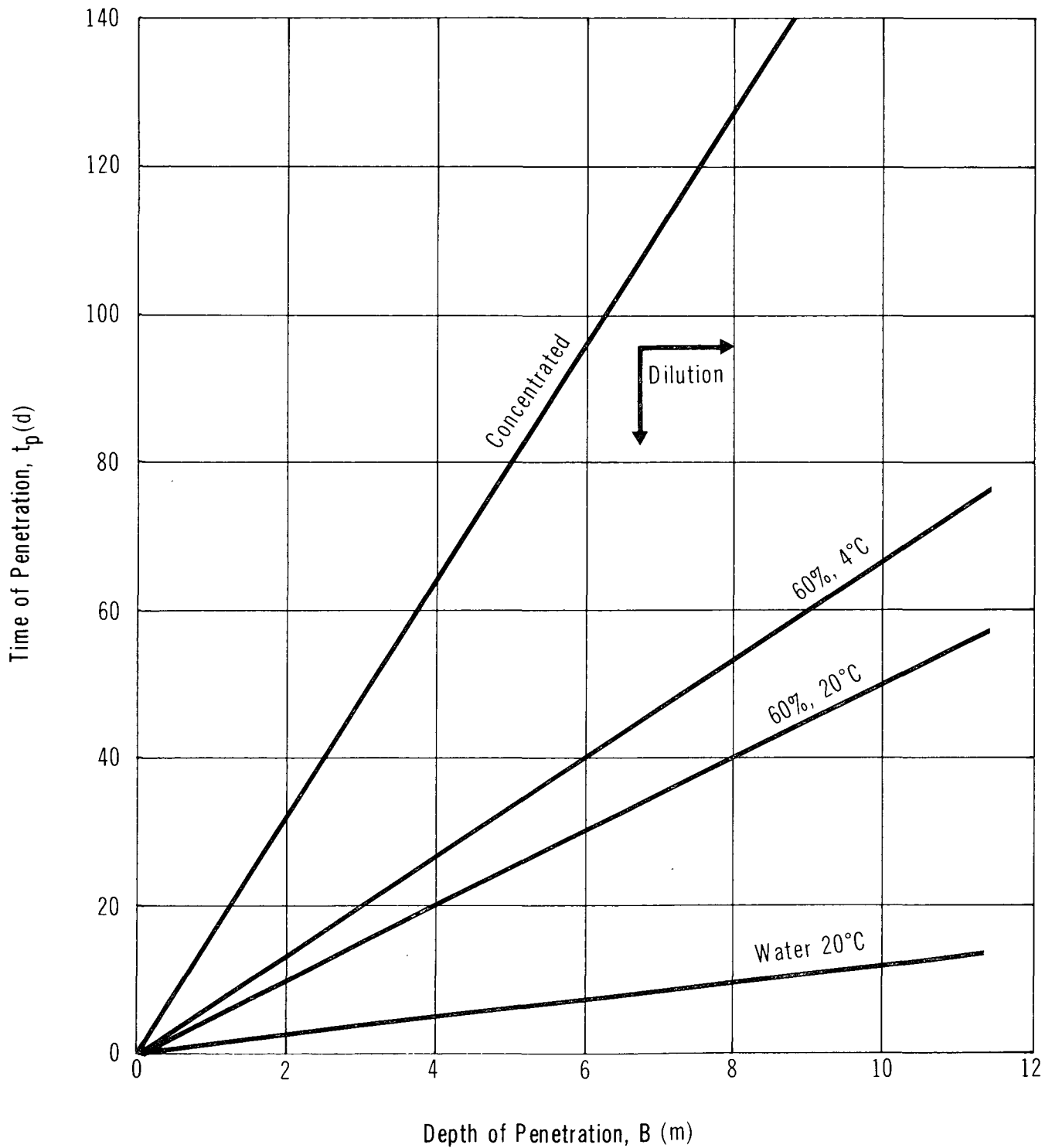
SULPHURIC ACID

PENETRATION IN COARSE SAND



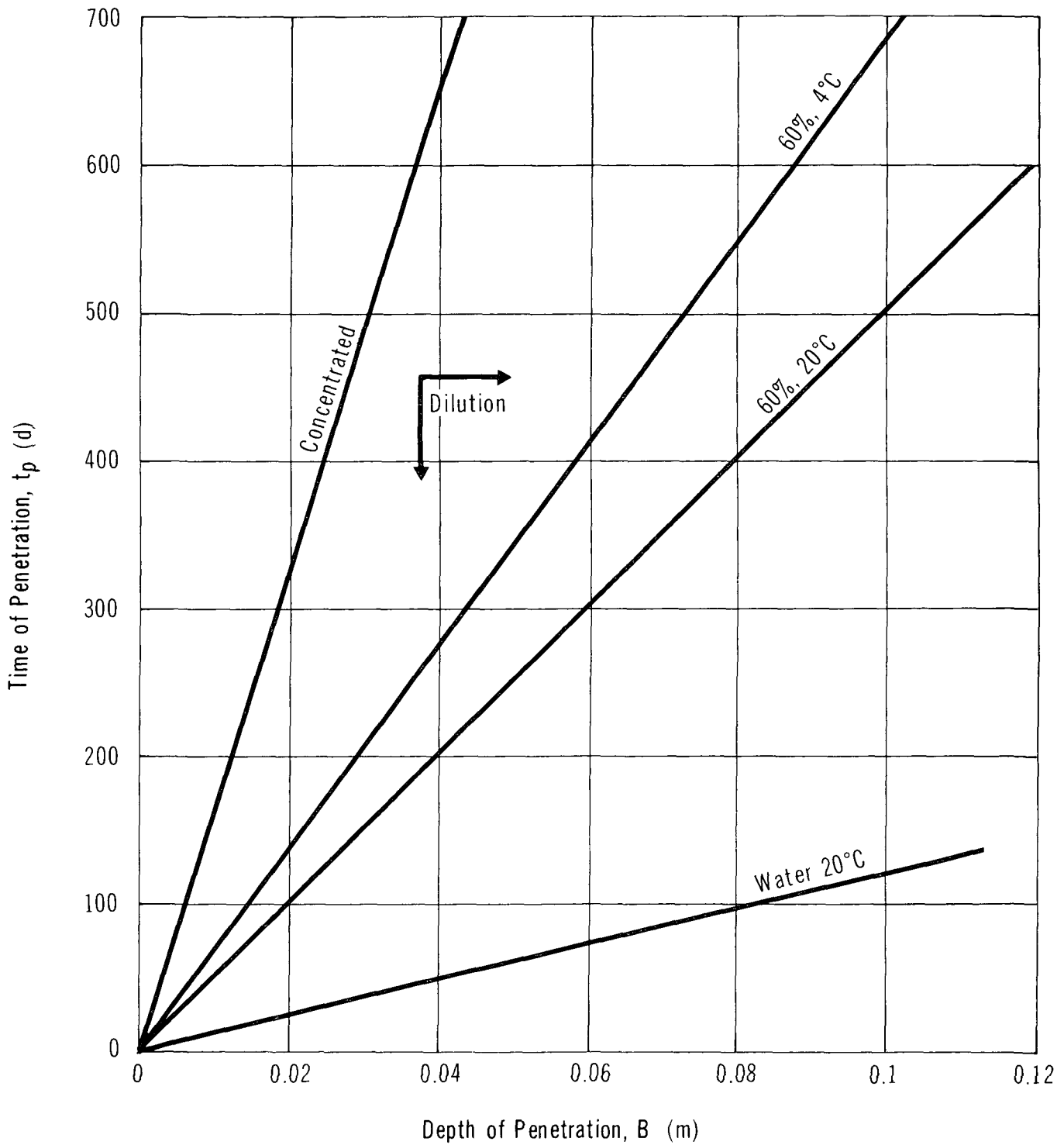
SULPHURIC ACID

PENETRATION IN SILTY SAND



SULPHURIC ACID

PENETRATION IN CLAY TILL



5.5.6 Sample Calculation. A 20 tonne spill of 60 percent sulphuric acid has occurred on coarse sand. The temperature is 20°C; the spill radius is 8.6 m. Calculate the depth of penetration 40 minutes after the spill.

Solution

Step 1: Define parameters

- Mass spilled = 20,000 kg (20 tonnes)
- $T = 20^{\circ}\text{C}$
- $r = 8.6\text{ m}$
- Soil = coarse sand
- Groundwater table depth (d) = 13 m
- Time since spill (t_p) = 40 min

Step 2: Calculate area of spill

- $A = \pi r^2 = 232\text{ m}^2$

Step 3: Estimate depth of penetration (B) at time (t_p)

- For coarse sand, $B = 5.5\text{ m}$ at $t_p = 40\text{ min}$
- Groundwater table has not been reached in this time

Step 4: Check evaporation loss

- Evaporation of 60% sulphuric acid is negligible after 40 minutes under the spill conditions

6 ENVIRONMENTAL DATA

6.1 Suggested or Regulated Limits

6.1.1 Water.

6.1.1.1 Canada. Sulphuric acid in itself is not regulated in Canada; however, there are guidelines for both sulphate and pH.

Nationally, 500 mg/L sulphate is the recommended upper limit; 150 mg/L is preferred. For livestock, a limit of 1,000 mg/L sulphate is acceptable (WQS 1979).

Ontario recommends that "alkalinity should not be decreased by more than 25 percent of the natural concentration". The pH should not go below 6.5 (Water Management Goals 1978).

6.1.1.2 Others. In the United States, 250 mg/L sulphate is the maximum acceptable, with a 50 mg/L objective (WQCDB-2 1971); 500 mg/L is acceptable for livestock (EPA-440/9-75-009). The World Health Organization recommended a limit of 250 mg/L sulphate in 1961 (WQCDB-2 1971).

For high levels of protection from acidity, a pH of not less than 6.5 is recommended; pH 5.5 affords the minimum acceptable protection. The extreme range of pH fluctuation should not exceed 2.0 units; total alkalinity should not be reduced by more than 25 percent (WQC 1972).

6.1.2 Air. Ontario limits airborne sulphuric acid to 100 $\mu\text{g}/\text{m}^3$ (Ontario E.P. Act 1971).

6.2 Aquatic Toxicity

6.2.1 U.S. Toxicity Rating. Sulphuric acid and oleum have been assigned a $\text{TL}_{\text{m}96}$ (4-day median lethal toxicity rating) of 10 to 100 mg/L (RTECS 1979).

6.2.2 Freshwater Toxicity.

Conc. (mg/L)	Time (hours)	Species	Result	Water Conditions	Reference
<u>Fish Kill Data</u>					
6.0 - 8.0	6	Minnows	harmful or lethal	20°C, distilled	WQC 1963

Conc. (mg/L)	Time (hours)	Species	Result	Water Conditions	Reference
110 - 120	6	Minnows	harmful or lethal	20°C, hard	WQC 1963
7.36	60	Bluegill	harmful or lethal	distilled	WQC 1963
6.25	24	Trout	harmful or lethal		WQC 1963
<u>Fish Toxicity Tests</u>					
42	48	Mosquito fish	TL _m	turbid	WQC 1963
49	48	Bluegill	TL _m	tap, 20°C	WQC 1963
<u>Microorganisms</u>					
0.1	168	<i>Daphnia magna</i>	lethal	static-soft	Ellis 1967
88	64	<i>Daphnia magna</i>	lethal	Lake Erie	WQC 1963
<u>Invertebrates</u>					
33.1	not stated	Bivalve larvae	harmful		WQC 1963

6.2.3 Saltwater Toxicity.

Conc. (mg/L)	Time (hours)	Species	Result	Water Conditions	Reference
<u>Fish Toxicity Tests</u>					
100 to 330	48	Flounder	LC ₅₀	aerated	Portman 1970
<u>Invertebrates</u>					
100	120	Oysters	18% lethal		WQC 1963
80 to 90	48	Shrimp	LC ₅₀	aerated	Portman 1970

6.3 Toxicity to Other Biota

6.3.1 Livestock.

Conc. (mg/L)	Species	Result	Water Conditions	Reference
2,104 to 3,500	Cattle	weakened and died	Minnesota drinking water 1971 - sulphate ion	WQCDB-2

6.3.2 Plant.

Conc.	Species	Result	Reference
<u>Trees</u>			
10-2N (approx. pH 2.0)	Pears	caused black spots on fruit	Ebara 1980

Conc.	Time (hours)	Species	Result	Reference
<u>Crops</u>				
pH 1.0 and 2.0 (mist)	48	Corn	damage	Wedding 1981
pH 0.5 (mist)	not stated	Corn	immediate damage	Wedding 1981
10% acid (mist)	not stated	Soybean (4 to 6 wk old)	severe necrotic lesions on leaves	Wedding 1979
18 M (mist)	10 h/d for 14 d	Soybean (4 to 6 wk old)	no visible toxicity damage	Wedding 1979
100 to 200 mg/m ³	4 to 16	Plants	marginal and tip necrosis of foliage	Lang 1979

6.3.2.1 Plant studies. Different plant species vary greatly in sensitivity to sulphuric acid aerosol; injury to sensitive species appears to be conditioned by biological as well as physiological factors (Lang 1979).

6.4 Other Air and Land Toxicity

Atmospheric aerosols contain varying quantities of both weak and strong acids. Measurements have demonstrated that strong acid concentrations equivalent to approximately $20 \mu\text{g}/\text{m}^3$ of sulphuric acid may exist in the ambient atmosphere for periods of several hours. Strong acid may frequently be present in low amounts in "fine" aerosol particles (Tanner 1981).

6.5 Effect Studies

The poisonous effect of sulphuric acid is primarily due to its acidity. While a pH of 4.0 has caused gill irritation, pH 3.5 has caused death in sunfish, bass and carp. As a consequence of this pH effect, a quantity of acid that would be lethal in soft water could be rendered harmless in hard or highly buffered water.

Generally, a pH greater than 4.5 permits fish to survive; other aquatic life requires at least a pH of 5.5. Below pH 5, specialized aquatic flora and fauna develop (WQC 1963).

Summary of pH effects (WQC 1972):

5.5-6.0	Eastern brook trout survive. Rainbow trout do not occur. Growth rate of carp is reduced. Spawning is reduced. Molluscs are rare.
5.0-5.5	Smaller populations of fish, but not lethal. May be lethal to eggs or larvae and some invertebrates. Algae and higher plants will grow.
4.5-5.0	No viable fishery can be maintained. Likely to be lethal to eggs and fry. Harmful to carp. Lethal to some invertebrates.
4.0-4.5	Only a few fish species survive. Only pike reproduce.
3.5-4.0	All flora and fauna are severely restricted.
3.0-3.5	Unlikely that any fish survive more than a few hours.

6.6 Degradation

Sulphuric acid does not chemically or biologically degrade naturally; however, it is neutralized and/or converted with time.

6.7 Long-term Fate and Effect

Sulphuric acid will ultimately react with calcium and magnesium in water to form sulphate salts. There is no bioaccumulation or food chain concentration effect cited.

6.8 Soil

6.8.1 Soil Degradation of Material.

Conc. (kg/ha/yr)	Time	Species	Effect	Reference
25 to 50	2 wk intervals	Conifer forest soils	little or no effect on cation removal or nitrification in soil; 15% increase in fresh needle decomposition	Roberts 1980

6.8.2 Effect of Soil Chemistry. Sulphuric acid has led to increased weathering of calcium from soils and rocks so that the calcium ion rises in concentration in waters above pH 6, and also in those below pH 5 (NRCC 1977).

6.9 Other Effects

6.9.1 Possible Effects on Water Treatment Process. Sulphuric acid interferes with some normal biological processes: 58 mg/L has caused 50 percent inhibition of sewage organisms (DPIMR 1981).

7 HUMAN HEALTH

The immediate and obvious effects of concentrated sulphuric acid splashes on living tissue may account for the limited amount of published report material dealing with skin contact, exposure, and ingestion. There are, however, numerous literature reports noting the animal and human health effects of inhalation of sulphuric acid mist and fuming sulphuric acid (SO₃). Scant literature was encountered on the effects of sulphuric acid exposure on reproduction and mutagenicity. There was no literature reporting on carcinogenicity. Testing to determine potential teratogenicity of sulphuric acid has yielded largely negative results. That sulphuric acid continues to be a topic of current interest is reflected in the 14 studies reported in TOX TIPS (a summary of current research activity) since 1976; all but one study examined inhalation toxicity.

Sulphuric acid was reported in the 1980 EPA TSCA inventory (RTECS (on-line) 1981). Published work on sulphuric acid has been reviewed recently. The data summarized here are representative of information in the literature.

The toxicological data summarized here have been extracted from reliable standard references only. It should be noted that some of the data are for chronic (long-term), low-level exposures and may not be directly applicable to spill situations. Only acute (short-term) exposure data are given for non-human mammalian species, to support interpretation of the human data where appropriate.

7.1 Recommended Exposure Limits

The exposure standards for sulphuric acid are based upon its irritant properties. Canadian provincial guidelines generally are similar to those of USA-ACGIH, unless indicated otherwise.

Guideline (Time)	Origin	Recommended Level	Reference
<u>Time-weighted Averages (TWA)</u>			
TLV* (8 h)	USA-ACGIH	1.0 mg/m ³	TLV 1981
PEL (10 h)	NIOSH	1.0 mg/m ³	NIOSH Guide 1978
Not stated	USSR	1.0 mg/m ³	NIOSH 1981
Not stated	Romania	0.5 mg/m ³	NIOSH 1981
<u>Short-term Exposure Limits (STEL)</u>			
STIL* (5 min)	-	10 mg/m ³	CHRIS 1978

Guideline (Time)	Origin	Recommended Level	Reference
STIL* (10 min)	-	5 mg/m ³	CHRIS 1978
(15 min)	Saskatchewan	3 mg/m ³	Sask. 1981
STIL* (30 min)	-	2 mg/m ³	CHRIS 1978
Ceiling	Romania	1.5 mg/m ³	NIOSH 1981
STIL* (60 min)	-	1 mg/m ³	CHRIS 1978
<u>Other Human Toxicities</u>			
IDLH	USA	80 mg/m ³	NIOSH Guide 1978
TC _{LO} (24 wk)		3 mg/m ³	RTECS (on-line) 1981
TC _{LO}		800 µg/m ³	AAR 1981
TC _{LO} (15 min)		5 mg/m ³	AAR 1981
TC _{LO}		800 µg/m ³	ITII 1981
TD _{LO}		135 mg/kg	RTECS (on-line) 1981

*STIL Short-term Inhalation Limit

7.2 Irritation Data

7.2.1 Skin Contact.

Exposure Level (and Duration)	Effects	Reference
SPECIES: Human		
Concentrated form	Rapid destruction of tissue, severe burns, necrosis	DPIMR 1981
Unspecified	Cicatrization with disfigurement	Goldman et al. 1953. <u>IN</u> NIOSH 1974
77-98% Acid	Severe second and third degree burns	CHRIS 1978
Dilute solutions	Repeated contact may cause dermatitis	Sax 1979

7.2.2 Eye Contact.

Exposure Level (and Duration)	Effects	Reference
SPECIES: Human		
Concentrated form	Extremely severe damage, often leading to blindness	NIOSH Guide 1978
Unspecified	Irreparable corneal damage resulting in blindness	Fasullo 1965. <u>IN</u> NIOSH 1974
Mist	Irritation	Amdur et al. 1953. <u>IN</u> NIOSH 1974
Vapours from hot acid (77 to 98%)	Moderate irritation	CHRIS 1978
SPECIES: Rabbit		
1,380 µg	Severe irritation	RTECS 1979

7.3 Threshold Perception Properties

7.3.1 Odour.

Odour Characteristics: Odourless unless heated, then choking (AAR 1981).
 Odour Index: 5,368 at 146°C (AAR 1981).

Parameter	Media	Concentration	Reference
100% Detection	-	3 mg/m ³	Lippmann 1980
Odour Threshold	air	>1 mg/m ³	CHRIS 1978
Threshold Odour Concentration	air	>1 mg/m ³	AAR 1981
Median Recognition Threshold	air	0.6 mg/m ³	AAR 1981
Subjective Limit of Detection	-	0.5 to 0.7 mg/m ³	NIOSH 1974

7.3.2 Taste. Taste Characteristic: Sour

Parameter	Media	Concentration	Reference
Detection Threshold	water	0.0013 g/100 mL	ASTM 1980
Detection Threshold	water	0.001 normality	ASTM 1980

7.4 Long-term Studies

7.4.1 Inhalation. (Data for sulphuric acid mist unless otherwise specified.)

Exposure Level (and Duration)	Effects	Reference
<u>Acute Exposures</u>		
SPECIES: Human		
800 $\mu\text{g}/\text{m}^3$	TC _{LO}	AAR 1981
3 to 39 mg/m^3 (10 min to 1 h) 1.0 μm MMD	Pulmonary resistance was increased more than 20% in most subjects and in some cases was as high as 150% above control values. Transient cough and bronchoconstriction were present	Lippmann 1980
3 to 39 mg/m^3 10 N acid mist, 1 μm mean diameter; 11.5 to 38 mg/m^3 4 N acid mist, 1.5 μm mean diameter (up to 60 min)	Irritant effect of 20.8 mg/m^3 at high humidity and larger particle size was greater than that of 39.4 mg/m^3 at lower humidity and smaller particle size. Increase in airway resistance was higher in the high humidity exposed group	Sim and Pattle 1957. <u>IN</u> NIOSH 1974
12 mg/m^3 and 0.6 mg/m^3	Significant concentrations of ammonia gas in respiratory tract may protect against low levels of acid aerosols and vapours	Larson et al. 1977. <u>IN</u> NIOSH 1981
8.3 to 3.12 mg/m^3 (expressed as SO_2)	Author experienced nosebleeds	Dorsch 1913. <u>IN</u> NIOSH 1974
6.0 to 2.4 mg/m^3	Acute irritation of mucous membranes. Reflexive cough. Eye irritation	Bushtueva 1957. <u>IN</u> NIOSH 1974
5 mg/m^3 (15 min)	TC _{LO} , toxic pulmonary effects	ITII 1981
5 mg/m^3 (15 min)	TC _{LO}	AAR 1981
5 mg/m^3 (5 to 15 min)	Deep breath produced coughing	Doc. TLV 1981
5 mg/m^3	Cough, increase in respiratory rate, and impairment of ventilatory capacity	NIOSH/OSHA 1981

Exposure Level (and Duration)	Effects	Reference
5 to 0.4 mg/m ³ (5 to 15 min) 1 µm particle size	Increase in respiratory rate, decrease in tidal volume. These changes occurred within 2 minutes of commencing inhalation	Amdur et al. <u>IN</u> Lippmann 1980
5 to 0.4 mg/m ³ (5 to 15 min) 1 µm particle size)	Retention of sulphuric acid in the respiratory tract averaged 77% over a 0.4 to 1.0 mg/m ³ exposure concentration range	Admur et al. 1952 <u>IN</u> NIOSH 1974
2.4 to 1.1 mg/m ³	Irritation at the base of esophagus. Some subjects noted eye irritation	Bushtueva 1957. <u>IN</u> NIOSH 1974
2.0 to 1.8 mg/m ³	Increase in respiratory rate	Bushtueva 1957. <u>IN</u> NIOSH 1974
>1,000 µg/m ³	Mild reversible broncho- constriction	Liekauf 1981
1,000 µg/m ³ (16 min)	Small but statistically significant changes in specific conductance	Liekauf 1981
1 mg/m ³ (1 h)	Administered by nasal mask, mean bronchial clearance half-time was increased by 48%	Lippmann 1980
1 mg/m ³ 0.5 mm MMD	Speeding in mucociliary clearance time probably due to irritant response	Newhouse et al. 1978. <u>IN</u> NIOSH 1981
1,000 to 10 µg/m ³ (10 min)	No significant alteration of lung volumes, distribution of ventilation, ear oximetry, dynamic mechanics of breath- ing, oscillation mechanics of chest-lung system, pul- monary capillary blood flow, diffusing capacity, oxygen consumption, pulmonary tissue volume	Sackner et al. 1978. <u>IN</u> NIOSH 1981
980 µg/m ³ (1 h)	Significant transient slowing of tracheobronchial mucociliary clearance	Liekauf 1981
0.85 to 0.6 mg/m ³	Detection of throat tickling and scratching	Bushtueva 1957. <u>IN</u> NIOSH 1974
800 µg/m ³	TC _{LO} , toxic mouth effects	ITII 1981
0.73 mg/m ³	19% prolongation of optical chronaxy (1 subject)	Bushtueva 1961. <u>IN</u> NIOSH 1974

Exposure Level (and Duration)	Effects	Reference
0.7 mg/m ³	24% increase in sensitivity to light (3 subjects)	Bushtueva 1961. <u>IN</u> NIOSH 1974
0.7 and 0.3 mg/m ³	No potentiation effect between sulphuric acid aerosol and sulphur dioxide at 0.65 and 3 mg/m ³ to light sensitivity in 3 women	Bushtueva 1961. <u>IN</u> NIOSH 1974
0.5, 0.4, 0.35 mg/m ³ (5 to 15 min) 1.0 µm mean particle size	Increased respiratory rate	Amdur et al. 1952. <u>IN</u> NIOSH 1974
110 µg/m ³ (1 h)	Significant acceleration in mucociliary clearance. Group mean tracheobronchial clearance half-time, TB1/2, decreased from 80 to 50 minutes	Liekauf 1981
0.1 mg/m ³ (1 h)	Administered by nasal mask, mean bronchial clearance half-time reduced by 38%	Lippmann 1980
100 µg/m ³ (2 h, 2 or 3 consecutive d) 0.5 or 0.59 µm MMD	No significant adverse changes in pulmonary function, including FVC, FEV, maximum expiratory flows with 50% and 25% of FVC remaining to be expired, total lung capacity, residual volume or total respiratory resistance	Avol et al. 1979. <u>IN</u> NIOSH 1981
100 µg/m ³ (4 h) 0.5 µm MMD	No significant difference between control and aerosol exposed group for glutathione, lysozyme, glutathione reductase, serum glutamic oxaloacetic transaminase, serum vitamin E, and 2,3-diphosphoglyceric acid	Chaney et al. 1980. <u>IN</u> NIOSH 1981
10 to 20 ppm	Unbearable	DPIMR 1981
1.5 to 2.5 ppm	Definitely unpleasant	DPIMR 1981
0.125 to 0.5 ppm	Mildly annoying	DPIMR 1981

Exposure Level (and Duration)	Effects	Reference
SPECIES: Donkey		
1,000 to 200 $\mu\text{g}/\text{m}^3$ (1 h) 0.5 μm mist	3 out of 4 animals demonstrated short-term slowing of bronchial mucociliary clearance. 2 of 4 animals showed a more persistent slowing of clearance values after about 6 exposures	Lippmann 1980
SPECIES: Guinea Pig		
200 mg/m^3 (1 h)	LC ₅₀	RMLTHH 1972
109 mg/m^3 (8 h) 0.4 μm MMAD	LC ₅₀ . Hyperinflated lungs	Wolff et al. 1979. <u>IN</u> NIOSH 1981
60 to 20 mg/m^3 (8 h)	LC ₅₀ . Death results from severe laryngeal spasm and bronchoconstriction. At concentrations which are lethal, 2.7 μm particles are more toxic than 0.8 μm particles	Doc. TLV 1981
50 mg/m^3 (8 h) 1 μm particle size	LC ₅₀ , adult guinea pigs	NIOSH/OSHA 1981
40 to 2 mg/m^3 0.8, 2.5 and 7 μm MMD	Largest particles, 7 μm at 30 mg/m^3 , produced only slight increase in airway resistance. 0.8 μm particles produced significant increase in resistance at 1.9 mg/m^3 . At 40 mg/m^3 , the 2.5 μm particles produced greatest increase in resistance. Large particles probably act to produce mucosal swelling, exudation of fluid; smaller particles produce simple reflex bronchoconstriction	Amdur 1958. <u>IN</u> NIOSH 1974
30 mg/m^3 (8 h) 0.8 μm MMAD	LC ₅₀ . Hemorrhage and transudation	Wolff et al. 1979. <u>IN</u> NIOSH 1981
30 mg/m^3 (1 h) 7 μm particle size	50% increase in pulmonary flow resistance. Particles of this size penetrate only to the upper respiratory tract and nasal passages	Doc. TLV 1981
18 mg/m^3	LC ₅₀	RTECS 1979

Exposure Level (and Duration)	Effects	Reference
18 mg/m ³ (8 h) 1 µm particle size	LC ₅₀ , young guinea pigs	NIOSH/OSHA 1981
8 mg/m ³ (8 h, 72 h) 1 µm particles	Some lung pathology at 8 hours. Increasing exposure time to 72 hours increased the severity of lung pathology	Doc. TLV 1981
6 mg/m ³ (1 h) 2.5 µm particle size	50% increase in pulmonary flow resistance	Doc. TLV 1981
3 mg/m ³ (1 h) 1.8 µm CMD 0.32 mg/m ³ (1 h) 0.6 µm CMD 0.03 mg/m ³ (1 h) 0.25 µm CMD	Animals exposed to 3 mg/m ³ acid and Streptococcus showed 60% greater deposition rate of bacteria. Authors concluded sulphuric acid exposure can result in pathophysiologic effects as well as respiratory physiologic alterations	Fairchild et al. 1975 <u>IN</u> NIOSH 1981
2 mg/m ³ (5 d)	Pulmonary edema, thickening of alveolar walls	Bushtueva 1957. <u>IN</u> NIOSH 1974
1 or 0.51 or 0.1 mg/m ³ (1 h) 0.3 µm MMD; 0.69 or 0.4 or 0.11 mg/m ³ (1 h) 1 µm MMD	Dose-related increases in pulmonary flow resistance. Except for 0.11 mg/m ³ exposures, pulmonary flow resistance did not return to normal values by 30 minutes after exposure	Amdur et al. 1978. <u>IN</u> NIOSH 1981
0.7 mg/m ³ (1 h) 1 µm particle size	50% increase in pulmonary flow resistance	Doc. TLV 1981
0.3 mg/m ³ (1 h) 0.3 µm particle size	50% increase in pulmonary flow resistance	Doc. TLV 1981
48 ppm (1 h)	LC _{LO}	RTECS 1979
SPECIES: Mouse		
549 mg/m ³ (35 h)	LC _{LO}	Treon et al. 1950. <u>IN</u> NIOSH 1974
500 mg/m ³ (8 h)	LC ₅₀	AAR 1981
165 mg/m ³	LC _{LO}	AAR 1981
140 ppm (3.5 h)	LC _{LO}	RTECS 1979
SPECIES: Rat		
347 ppm (1 h)	LC ₅₀	RTECS 1979
178 ppm (7 h)	LC _{LO}	RTECS 1979

Exposure Level (and Duration)	Effects	Reference
699 mg/m ³	LC _{LO}	Treon et al. 1950. <u>IN</u> NIOSH 1974
500 mg/m ³	LC _{LO}	AAR 1981
SPECIES: Hamster		
1.1 mg/m ³ , 1.5 mg/m ³ carbon black part- icles or carbon black particles onto which sulphuric acid has been condensed	Cytotoxic effects on tracheal tissue exposed to carbon/acid particles were greater than damage produced by either acid or carbon alone	Schiff et al. 1979. <u>IN</u> NIOSH 1981
1 mg/m ³ (2 h) 0.24 to 0.3 µm VMD	Depressed tracheal ciliary activity when exposed to sulphuric acid alone	Grose et al. 1980. <u>IN</u> NIOSH 1981
Ozone 196 µg/m ³ (3 h)	In sequential exposure to ozone and then sulphuric acid, lowering of ciliary beating frequency was significantly less than with exposure to sulphuric acid alone	Grose et al. 1980. <u>IN</u> NIOSH 1981
<u>Chronic Exposures</u>		
SPECIES: Human		
35 to 12.6 mg/m ³	Decrease in forced expiratory volume. Slightly greater acidity in salivary pH of exposed group. 40% of exposed workers had dental erosion, discolouration	El-Sadik 1972. <u>IN</u> NIOSH 1974
16 to 3 mg/m ³	Severe erosion of teeth	Doc. TLV 1981
3 mg/m ³ (24 wk)	TC _{LO} , mouth effects	RTECS 1979
2.5 to 0.8 mg/m ³	Less severe erosion of teeth	Doc. TLV 1981
SPECIES: Monkey		
4.79 mg/m ³ (2 yr)	Moderate to severe histo- pathology	Doc. TLV 1981
>2.5 mg/m ³	Impaired pulmonary function	Alarie et al. 1971. <u>IN</u> NIOSH 1981

Exposure Level (and Duration)	Effects	Reference
2.43 mg/m ³ (2 yr) 3.6 µm particle size	Moderate changes in histopathology, moderate alteration in distribution of ventilation, and a slight decrease in arterial O ₂	Doc. TLV 1981
0.48 mg/m ³ (2 yr)	Slight alteration in distribution of ventilation	Doc. TLV 1981
0.38 mg/m ³ (2 yr) 2.15 µm particle size	Slight histopathology	Doc. TLV 1981
0.1 to 1 mg/m ³	Slight histopathologic changes in pulmonary tissues	Alarie et al. 1975. <u>IN</u> NIOSH 1981
SPECIES: Guinea Pig		
25 mg/m ³ (2 d, 6 h/d) 1 µm MMD	Collapsed, fluid-filled areas of lung. Edema, hemorrhage. Macrophages in alveoli. Interstitial edema and vesiculation of capillary endothelium	Cockrell et al. 1978. <u>IN</u> NIOSH 1981
10 mg/m ³ and/or 0.5 ppm ozone (6 h/d, 5 d/wk for 2 mo)	Minimal proliferation of alveolar macrophages, mild tracheal changes. No evidence of a synergistic effect for combined exposure	Cockrell et al. 1978. <u>IN</u> NIOSH 1981
5 mg/m ³ (16 h/d, 7 d/wk, for 45 or 90 d)	Increase in total lung capacity after 90-day exposure. Ratio of functional residual capacity to total lung capacity lower at 45 days	Pepelko et al. 1979. <u>IN</u> NIOSH 1981
4 to 1 mg/m ³ (18 to 140 d) particle sizes at 0.6, 0.9 and 4 µm	The 0.9 µm particles produced greatest effects including slight lung edema, rare capillary hemorrhages	Thomas et al. <u>IN</u> NIOSH 1974
4 mg/m ³ (up to 140 d, 24 h/d)	Pulmonary pathology	Doc. TLV 1981
2 mg/m ³ (2 to 3 mo)	Slight catarrhal reaction in tracheal and bronchial mucosa with interstitial proliferation. Round lymphoid cell infiltration around blood vessels and bronchi	Bushtueva 1957. <u>IN</u> NIOSH 1974

Exposure Level (and Duration)	Effects	Reference
0.10 mg/m ³ (up to 52 wk, at 23 h/d) 2.8 µm MMD 0.08 mg/m ³ (up to 52 wk, at 23 h/d) 0.8 µm MMD	Normal growth and survival rates, normal lung function test results. No exposure related changes in lungs, trachea, peribronchial lymph nodes, heart, liver, or kidneys	Best et al. 1966. <u>IN</u> NIOSH 1981
SPECIES: Rat		
1.1 mg/m ³ and 0.5 ppm ozone (3 d, 14 d)	Increased tracheal glycoprotein secretion. Increased DNA, RNA content in lung homogenate	Last and Cross 1978. <u>IN</u> NIOSH 1981
SPECIES: Mouse		
20 or 5 mg/m ³ (7 h/d during major period of organo- genesis)	No teratogenicity noted	Murray et al. 1979. <u>IN</u> NIOSH 1981
Carbon black parti- cles onto which sul- phuric acid vapour had been condensed: 1.4 ± 0.4 mg H ₂ SO ₄ /m ³ on carbon black particles: 1.5 ± 0.4 mg carbon/m ³	Alterations of defense system suggest prolonged exposure to low concentrations of sulphuric acid and carbon particle mixtures reduces ability of mice to resist secondary stress of respiratory infection	Fenters et al. 1979. <u>IN</u> NIOSH 1981

7.4.2 Ingestion. (Data for sulphuric acid solutions.)

Exposure Level (and Duration)	Effects	Reference
SPECIES: Human		
Accidental ingestion 50% w/v	Damage from lips to colon. Most severe in pylorus and antrum. Severe stomatitis, strictures of esophagus, gas- troesophageal junction and gastric antrum. Coagulation necrosis of the stomach, duo-	Jelenko et al. 1974. <u>IN</u> NIOSH 1981

Exposure Level (and Duration)	Effects	Reference
	denum, jejunum and ileum. Pan- creatitis. Omental fat necrosis. Severe peritonitis. Surgical intervention necessary	
SPECIES: Rat		
2,140 mg/kg	LD ₅₀	RTECS 1979

7.4.3 Teratogenicity.

Exposure Level (and Duration)	Effects	Reference
SPECIES: Rabbit		
5 or 20 mg/m ³ , (7 h/d) during major period of organogenesis)	No teratogenicity noted	Murray et al. 1979. <u>IN NIOSH 1981</u>
SPECIES: Mouse		
5 or 20 mg/m ³ , (7 h/d) during major period of organogenesis)	No teratogenicity noted	Murray et al. 1979. <u>IN NIOSH 1981</u>
SPECIES: Chicken Eggs		
6.5 mg/m ³ (14 d) 0.2 to 0.3 MMD	Embryonic weights signifi- cantly reduced (P < 0.05), but survival rate and organ/body weight ratios for heart, liver and spleen were not. Serum lactic dehydrogenase activity of surviving embryos was signi- ficantly reduced. Hematocrit values normal	Hoffman and Campbell 1977. <u>IN NIOSH 1981</u>

7.5 Symptoms of Exposure

General symptoms of exposure found in most information sources have not been specifically referenced. Only those of a more specific or unusual nature have their sources indicated.

7.5.1 Inhalation.

1. Coughing, sneezing, tickling in nose and throat.
2. Rhinorrhea (USDHEW 1977).
3. Reflex increase in respiratory rate, and diminution of depth (NIOSH 1974).
4. Lacrimation (USDHEW 1977).
5. Conjunctivitis (USDHEW 1977).
6. Changes in mucociliary function (Newhouse et al. IN NIOSH 1981).
7. Epitaxis (USDHEW 1977).
8. Various lesions of the skin (Doc. TLV 1981)
9. Mouth becomes sore (NIOSH/OSHA 1981).
10. Mild to severe erosion of dental enamel and loss of tooth substance (USDHEW 1977).
11. Teeth may become sensitive to temperature extremes (NIOSH 1974).
12. Discolouration of teeth (Proctor 1978).
13. Inflammation of upper respiratory tract (Sax 1979).
14. Frequent respiratory infections (USDHEW 1977).
15. Tracheobronchitis (Doc. TLV 1981).
16. Residual bronchiectasis (NIOSH 1974).
17. Chronic bronchitis (Sax 1979).
18. Pulmonary fibrosis (NIOSH 1974).
19. Emphysema (USDHEW 1977).
20. Chemical pneumonitis.
21. A single overexposure may cause laryngeal, tracheobronchial and pulmonary edema (USDHEW 1977).
22. Acclimatization to subjective effects of inhalation may occur (NIOSH 1974).
23. Sensitization to the effects of sulphuric acid may occur (NIOSH 1974).

7.5.2 Ingestion.

1. Brown staining of teeth (AAR 1981).
2. Mucous membrane burns, circumoral burns (Sax 1979).
3. Inability to swallow, or pain upon swallowing (ITII 1981).

4. Abdominal pain (ITII 1981).
5. Stomatitis (Doc. TLV 1981).
6. Digestive disturbances (USDHEW 1977).
7. Respiratory distress (secondary to epiglottal edema) (Sax 1979).
8. Hematemesis (ITII 1981).
9. Perforation of gastrointestinal tract (AAR 1981).
10. Residual sequelae include gastrointestinal scarring and strictures (Sax 1979).
11. Shock (Sax 1979).
12. Albumin, blood and casts in urine (AAR 1981).
13. Anuria (AAR 1981).
14. Renal failure (Sax 1979).
15. Death (GE 1980).

7.5.3 Skin Contact.

1. Repeated contact with dilute solutions may cause dermatitis (NIOSH 1974).
2. Acid burns of eyelids and surrounding parts of face will produce cicatrization (NIOSH 1974).
3. In concentrated form, destruction of epidermis and subcutaneous tissue causing necrosis, charring, burning of skin (Sax 1979).
4. Ulceration.
5. If large area of skin exposed, shock, collapse and symptoms similar to those seen in severe burn cases (Sax 1979).
6. Pulmonary edema from inhalation of the liquid and subsequent pulmonary fibrosis, residual bronchitis and pulmonary emphysema when sprayed with fuming sulphuric acid (Goldman and Hill 1953. IN NIOSH 1974).

7.5.4 Eye Contact.

1. Burning sensation in eyelids and eyes, with ulceration of the tissues (Lefèvre 1980).
2. Corneal necrosis (AAR 1981).
3. Blindness (concentrated acid) (NIOSH/OSHA 1981).

7.6 Human Toxicity to Decay or Combustion Products

Sulphuric acid is not flammable in fire (AAR 1981). On reaction, it may evolve flammable hydrogen (AAR 1981). Sulphur oxides can result from decomposition and from oxidizing reactions of sulphuric acid (GE 1980). Toxic gases and vapours (such as

sulphuric acid fume and sulphur dioxide) may be released when sulphuric acid decomposes (NIOSH/OSHA 1981).

7.6.1 Hydrogen and Sulphur Dioxide. Hydrogen is a colourless, tasteless, odourless gas which when mixed with air forms explosive mixtures. With an ignition source, the air-gas mixture burns with a very hot, nonluminous flame (i.e. difficult to see).

In the absence of air and other oxidizing materials, hydrogen acts as an asphyxiant by displacing air. Persons breathing an oxygen-deficient atmosphere (< 18 percent oxygen) become cyanotic, suffer impaired alertness and muscular coordination, followed by collapse and death if exposure is prolonged. No TLV® for hydrogen is given (Doc. TLV 1981).

Sulphur dioxide is a colourless, nonflammable gas with a strong suffocating odour. It is extremely irritating to the eyes and respiratory tract (Merck 1976). The irritation of the mucous membranes probably results from the action of sulphurous acid formed when the highly soluble gas dissolves. Short-term exposure causes bronchoconstriction. The magnitude of the response is dose-related. The TLV® for sulphur dioxide is 2 ppm (8 h-TWA) and 5 ppm (STEL) (Doc. TLV 1981).

8 CHEMICAL COMPATIBILITY

8.1 Compatibility of Sulphuric Acid With Other Chemicals and Chemical Groups

SPECIFIC CHEMICAL OR CHEMICAL GROUP	HEAT GENERATION	FIRE	EXPLOSION	FORMATION OF VIOLENT POLYMERIZATION	FORMATION OF FLAMMABLE GASES	DECOMPOSITION	FORMATION OF TOXIC FUMES	PRESSURIZATION OF SUBSTANCES IN CLOSED VESSELS	SOLUBILIZATION	VIOLENT REACTION	NON-HAZARDOUS REACTION	SPECIFICS	REFERENCE
<u>GENERAL</u> Water	•						•	•					Bretherick 1979
Heat					•								Sax 1979
<u>SPECIFIC CHEMICALS</u>													
Acetaldehyde			•										Bretherick 1979
Acetic Anhydride	•						•						NFPA 1978
Acetone Cyanhydrin		•					•						NFPA 1978
Acetonitrile	•						•						NFPA 1978
Acrolein	•						•						NFPA 1978
Acrylonitrile								•	May yield unstable mixture				Bretherick 1979
Allyl Alcohol	•						•						NFPA 1978
Allyl Chloride	•		•				•						NFPA 1978
2-Aminoethanol	•						•						NFPA 1978
Aqueous Ammonia	•						•						NFPA 1978

8.1 Compatibility of Sulphuric Acid With Other Chemicals and Chemical Groups (Cont'd)

SPECIFIC CHEMICAL OR CHEMICAL GROUP	HEAT GENERATION	FIRE	EXPLOSION	FORMATION OF VIOLENT POLYMERIZATION	FORMATION OF FLAMMABLE GASES	DECOMPOSITION OF GREATER TOXICITY	FORMATION OF TOXIC FUMES	PRESSURIZATION OF VESSELS	SOLUBILIZATION IN CLOSED	VIOLENT REACTION	NON-HAZARDOUS REACTION	SPECIFICS	REFERENCE
Ammonium Iron (III) Sulphate Dodecahydrate	•	•											Bretherick 1979
Ammonium Triperchromate			•				•						NFPA 1978
Aniline	•						•						NFPA 1978
Benzyl Alcohol			•	•									Bretherick 1979
Bromine Penta- fluoride		•								•			Bretherick 1979
n-Butyraldehyde	•						•						NFPA 1978
Cesium Acetylene Carbide		•										Burns in sulphuric acid	NFPA 1978
Chlorine Tri- fluoride										•			NFPA 1978
1-Chloro-2,3- epoxypropane										•			Bretherick 1979
Chlorosulphonic Acid	•						•						NFPA 1978
Copper					•							Forms sulphur dioxide	Bretherick 1979
Cuprous Nitride										•			NFPA 1978

8.1 Compatibility of Sulphuric Acid With Other Chemicals and Chemical Groups (Cont'd)

SPECIFIC CHEMICAL OR CHEMICAL GROUP	HEAT GENERATION	FIRE	EXPLOSION	FORMATION OF VIOLENT REACTION	FORMATION OF FLAMMABLE GASES	DECOMPOSITION	POLYMERIZATION	FORMATION OF TOXIC FUMES	PRESSURIZATION OF VESSELS	SOLUBILIZATION	VIOLENT REACTION	NON-HAZARDOUS REACTION	SPECIFICS	REFERENCE
2-Cyano-2-propanol	•							•						Bretherick 1979
Cyclopentadiene		•	•											Bretherick 1979
Cyclopentanone Oxime													Causes eruptions	Bretherick 1979
1,3-Diazidobenzene		•	•										Mild explosion	Bretherick 1979
Diisobutylene	•							•						NFPA 1978
ρ -Dimethylaminobenzaldehyde	•		•											Bretherick 1979
Epichlorohydrin													•	NFPA 1978
Ethylene Cyanohydrin													•	NFPA 1978
Ethylene Diamine	•							•						NFPA 1978
Ethylene Glycol	•							•						NFPA 1978
Ethylenimine	•							•						NFPA 1978
Hexalithium disilicide		•											Incandescens and yields silicon hydrides which ignite	Bretherick 1979
Hydrochloric Acid	•							•						NFPA 1978

8.1 Compatibility of Sulphuric Acid With Other Chemicals and Chemical Groups (Cont'd)

SPECIFIC CHEMICAL OR CHEMICAL GROUP	HEAT GENERATION	FIRE	EXPLOSION	VIOLENT POLYMERIZATION	VIOLENT DECOMPOSITION	FORMATION OF FLAMMABLE GASES	FORMATION OF TOXIC FUMES	PRESSURIZATION OF VESSELS	SOLUBILIZATION	VIOLENT REACTION IN CLOSED	NON-HAZARDOUS REACTION	SPECIFICS	REFERENCE
Hydrofluoric Acid	•					•						NFPA 1978	
Hydrogen Peroxide		•								Loud but non-shattering explosion		Bretherick 1979	
Isoprene	•					•						NFPA 1978	
Mercuric Nitride		•										NFPA 1978	
Mesityl Oxide	•					•						NFPA 1978	
Nitrobenzene		•	•							Yields hydrogen if acid is added to nitrobenzene		Bretherick 1979	
<i>m</i> -Nitrobenzene-sulphonic Acid	•	•										Bretherick 1979	
Nitromethane	•	•								Susceptible to initiation by a detonator		Bretherick 1979	
N-Nitromethylamine		•		•								Bretherick 1979	
<i>p</i> -Nitrotoluene				•				•				Bretherick 1979	
Pentasilver Trihydroxydiamidophosphate		•										NFPA 1978	

8.1 Compatibility of Sulphuric Acid With Other Chemicals and Chemical Groups (Cont'd)

SPECIFIC CHEMICAL OR CHEMICAL GROUP	HEAT GENERATION	FIRE	EXPLOSION	FORMATION OF POLYMERIZATION	VIOLENT POLYMERIZATION	DECOMPOSITION OF FLAMMABLE GASES	FORMATION OF TOXIC FUMES	PRESSURIZATION OF VESSELS	SOLUBILIZATION	VIOLENT REACTION	NON-HAZARDOUS REACTION	SPECIFICS	REFERENCE
Phosphorus	•												Bretherick 1979
Phosphorous Isocyanate													NFPA 1978
Potassium		•											Bretherick 1979
Potassium t-Butoxide		•											NFPA 1978
Potassium Chlorate		•	•										NFPA 1978
Potassium Permanganate			•										NFPA 1978
β -Propiolactone	•						•						NFPA 1978
Propylene Oxide	•						•						NFPA 1978
Pyridine	•						•						NFPA 1978
Rubidium Acetylene Carbide		•										Burns with sulphuric acid	NFPA 1978
Sodium		•										Anhydrous acids react slowly, while aqueous acids react explosively	Bretherick 1979
Sodium Carbonate											•		NFPA 1978

8.1 Compatibility of Sulphuric Acid With Other Chemicals and Chemical Groups (Cont'd)

SPECIFIC CHEMICAL OR CHEMICAL GROUP	HEAT GENERATION	FIRE	EXPLOSION	FORMATION OF VIOLENT POLYMERIZATION	DECOMPOSITION OF TOXIC SUBSTANCES	FORMATION OF FLAMMABLE GASES	FORMATION OF PRESSURIZATION IN CLOSED VESSELS	SOLUBILIZATION	VIOLENT REACTION	NON-HAZARDOUS REACTION	SPECIFICS	REFERENCE
Sodium Chlorate	•	•										NFPA 1978
Sodium Hydroxide	•					•		•				NFPA 1978
Styrene Monomer	•					•						NFPA 1978
Vinyl Acetate	•					•						NFPA 1978
Zinc Chlorate	•	•										NFPA 1978
Zinc Iodide								•				Bretherick 1979
<u>CHEMICAL GROUPS</u>												
Metalacetylides or Carbides		•										Bretherick 1979
Organic Acids	•			•								EPA-600/2- 80-076
Alcohols & Glycols	•			•								EPA-600/2- 80-076
Aldehydes	•			•								EPA-600/2- 80-076
Amides	•			•					Forms nitrogen oxides			EPS-600/2- 80-076
Amines	•			•					Forms nitrogen oxide			EPA-600/2- 80-076

8.1 Compatibility of Sulphuric Acid With Other Chemicals and Chemical Groups (Cont'd)

SPECIFIC CHEMICAL OR CHEMICAL GROUP	HEAT GENERATION	FIRE	EXPLOSION	FORMATION OF TOXIC GASES	VIOLENT POLYMERIZATION	FORMATION OF FLAMMABLE GASES	DECOMPOSITION	FORMATION OF TOXIC FUMES	PRESSURIZATION OF VESSELS	GREATER TOXICITY	SOLUBILIZATION	VIOLENT REACTION	NON-HAZARDOUS REACTION	SPECIFICS	REFERENCE
Azo Compounds	•	•			•	•							Evolves nitrogen or nitrogen oxide. Can decompose explosively	EPA-600/2-80-076	
Carbamates	•					•							Can generate nitrogen and sulphur oxides	EPA-600/2-80-076	
Caustics	•								•					EPA-600/2-80-076	
Cyanides			•			•								EPA-600/2-80-076	
Dithiocarbamates	•	•	•		•								Evolves carbon disulphide which may be ignited by the heat of decomposition	EPA-600/2-80-076	
Esters	•	•			•								Ignition of more flammable esters may occur	EPA-600/2-80-076	
Ethers	•	•											Heat generated from oxidation may ignite more flammable ethers	EPA-600/2-80-076	

8.1 Compatibility of Sulphuric Acid With Other Chemicals and Chemical Groups (Cont'd)

SPECIFIC CHEMICAL OR CHEMICAL GROUP	HEAT GENERATION	FIRE	EXPLOSION	FORMATION OF VIOLENT POLYMERIZATION	FORMATION OF FLAMMABLE GASES	DECOMPOSITION OF GREATER TOXIC SUBSTANCES	PRESSURIZATION OF VESSELS	SOLUBILIZATION	VIOLENT REACTION IN CLOSED	NON-HAZARDOUS REACTION	SPECIFICS	REFERENCE
Fluorides	•				•						Can evolve hydrogen fluoride which is toxic and corrosive	EPA-600/2-80-076
Aromatic Hydrocarbons	•	•									May generate sufficient heat to ignite the mixture	EPA-600/2-80-076
Halogenated Organics	•			•	•						Can give off hydrogen chloride and phosgene	EPA-600/2-80-076
Isocyanates	•				•						Yields carbon dioxide or nitrogen oxides	EPA-600/2-80-076
Ketones	•	•			•							EPA-600/2-80-076
Mercaptans	•		•		•						Can form hydrogen sulphide or sulphur dioxide	EPA-600/2-80-076
Alkali and Alkaline Earth Metals		•	•	•						•	Hydrogen gas can be generated on contact	EPA-600/2-80-076
Metals	•		•								Evolves hydrogen	EPA-600/2-80-076

8.1 Compatibility of Sulphuric Acid With Other Chemicals and Chemical Groups (Cont'd)

SPECIFIC CHEMICAL OR CHEMICAL GROUP	HEAT GENERATION	FIRE	EXPLOSION	FORMATION OF VIOLENT POLYMERIZATION	FORMATION OF FLAMMABLE GASES	DECOMPOSITION OF TOXIC FUMES	PRESSURIZATION IN CLOSED VESSELS	SOLUBILIZATION	VIOLENT REACTION	NON-HAZARDOUS REACTION	SPECIFICS	REFERENCE
Nitrides	•	•						•			Generates ammonia gas	EPA-600/2-80-076
Nitriles	•				•							EPA-600/2-80-076
Nitro Compounds	•				•			•			Produces nitrogen oxide	EPA-600/2-80-076
Nitroaryl Bases							•	•				Bretherick 1979
Unsaturated Aliphatics	•	•										EPA-600/2-80-076
Saturated Aliphatics	•										Yields carbon dioxide	EPA-600/2-80-076
Organic Peroxides	•	•		•								EPA-600/2-80-076
Phenols and Cresols	•											EPA-600/2-80-076
Organophosphates	•				•							EPA-600/2-80-076
Permanganates		•										Bretherick 1979
Sulphides			•		•			•			Can form hydrogen sulphide or sulphur dioxide	Bretherick 1979

8.1 Compatibility of Sulphuric Acid With Other Chemicals and Chemical Groups (Cont'd)

SPECIFIC CHEMICAL OR CHEMICAL GROUP	HEAT GENERATION	FIRE	EXPLOSION	FORMATION OF TOXIC SUBSTANCES	VIOLENT POLYMERIZATION	DECOMPOSITION OF FLAMMABLE GASES	FORMATION OF POLYMERIZATION	FORMATION OF TOXIC FUMES	PRESSURIZATION OF VESSELS	SOLUBILIZATION	VIOLENT REACTION	NON-HAZARDOUS REACTION	SPECIFICS	REFERENCE
Epoxides	•	•	•										EPA-600/2-80-076	
Combustible Materials	•	•		•	•								EPA-600/2-80-076	
Explosives	•	•											EPA-600/2-80-076	
Polymerizable Compounds	•		•		•								EPA-600/2-80-076	
Reducing Agents	•	•	•						•				EPA-600/2-80-076	

8.2 Compatibility of Oleum with Other Chemicals and Chemical Groups

The compatibility of oleum with various materials is expected to be similar to sulphuric acid as indicated in the previous Section. In addition, the following data were obtained.

A temperature increase and pressurization of closed vessels occurs when oleum is mixed with acetic acid, acetic anhydride, acetonitrile, acrolein, acrylic acid, acrylonitrile, allyl alcohol, allyl chloride, 2-aminoethanol, ammonia (aqueous), aniline, n-butyraldehyde, cresol, cumene, dichloroethyl ether, diethylene glycol monomethyl ether, diisobutylene, epichlorohydrin, ethyl acetate, ethylene cyanohydrin, ethylene diamine, ethylene glycol, ethyleneimine, glyoxal, hydrochloric acid, hydrofluoric acid, isoprene, isopropyl alcohol, mesityl oxide, methyl ethyl ketone, nitric acid, 2-nitropropane, β -propiolactone, propylene oxide, pyridine, sodium hydroxide, styrene, sulpholane, vinyl acetate, or vinylidene chloride (NFPA 1978) which may cause an explosion hazard (Sax 1979).

9 COUNTERMEASURES

9.1 Recommended Handling Procedures

The following procedures have been derived from a review of information found in the literature. To avoid any deviation from the intended meaning, the wording of the original source has been presented essentially unchanged - in so doing, it is recognized that there may be some discrepancies between different sources of information. These procedures should not be considered as Environment Canada's recommendations.

9.1.1 Fire Concerns. Sulphuric acid is a nonflammable liquid. In the concentrated form, it may cause combustible materials to ignite on contact. It reacts violently with water resulting in splattering, evolution of heat and release of an irritant mist. Contact with some metals can generate explosive hydrogen gas (GE 1980; NFPA 1978). Sulphur oxides can result from decomposition and from oxidizing reactions of sulphuric acid (GE 1980).

9.1.2 Fire Extinguishing Agents. Use water spray to cool containers involved in a fire to help prevent rupture (GE 1980).

Small fires: Dry chemical or CO₂.

Large fires: Water spray or fog.

Move containers from fire area if this can be done without risk (ERG 1980). Do not get water inside containers (EAG 1978).

9.1.3 Evacuation. The following are evacuation distances which appear in the literature for oleum, based on prevailing winds of 10 to 19 km/h (EAG 1978). Important parameters such as spill quantity, concentration level to which evacuation is suggested, and environmental conditions, may not be defined. Readers are advised to evaluate the use of these values with those derived from the methods to calculate hazard zones in Section 5.3 of this manual, which uses the above data.

Approximate Size of Spill	Distance to Evacuate from Immediate Danger Area	For Maximum Safety Downwind Evacuation Area Should Be
20 m ²	170 m (222 paces)	1,620 m long, 810 m wide
35 m ²	245 m (322 paces)	2,430 m long, 1,620 m wide
55 m ²	295 m (398 paces)	3,240 m long, 1,620 m wide
75 m ²	355 m (465 paces)	3,240 m long, 1,620 m wide

In the event of an explosion, the minimum safe distance from flying fragments is 600 m in all directions.

9.1.4 Spill Actions.

9.1.4.1 General. Stop or reduce discharge of material if this can be done without risk. Eliminate all sources of ignition. Avoid skin contact and inhalation (GE 1980).

Vapour suppression and/or containment of sulphuric acid or oleum spills may be accomplished by using the following recommended materials (Braley 1982): polycarbonate, anhydrous sodium sulphate, polyacrylamide, polymethyl methacrylate, silicone oil, expanded perlite and sulphonated oil.

9.1.4.2 Spills on land. For small spills, cover the contaminated area with sodium bicarbonate or a mixture of soda ash/slaked lime (50/50) and mix. Shovel the neutralized residues into containers for disposal. If neutralizing agent is not available, cover the area with sand or earth to absorb the liquid and shovel into containers for disposal (GE 1980; Ashland MSDS 1977). Difficulty may be encountered in neutralizing large spills with solid agents unless a good means of mixing is available. The addition of neutralizing solutions or slurries may be considered (CCPA 1982).

For large spills, contain if possible by forming dykes or use of lagoons. Pump liquid in salvage tank for recovery. The remaining liquid can be neutralized with sodium bicarbonate or soda ash/slaked lime mixture or absorbed on sand or earth. The residue can then be shoveled into containers for disposal (GE 1980; Ashland MSDS 1977).

Application of fly ash or cement powder to absorb the liquid bulk should also be considered (EPA 670/2-75-042). Sorbents such as activated carbon, Dowex, Amberlite, DeSal Process mixture and Universal Sorbent Material (USM) may also be used (CG-D-38-76).

9.1.5 Cleanup and Treatment.

9.1.5.1 Spills in water. Sodium bicarbonate is recommended as an in situ neutralizing agent to avoid overdosing, resulting in too great a pH increase as well as the lower heat of reaction (CG-D-16-77). Other treating agents that may be considered for neutralization are: calcined dolomite (where overrun of alkali can be tolerated), calcium oxide (where overrun of alkali can be tolerated), calcium hydroxide (where gypsum forms and slows neutralization), and sodium carbonate (where Ca and Mg content are to be kept low) (CG-D-38-76).

9.1.5.2 General. For treatment of contaminated water, gravity separation of solids followed by neutralization with a mixture of soda ash and lime (50/50) is recommended. Care should be taken not to create a violent reaction by fast base addition (EPA 600/2-77-227).

9.1.6 Disposal. Waste sulphuric acid must never be discharged directly into sewers or surface waters. Following neutralization either at the spill site or at a waste management facility, the resultant sludge can be disposed of at a secure landfill.

9.1.7 Protective Measures. For entry into a situation where the spilled material and its characteristics are unknown, self-contained breathing apparatus and a totally encapsulated chemical suit should be worn.

If the spilled material is known to be sulphuric acid:

- Response personnel should be provided with and required to use impervious clothing, gloves, face shields (20 cm minimum), and other appropriate clothing necessary to prevent any possibility of repeated or prolonged skin contact with liquid sulphuric acid or its solutions (NIOSH/OSHA 1981).
- Close fitting, "mono goggles" type of safety glasses with plastic frames are recommended where splashing in the eyes may occur (CIL). Splash-proof or chemical safety goggles should also be considered (GE 1980; NIOSH/OSHA 1981).
- Rubber gloves, aprons, boots and suits are recommended to avoid body contact with this acid (GE 1980). Gauntlet-type, acid resistant gloves may also be used (CIL).
- PVC has been recommended as a chemical suit material (good resistance) for protection against sulphuric acid (EE-20). Vinyl has also been recommended as a suitable material (CCPA 1982).
- Nonimpervious clothing which becomes contaminated with sulphuric acid should be removed immediately and not reworn until the sulphuric acid is removed from the clothing (NIOSH/OSHA 1981).
- Eyewash fountains and safety showers with deluge type heads should be readily available to areas of use and spill situations (GE 1980).

The following is a list of the minimum respiratory protection recommended for personnel working in areas where sulphuric acid is present (NIOSH/OSHA 1981).

Condition	Minimum Respiratory Protection* Required Above 1 mg/m ³
Particulate concentration 50 mg/m ³ or less	A gas mask with a chin-style or a front- or back-mounted acid gas canister with a high efficiency particulate filter.
100 mg/m ³ or less	A high efficiency particulate filter respirator with a full facepiece. Any supplied-air respirator with a full facepiece, helmet, or hood. Any self-contained breathing apparatus with a full facepiece.
Greater than 100 mg/m ³ or entry and escape from unknown concentrations	A Type C supplied-air respirator with a full facepiece operated in pressure-demand or other positive pressure mode or with a full facepiece, helmet, or hood operated in a continuous-flow mode. Self-contained breathing apparatus with a full facepiece operated in pressure-demand or other positive pressure mode. A combination respirator which includes a Type C supplied-air respirator with a full facepiece operated in pressure-demand or other positive pressure or continuous-flow mode and an auxiliary self-contained breathing apparatus operated in pressure-demand or other positive pressure mode.
Fire Fighting	Self-contained breathing apparatus with a full facepiece operated in pressure-demand or other positive pressure mode.
Escape	A gas mask with a chin-style or a front- or back-mounted acid gas canister with a high efficiency particulate filter. Any escape self-contained breathing apparatus.

*Only NIOSH-approved or OSHA-approved equipment should be used.

9.1.8 Special Precautions. Sulphuric acid in carboys or drums should be stored in clean, ventilated storage areas having acid-resistant floors with good drainage. Keep out

of direct sunlight; do not store above 32°C. Storage facilities should be separated from metallic powders, chromates, chlorates, nitrates, carbides, oxidizables, etc. Soda ash, sand or lime should be kept in general storage or work areas for emergency use. Protect containers against physical damage. Glass bottles need extra protection. Sulphuric acid is highly corrosive to most metals especially below 77 percent H₂SO₄. Do not add water to concentrated acid. Use nonsparking tools and vapour-proof type electrical fixtures (GE 1980).

9.2 Specialized Countermeasures Equipment, Materials or Systems

The following items are taken from a previous study (Dillon 1982) and should not be considered to be the only suitable specialized countermeasures equipment, materials or systems available. More details on the specifications, performance and availability of these items can be found in the referenced study.

Leak Plugging:	Plug N'Dike™
Land Containment:	Bentonite Soil Sealants
Temporary Storage:	Portable Collection Bag System
Treating Agents:	Hazorb (sorbent)

10 PREVIOUS SPILL EXPERIENCE

10.1 Tanker Truck Spill (PC SE 1982; Summary Report 1981)

A tanker truck carrying approximately 18,000 kg of concentrated sulphuric acid overturned and spilled about 95 percent of its contents off a roadway. An area of approximately 1,150 m² (230 m long by 5 m wide) was contaminated by the spill. No environmental hazards were suspected due to the frozen ground conditions at that time of year and the area being remote to family dwellings. A nearby creek was not affected.

Response crews arrived at the spill site, wearing PVC acid suits, rubber boots and gloves, but no respiratory protection. Lime was shipped to the site and applied over the contaminated area. The surface material was then excavated and hauled to a nearby landfill site. Soil samples were taken in the excavated area; the test results showed some residual acid concentrations in the soil.

Additional lime was applied to the area and mixed with the soil. More than 300 bags (45 kg/bag) of lime were used during cleanup procedures. The soil was then excavated to a depth of 1 m and hauled away to a nearby construction site, where it was incorporated into the road bed construction. The spill site was backfilled with clean soil.

10.2 Storage Tank Spill (PC EPS 1982; PC MWC 1982)

A storage tank, holding 92% sulphuric acid solution, started to leak its contents when the steel plug at the bottom of the tank corroded and the acid dissolved the flange. Approximately 10,000 L of sulphuric acid spilled on the ground. Company personnel dug two holes, about 1.5 m deep and 1.8 m across, to contain the acid. No remedial action was taken for 2 days due to a long holiday weekend.

On the third day, cleanup crews arrived at the spill site. Lime was carefully added on the perimeter of the holes, to partially neutralize the acid and to form an inner liner to prevent seepage. The acid was pumped into a tank and further neutralized with additional lime to pH 7.0. The resultant sludge was disposed of into a nearby landfill. The contaminated soil was then dug to a depth of about 0.5 m, mixed with lime and finally graded to its original surface condition. Approximately 12,000 kg of lime were used during cleanup and treatment.

No environmental effects resulted from the spill. The heavy clay soil in the area prevented the acid from migrating further underground. It should be noted, however, that the company where the spill occurred was neither prepared nor equipped to handle such a spill.

11 ANALYTICAL METHODS

The general approach adopted for each of the Priority Chemicals was as follows.

Methods have been documented here for analyses of samples from air, water and soil in a normally equipped chemical laboratory remote from the spill site. Customary sources of standard or recommended analytical methods were consulted, and outlines are presented for each chemical. These sources included publications of the U.S. National Institute for Occupational Safety and Health (NIOSH), the U.S. Environmental Protection Agency (EPA), the American Water Works Association (AWWA), the American Society for Testing and Materials (ASTM), and the American National Standards Institute (ANSI).

If the standard or recommended methods were judged to be reliable and specific enough for the analysis of environmental and materials samples from spill sites and if they do not require highly specialized laboratory equipment, no additional methods were sought.

If especially simple, reliable tests (e.g. commonly used industrial methods) were found, they have been presented as well.

11.1 Quantitative Methods for the Detection of Sulphuric Acid in Air

11.1.1 Titration (NIOSH 1974). This method may be used to determine from 0.56 l to 2.577 mg/m³ (0.14 to 0.64 ppm) sulphuric acid in air. The precision is ± 0.082 mg/m³ for this method.

A filter unit consisting of a mixed cellulose ester membrane filter, 0.8 μ m pore size and 37 mm diameter, held in place by a cellulose backup pad in a polystyrene 37 mm three-piece cassette filter holder is used. A sample of 180 L is collected at a rate of 1.5 L/min. The filter must be placed in a clean screw cap bottle within 1 hour of collection. The filter is extracted with isopropyl alcohol which is then titrated with barium perchlorate using thordin as the indicator. Most metal ions interfere by forming coloured complexes with the thordin indicator. There is an advantage to this method in that the sampling device is small, portable and involves no liquids. The titration is rapid and simple. The method does not distinguish between sulphuric acid and other sulphates. Acidity should also be measured to determine the fraction of sulphate that is in the acid form.

Alternately, sodium hydroxide is used for titration (Patton 1963). The indicators used are either bromophenol blue or phenolphthalein. The method is simple,

direct and easy but is not specific for sulphuric acid. It assumes that there are no other acids or bases present.

11.1.2 Ion Chromatography (Hussar 1978). Concentrations as low as 0.02 $\mu\text{g/mL}$ sulphate in the extracting solution may be determined.

Samples are collected using dichotomous samplers. The filters are extracted with perchloric acid using ultrasound. A 5 mL aliquot of the extract is spiked with a 1:1 mixture of standard eluent. This eluent contains 0.003 M sodium bicarbonate and 0.0024 M sodium carbonate. A suitable volume is injected into an ion chromatograph. Peak areas and retention times are used to identify and quantify species of interest relative to standards. This method is useful over a wide range of concentrations.

11.1.3 Flame Photometric Detection (EPA-600/52-81-013). Total sulphuric acid may be determined in air at concentrations as low as 0.26 $\mu\text{g/m}^3$ (0.07 ppb) using a sulphuric acid analyzer equipped with a flame photometric detector.

A volume of air is drawn into the sulphuric acid analyzer and is mixed with moist air followed by hydrogen chloride gas (dilute). The sample gas is passed through a heating chamber, rapidly heated and then condensed on the walls of a collector chamber. The flame photometric detector is connected directly to the downstream side of the collector tube and receives a continuous supply of hydrogen gas (140 mL/min) and sample gas (200 mL/min). The analyzer uses hydrogen chloride to prevent contaminants such as ammonia, sulphur dioxide, and ammonium sulphates from interfering with the analysis. The method is open to further development and evaluative testing.

11.2 Qualitative Method for the Detection of Sulphuric Acid in Air

The sample is collected as in Section 11.1.1. A 1.0 mL volume of sample is acidified with 6 M hydrochloric acid followed by 1 mL of 1 M barium chloride solution. A finely divided white precipitate indicates the presence of the sulphate ion (Welcher 1955).

11.3 Quantitative Methods for the Detection of Sulphuric Acid in Water

11.3.1 Gravimetric (ASTM 1979; AWWA 1976). The range of concentrations which can be analyzed gravimetrically is 20 to 100 ppm sulphate in water. This may be adapted to higher or lower ranges depending on sample size. Precision is ± 1 percent. This method measures the sulphate ion; thus, other sulphates, e.g. natural gypsum, present are also measured.

The sample is filtered if it is turbid. The pH is adjusted to the methyl orange end with 10 percent hydrochloric acid and a 10 mL excess of hydrochloric acid is added.

The solution is heated and an 11.8 percent solution of barium chloride is added until precipitation is complete. The precipitated barium sulphate is filtered, washed, and ignited to consume all the carbon. If silicon is present, concentrated hydrofluoric acid is added to expel it as SiF_4 . The residue is re-ignited, cooled and weighed. This method is applicable to all types of water but it is tedious and time consuming. Calcium interferes with the analysis since it is strongly coprecipitated.

11.3.2 Turbidimetric (ASTM 1979; AWWA 1976). This method may be used to determine from 10 to 100 ppm sulphate ion in water with a precision of ± 5 percent or 2 mg/L, whichever is greater.

The sample is filtered if it is turbid and the temperature is adjusted to between 15 and 30°C. A conditioning reagent is added to stabilize the solution and remove interferences. It is prepared by mixing 50 mL glycerol with a solution containing 30 mL concentrated hydrochloric acid, 300 mL distilled water, 100 mL 95 percent ethyl or isopropyl alcohol and 75 g sodium chloride. A 100 mL sample aliquot is mixed with 5.0 mL conditioning reagent. While the solution is being stirred, barium chloride crystals are added and stirring continues for 1 minute. The sulphate ion is converted to a barium sulphate suspension. The turbidity is determined using a photoelectric colourimeter or a spectrophotometer and compared to a standard curve. Insoluble suspended matter and coloured components interfere. This method is suitable for rapid routine or control tests where extreme accuracy and precision are not required.

11.4 Qualitative Method for the Detection of Sulphuric Acid in Water

The sample is collected as in Section 11.3.1. A 1 mL volume of sample is acidified with 6 M hydrochloric acid. This is followed by 1 mL of 1 M barium chloride solution. A finely divided white precipitate indicates the presence of the sulphate ion (Welcher 1955).

11.5 Quantitative Methods for the Detection of Sulphuric Acid in Soil

11.5.1 Ion Chromatography (Dionex 1978). The detection limit for sulphate is 3 ppm in the lithium chloride extracting solution. The precision is ± 3 percent. As the sulphate ion is measured, this method then yields the total amount of sulphate present.

A 5 g sample of soil is collected and extracted with 0.001 M lithium chloride solution, centrifuged and filtered. The sample solution is injected into an ion chromatograph and quantitated using retention times and peak heights. The method is simple but requires specialized equipment.

11.5.2 Gravimetric (Hesse 1972). The range of concentrations which can be analyzed gravimetrically is 20 to 100 ppm sulphate in the extract. The size of the soil sample used for extraction may be decreased if a high concentration of sulphuric acid is present.

A soil sample of known weight is extracted with a solution of sodium acetate and acetic acid buffered to pH 4.5. One part soil is shaken with five parts extractant for 30 minutes and then centrifuged or filtered. A suitable aliquot is taken. The pH is adjusted with 1 M hydrochloric acid to the methyl orange end point and an excess of 1 mL hydrochloric acid is added. Barium chloride is added with heating and shaking. The liquid is removed and the barium sulphate precipitate dried by heating overnight at 105°C. It is cooled and weighed. This method is applicable to samples containing large amounts of sulphuric acid. The method is accurate and precise but is tedious and slow. It is not suitable for situations where the results of the analysis are needed quickly.

11.5.3 Turbidimetric (Hesse 1972). Concentrations of 2 to 10 ppm sulphate in the extracting solution may be analyzed using this method. The range may be varied by varying the amount of soil used.

A soil sample of known weight is extracted with a solution of sodium acetate and acetic acid buffered to pH 4.5. One part soil is shaken with five parts extractant for 30 minutes and then centrifuged or filtered. Iron (III) chloride solution is added to a suitable aliquot of soil extract. This is followed by sodium hydroxide added dropwise with shaking. The solution is filtered or centrifuged, acidified with acetic acid and diluted to volume. Barium chloride is added to a suitable aliquot of the clear extract and mixed. Gum acacia solution is added, the extract is diluted to volume and mixed. The turbidity is measured with a spectrophotometer at 490 nm or with a blue filter. The calibration curve should cover the range 0 to 10 $\mu\text{g}/\text{cm}^3$ sulphur. Calcium interferes with the analysis since calcium sulphate is coprecipitated. This method is suitable for rapid routine or control tests where extreme accuracy and precision are not required.

11.6 Qualitative Method for the Detection of Sulphuric Acid in Soil

One sample is collected and extracted as in Section 11.5.1. A 1 mL volume of sample is acidified with 6 M hydrochloric acid followed by 1 mL of 1 M barium chloride solution. A finely divided white precipitate indicates the presence of the sulphate ion (Welcher 1955).

12 REFERENCES AND BIBLIOGRAPHY

12.1 References

AAR 1981: BDM Corporation, The AAR Hazardous Materials Data Base, Prepared for the Association of American Railroads, Parts I and II, McLean, Virginia. (May, 1981).

AAR 1982: The Association of American Railroads, Private Communication. (1982).

ASA 1978: Allied Chemical Corporation, Sulphuric Acid, Morristown, New Jersey. (1978).

Ashland MSDS 1977: Ashland Chemical Company, Material Safety Data Sheet - Sulphuric Acid 66°Be, Columbus, Ohio. (November, 1977).

ASS: Atlas Steel, Atlas Stainless Steels, Toronto, Ontario. Not dated.

ASTM 1979: American Society for Testing and Materials, Annual Book of ASTM Standards, Part 31: Water, ASTM, Philadelphia, Pennsylvania, DS16-68. (1979).

ASTM 1980: American Society for Testing and Materials, Compilation of Odor and Taste Threshold Values Data, ASTM, Philadelphia, Pennsylvania, ASTM Data Series DS-48A. (1980).

AWWA 1976: American Water Works Association, Standard Methods for the Examination of Water and Wastewater, 14th Edition, American Public Health Association, Washington, D.C., pp. 493-496. (1976).

Braley 1982: Braley, G.K., "Treatment of Sulphuric Acid Spillages", Imperial Chemical Industries, Mond Division, Cheshire, England, Proceedings of the 1982 National Conference on Control of Hazardous Material Spills, Milwaukee, Wisconsin. (April, 1982).

Bretherick 1979: Bretherick, L., Handbook of Reactive Chemical Hazards, Second Edition, Butterworths, London, England. (1979).

CBG 1980: Southam Business Publications Ltd., "1981 Chemical Buyers' Guide", Canadian Chemical Processing, Vol. 64, No. 9, Don Mills, Ontario. (December, 1980).

CCP 1981: "Canada Strong in Sulphuric Acid", Canadian Chemical Processing, Vol. 65, No. 7, pp. 18-19. (October, 1981).

CCPA 1982: Canadian Chemical Producers Association, Private Communication. (1982).

CCR 1978: Department of Industry, Trade and Commerce, Canadian Chemical Register, Ottawa, Canada. (1978).

CDS 1967: National Association of Corrosion Engineers, Corrosion Data Survey, Houston, Texas. (1967).

CG-D-16-77: Drake, E. et al., A Feasibility Study of Response Techniques for Discharges of Hazardous Chemicals that Disperse Through the Water Column, U.S. Coast Guard, Washington, D.C., CG-D-16-77. (July, 1976).

CG-D-38-76: Bauer, W.H., Borton, D.N. et al., Agents, Methods and Devices for Amelioration of Discharge of Hazardous Chemicals on Water, Rensselaer Polytechnic Institute for the U.S. Coast Guard, Washington, D.C., CG-D-38-76. (August, 1975).

CHRIS 1978: U.S. Department of Transportation, Coast Guard, Chemical Hazards Response Information System (CHRIS), Washington, D.C. (1978).

CIL: Canadian Industries Limited, Sulphuric Acid, Willowdale, Ontario. Not dated.

Cities MSDS: Cities Service Company, Material Safety Data Sheet - Oleum, Atlanta, Georgia. Not dated.

Corpus 1981: Corpus Information Services Ltd., "Sulphuric Acid", Chemical Product Profiles, Don Mills, Ontario. (15 June 1981).

CRC 1980: Weast, R.C. (ed.), CRC Handbook of Chemistry and Physics, 60th Edition, Chemical Rubber Publishing Company, Cleveland, Ohio. (1980).

CSA 1976: Canadian Industries Limited, Sulphuric Acid, Montreal, Quebec. (1976).

DCRG 1978: Dow Chemical Company, Dow Chemical Resistance Guide for Dow Plastic Lined Piping Products, Midland, Michigan. (1978).

Dillon 1982: M.M. Dillon Ltd., Survey of Countermeasures Systems for Hazardous Material Spills, Prepared for Environment Canada, Ottawa, Canada. (In preparation, 1982).

Dionex 1978: Wetzel, R., Menear, J., Applications Note No. 8, Dionex Corp., Sunnyvale, California. (May, 1978).

Doc. TLV 1981: American Conference of Governmental Industrial Hygienists (ACGIH), Documentation of Threshold Limit Values, Fourth Edition, Cincinnati, Ohio. (1981).

Doull 1980: Doull, J., Klaassen, C.D., Amdur, M.O., Casarett's and Doull's Toxicology - The Basic Science of Poisons, Second Edition, Collier Macmillan Canada Inc., Toronto, Ontario. (1980).

Dow SA: Dow Chemical Company, Sulphuric Acid, Midland, Michigan. Not dated.

DPIMR 1981: "Sulphuric Acid", Dangerous Properties of Industrial Materials Report, Vol. 15, No. 5, pp. 80-83. (May/June, 1981).

DPPED 1967: DOM-X, DOM-X Plastic Pipe Engineering Data, Toronto, Ontario. (1967).

EAG 1978: U.S. Department of Transportation, Emergency Action Guide for Selected Hazardous Materials, U.S. D.O.T. Research and Special Programs Administration, Materials Transportation Bureau, Washington, D.C. (1978).

Ebara 1980: Ebara, T., "Sulphuric Acid Test on Rear", Ibaraki-ken Kogai Gijutsu Senta Nempo, Vol. 12, pp. 33-35. (1980).

Eco/Log 1981: "Cominco Moves to Reduce SO₂ Emissions, Clean Up Effluents", Eco/Log, Vol. 9, No. 44, pp. 2-3. (13 November 1981).

EE-20: Buchan, Lawton, Parent Ltd., A Survey of Self-Contained Breathing Apparatus and Totally-Encapsulated Chemical Protection Suits, Prepared for Environmental Protection Service, Environment Canada, Manuscript EE-20. Unpublished report. (1981).

Ellis 1967: Ellis, M.M., Detection and Measurement of Stream Pollution, Biology of Water Pollution, U.S. Dept. of Interior (FWPCA), pp. 129, 185. (1967).

EPA-440/9-75-009: Environmental Protection Agency, Supplement to Development Document: Hazardous Substances Regulations, Section 311 Federal Water Pollution Control Act, U.S. Environmental Protection Agency, Office of Water Planning and Standards, Washington, D.C., EPA-440/9-75-009. (November, 1975).

EPA-600/2-77-227: Huibregtse, K.R. et al., Manual for the Control of Hazardous Material Spills - Volume One - Spill Assessment and Water Treatment Techniques, U.S. Environmental Protection Agency, National Environmental Research Center, Cincinnati, Ohio, EPA-600/2-77-227. (November, 1977).

EPA-600/2-80-076: Hatayama, H.K., Chen, J.J., deVera, E.R., Stephens, R.D., Storm, D.L., A Method for Determining the Compatibility of Hazardous Wastes, Municipal Environmental Research Laboratory, Office of Research and Development, U.S. Environmental Protection Agency, Cincinnati, Ohio. (April, 1980).

EPA-600/52-81-013: Barden, J.D., Analysis System for Total Sulphuric Acid in Ambient Air - Development and Preliminary Evaluation, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, EPA-600/52-81-013. (May, 1981).

EPA-670/2-75-042: Pilie, R.J. et al., Methods to Treat, Control and Monitor Spilled Hazardous Materials, U.S. Environmental Protection Agency, National Environmental Research Center, Cincinnati, Ohio, EPA-670/2-75-042. (June, 1975).

ERG 1980: U.S. Department of Transportation, Hazardous Materials, 1980 Emergency Response Guidebook, U.S. Department of Transportation, Research and Special Programs Administration, Materials Transportation Bureau, Washington, D.C. (1980).

GE 1980: General Electric Company, Material Safety Data Sheets, Material Safety Information Services, Schenectady, New York. (October, 1980).

GF: GF Plastic Systems Inc., GF Plastic Systems, Santa Ana, California. Not dated.

GPP: Uniroyal, Guide to Polymer Properties, Uniroyal Inc., Mishawaka, Indiana. Not dated.

Hesse 1972: Hesse, P.R., A Textbook of Soil Chemical Analysis, Chemical Publishing Co. Inc., New York, New York, p. 321. (1972).

HIS 1969: Hydraulic Institute, Hydraulic Institute Standards, 12th Edition, New York, New York. (1969).

Hussar 1978: Hussar, R.B. et al. (ed.), Sulphur in the Atmosphere, United Nations Environment Program, Pergamon Press, Elmsford, New York, p. 55. (1978).

ITII 1981: International Technical Information Institute, Toxic and Hazardous Industrial Chemicals Safety Manual for Handling and Disposal with Toxicity and Hazard Data, Japan. (1981).

JANAF 1971: Stull, D.R., Prophet, H., JANAF Thermochemical Tables, Second Edition, Office of Standard Reference Data, U.S. National Bureau of Standards, Washington, D.C. (June, 1971).

JSSV 1979: Jenkins Brothers, Jenkins Corrosion Resistant Stainless Steel Valves, New York, New York. (1979).

Lang 1979: Lang, D.C., Effects of Sulphuric Acid Aerosols on Vegetation, Prepared for the U.S. Environmental Protection Agency, Washington, D.C., EPA-600/3-79-002. (1979).

Lange's Handbook 1979: Dean, J.A. (ed.), Lange's Handbook of Chemistry, 12th Edition, McGraw-Hill Book Company, New York, New York. (1979).

Lefèvre 1980: Lefèvre, M.J., Becker, E.O., First Aid Manual for Chemical Accidents - For Use with Nonpharmaceutical Chemicals, Dowden, Hutchinson, and Ross Inc., Stroudsburg, Pennsylvania. (1980).

Liekauf 1981: Liekauf, G., Yeates, D.B., Wales, K.A., Spektor, D., Albert, R., Lippmann, M., "Effects of Sulphuric Acid Aerosol on Respiratory Mechanics and Mucociliary Particle Clearance in Healthy Non-Smoking Adults", American Industrial Hygiene Association Journal, Vol. 42, No. 4, pp. 273-282. (1981).

Lippmann 1980: Lippmann, M., Schlesinger, R.B., Liekauf, G., "Effects of Sulphuric Acid Aerosol Inhalations", American Journal of Industrial Medicine, Vol. 1, No. 3/4, pp. 375-381. (1980).

MCA 1963: Manufacturing Chemists Association, Chemical Safety Data Sheet, Washington, D.C. (1963).

Merck 1976: Windholz, M., Budavari, S., Stroumstos, L.Y., Fertig, M.N. (ed.), The Merck Index, Ninth Edition, Merck & Co. Inc., Rahway, New Jersey. (1976).

NFPA 1978: National Fire Protection Association, Fire Protection Guide on Hazardous Materials, Seventh Edition, Boston, Massachusetts. (1978).

NIOSH 1974: National Institute for Occupational Safety and Health, Criteria for a Recommended Standard - Occupational Exposure to Sulphuric Acid, U.S. Department of Health, Education and Welfare, Cincinnati, Ohio, NIOSH 74-128. (1974).

NIOSH 1977: National Institute for Occupational Safety and Health, Manual of Analytical Methods, Second Edition, Vol. 3, S. 174., Cincinnati, Ohio. (April, 1977).

NIOSH 1981: U.S. Department of Health and Human Services, Review and Evaluation of Recent Literature, Occupational Exposure to Sulphuric Acid, Washington, D.C., NIOSH Publication No. 82-104. (1981).

NIOSH Guide 1978: U.S. Department of Health, Education and Welfare, Pocket Guide to Chemical Hazards, United States Department of Health, Education, and Welfare, and U.S. Department of Labor, Washington, D.C. (1978).

NIOSH/OSHA 1981: U.S. Department of Health and Human Services, National Institute for Occupational Safety and Health (NIOSH), U.S. Department of Labor, Occupational Safety and Health Administration (OSHA), Occupational Health Guidelines for Chemical Hazards, NIOSH Publication No. 81-123. (1981).

NRCC 1977: National Research Council of Canada, Sulphur and Its Inorganic Derivatives in the Canadian Environment, NRCC No. 15015, Ottawa, Canada. (1977).

Ontario E.P. Act 1971: Ontario Ministry of the Environment, "The Environmental Protection Act, Statutes of Ontario 1971", Chapter 86, as amended; and Regulation 15 (General) as amended. (1971).

Patton 1963: Patton, W.F., Brink, J.A. Jr., "New Equipment and Techniques for Sampling Chemical Process Gases", JAPCA, Vol. 13, p. 162. (1963).

Perry 1973: Perry, R.H., Chilton C.H. (ed.), Chemical Engineer's Handbook, Fifth Edition, McGraw-Hill Book Company, New York, New York. (1973).

PC EPS 1982: Personal Communication, Environmental Protection Service, Nova Scotia, Environment Canada, Halifax, Nova Scotia. (20 January 1982).

PC MWC 1982: Personal Communication, Marten Wild of Canada, Amherst, Nova Scotia. (21 January 1982).

PC SE 1982: Personal Communication, Saskatchewan Environment, Regina, Saskatchewan. (19 January 1982).

Portman 1970: Portman, J.E., The Toxicity of 120 Substances to Marine Organisms, Shellfish Information Leaflet, Fisheries Experimental Station, Conway, N. Wales, Ministry of Agriculture, Fisheries and Food. (September, 1970).

Proctor 1978: Proctor, N.H., Hughes, J.P., Chemical Hazards of the Workplace, J.B. Lippincott Company, Toronto, Ontario. (1978).

RMLTHH 1972: Back, K.C., Thomas, A.A., MacEwen, J.E., Reclassification of Materials Listed As Transportation Health Hazards, Aerospace Medical Research Laboratory, Wright-Patterson Airforce Base, Ohio. (1972).

Roberts 1980: Roberts, T.M., Clarke, T.A., Ineson, P. et al., "Effects of Sulphur Deposition on Litter Decomposition and Nutrient Leaching in Coniferous Forest Soils", NATO Conf. Ser. 1: Eff. Acid Precipitation Terr. Ecosyst., Vol. 4, pp. 381-393. (1980).

Rosenstock 1977: Rosenstock, H.M., Draxl, K., Steiner, B., Herron, J.T., Energetics of Gaseous Ions, National Bureau of Standards, Washington, D.C. (1977).

RTDCR 1974: Regulations for the Transport of Dangerous Commodities by Rail, Canadian Transport Commission, Ottawa, Ontario. (1974).

RTECS 1979: Lewis, R.J., Tatken, R.L., Registry of Toxic Effects of Chemical Substances, 1979, Vols. 1 and 2, National Institute for Occupational Safety and Health (NIOSH), Cincinnati, Ohio. (September, 1980).

RTECS (on-line) 1981: National Institute for Occupational Safety and Health, Registry of Toxic Effects of Chemical Substances, U.S. Department of Health and Human Services. Microfiche. (October, 1981).

Sask 1981: Saskatchewan Labour, Occupational Health and Safety Branch, "Occupational Health and General Regulations", Saskatchewan Regulation 55/81, Regina, Saskatchewan. (1981).

Sax 1979: Sax, N.I., Dangerous Properties of Industrial Materials, Fifth Edition, Van Nostrand Reinhold Company, New York, New York. (1979).

Scott 1979: Scott's Industrial Directory of Ontario Manufacturers, 12th Edition, Penstock Directories Limited, Oakville, Ontario. (1979).

Shreve 1977: Shreve, R.N., Brink, J.A., Chemical Process Industries, Fourth Edition, McGraw-Hill Book Company, New York, New York. (1977).

Streeter 1971: Streeter, V.L., Fluid Mechanics, Fifth Edition, McGraw-Hill Book Company, New York, New York. (1971).

Summary Report 1981: Summary Report, Cleanup of March 5, 1981 Acid Spill near La Loche, Saskatchewan Environment, Regina, Saskatchewan. (April 16, 1981).

Tang et al. 1982: Tang, I.N., Wong, W.T., Munkelwitz, H.R., "Laboratory Study of Sulfuric Acid Spill Characteristics Pertaining to Maritime Accidents", Environmental Science and Technology, Vol. 16, pp. 587-593. (1982).

Tanner 1981: Tanner, R.L., Leaderer, B.P., Spengler, J.D., "Acidity of Atmospheric Aerosols", Environmental Science and Technology, Vol. 15, No. 10, pp. 1150-1153. (October, 1981).

TCM 1979: General American Transportation Corporation, Tank Car Manual, Chicago, Illinois. (May, 1979).

TDGC 1980: Transport Canada, Transportation of Dangerous Goods Code, Vol. 1 (Lists), Vol. 2, Ottawa, Canada. (June, 1980).

TLV 1981: American Conference of Governmental Industrial Hygienists, TLV's Threshold Limit Values for Chemical Substances and Physical Agents in the Workroom Environment With Intended Changes for 1981, Cincinnati, Ohio. (1981).

TOX TIPS 1981: Toxicology Testing in Progress, Sponsored by Toxicology Information Subcommittee, DHEW Committee to Coordinate Environmental and Related Programs. Available from the National Library of Medicine and NTIS. (1981).

TPS 1978: GSR Fluid Handling, Thermoplastic Piping Systems, Sun Valley, California. (1978).

USDHEW 1977: U.S. Department of Health, Education and Welfare, Occupational Diseases. A Guide to Their Recognition, National Institute for Occupational Safety and Health, DHEW NIOSH No. 77-181. (1977).

Water Management Goals 1978: Ontario Ministry of the Environment, Water Management Goals, Policies, Objectives and Implementation Procedures for the Ministry of the Environment, Toronto, Ontario. (November, 1978).

Wedding 1979: Wedding, J.B., Ligothe, M.W., Hess, F.D., "Effects of Sulphuric Acid Mist on Plant Canopies", Environmental Science and Technology, Vol. 13, No. 7, pp. 875-878. (1979).

Wedding 1981: Wedding, J.N., Ligothe, M.W., Physiological Effects of Sulphuric Acid Mist on Plant Canopies, Prepared for U.S. Government Reports Announcements and Index, No. 23. (1981).

Welcher 1955: Welcher, F.J., Hahn, R.B., Semimicro Qualitative Analysis, D. Van Nostrand Co., Inc., Princeton, New Jersey, pp. 456-457. (1955).

WQC 1963: McKee, J.E., Wolf, H.W., Water Quality Criteria, Second Edition, Resources Agency of California, State Water Quality Control Board. (1963).

WQC 1972: National Academy of Sciences, Water Quality Criteria 1972, A Report of the Committee on Water Quality Criteria, Environmental Studies Board, National Academy of Sciences, Washington, D.C. (1972).

WQCDB-2 1971: Environmental Protection Agency, Water Quality Criteria Data Book: Inorganic Chemical Pollution of Freshwater, U.S. Environmental Protection Agency, Water Quality Office, Washington, D.C., Vol. 2, pp. 237, 239. (July, 1971).

WQS 1979: McNeily, R.N., Neimans, V.P., Dwyer, L., Water Quality Sourcebook: A Guide to Water Quality Parameters, Inland Waters Directorate, Water Quality Branch, Environment Canada, Ottawa, Canada. (1979).

12.2 Bibliography

Allied Chemical Corporation, Sulphuric Acid, Morristown, New Jersey. (1978).

American Conference of Governmental Industrial Hygienists (ACGIH), Documentation of Threshold Limit Values, Fourth Edition, Cincinnati, Ohio. (1981).

American Conference of Governmental Industrial Hygienists, TLV®s Threshold Limit Values for Chemical Substances and Physical Agents in the Workroom Environment with Intended Changes for 1981, Cincinnati, Ohio. (1981).

American Society for Testing and Materials, Compilation of Odor and Taste Threshold Values Data, ASTM, Philadelphia, Pennsylvania, ASTM Data Series DS-48A. (1980).

American Society for Testing and Materials, Annual Book of ASTM Standards, Part 31: Water, ASTM, Philadelphia, Pennsylvania, DS16-68. (1979).

American Water Works Association, Standard Methods for the Examination of Water and Wastewater, 14th Edition, American Public Health Association, Washington, D.C., pp. 493-496. (1976).

Ashland Chemical Company, Material Safety Data Sheet - Sulphuric Acid 66°Bé, Columbus, Ohio. (November, 1977).

Association of American Railroads, Private Communication. (1982).

Atlas Steel, Atlas Stainless Steels, Toronto, Ontario. Not dated.

Back, K.C., Thomas, A.A., MacEwen, J.E., Reclassification of Materials Listed As Transportation Health Hazards, Aerospace Medical Research Laboratory, Wright-Patterson Airforce Base, Ohio. (1972).

Barden, J.D., Analysis System for Total Sulphuric Acid in Ambient Air - Development and Preliminary Evaluation, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, EPA-600/52-81-013. (May, 1981).

Bauer, W.H., Borton, D.N. et al., Agents, Methods and Devices for Amelioration of Discharge of Hazardous Chemicals on Water, Rensselaer Polytechnic Institute for the U.S. Coast Guard, Washington, D.C., CG-D-38-76. (August, 1975).

BDM Corporation, The AAR Hazardous Materials Data Base, Prepared for the Association of American Railroads, Parts I and II, McLean, Virginia. (May, 1981).

Brale, K., "Treatment of Sulphuric Acid Spillages", Imperial Chemical Industries, Mond Division, Cheshire, England. Proceedings of the 1982 National Conference on Control of Hazardous Material Spills, Milwaukee, Wisconsin. (April, 1982).

Bretherick, L., Handbook of Reactive Chemical Hazards, Second Edition, Butterworths, London, England. (1979).

Buchan, Lawton, Parent Ltd., A Survey of Self-Contained Breathing Apparatus and Totally-Encapsulated Chemical Protection Suits, Unedited Version. Not dated.

"Canada Strong in Sulphuric Acid", Canadian Chemical Processing, Vol. 65, No. 7, pp. 18-19. (October, 1981).

Canadian Chemical Producers Association, Private Communication. (1982).

Canadian Industries Limited, Sulphuric Acid, Willowdale, Ontario. Not dated.

Canadian Industries Limited, Sulphuric Acid, Montreal, Quebec. (1976).

Canadian Transport Commission, Regulation and Transportation of Dangerous Commodities by Rail, Ottawa, Ontario. (1974).

Cities Service Company, Material Safety Data Sheet - Oleum, Atlanta, Georgia. Not dated.

"Cominco Moves to Reduce SO₂ Emissions, Clean Up Effluents", Eco/Log, Vol. 9, No. 44, pp. 2-3. (13 November 1981).

Corpus Information Services Ltd., "Sulphuric Acid", Chemical Product Profiles, Don Mills, Ontario. (15 June 1981).

Dean, J.A. (ed.), Lange's Handbook of Chemistry, 12th Edition, McGraw-Hill Book Company, New York, New York. (1979).

Department of Industry, Trade and Commerce, Canadian Chemical Register, Ottawa, Canada. (1978).

M.M. Dillon Ltd., Survey of Countermeasures Systems for Hazardous Material Spills, prepared for Environment Canada, Ottawa, Canada. (In preparation, 1982).

DOM-X, DOM-X Plastic Pipe Engineering Data, Toronto, Ontario. (1967).

Doull, J., Klaassen, C.D., Amdur, M.O., Casarett's and Doull's Toxicology - The Basic Science of Poisons, Second Edition, Collier Macmillan Canada Inc., Toronto, Ontario. (1980).

Dow Chemical Company, Dow Chemical Resistance Guide for Dow Plastic Lined Piping Products, Midland, Michigan. (1978).

Dow Chemical Company, Sulphuric Acid, Midland, Michigan. Not dated.

Drake, E. et al., A Feasibility Study of Response Techniques for Discharges of Hazardous Chemicals that Disperse Through the Water Column, U.S. Coast Guard, Washington, D.C., CG-D-16-77. (July, 1976).

Ebara, T., "Sulphuric Acid Test on Rear", Ibaraki-ken Kogai Gijyutsi Senta Nempo, Vol. 12, pp. 33-35. (1980).

Ellis, M.M., Detection and Measurement of Stream Pollution, Biology of Water Pollution, U.S. Dept. of Interior (FWPCA), pp. 129, 185. (1967).

Environmental Protection Agency, Supplement to Development Document: Hazardous Substances Regulations, Section 311 Federal Water Pollution Control Act, U.S. Environmental Protection Agency, Office of Water Planning and Standards, Washington, D.C., EPA-440/9-75-009. (November, 1975).

Environmental Protection Agency, Water Quality Criteria Data Book: Inorganic Chemical Pollution of Freshwater, U.S. Environmental Protection Agency, Water Quality Office, Washington, D.C., Vol. 2, pp. 237, 239. (July, 1971).

General American Transportation Corporation, Tank Car Manual, Chicago, Illinois. (May, 1979).

General Electric Company, Material Safety Data Sheets, Material Safety Information Services, Schenectady, New York. (October, 1980).

GF Plastic Systems Inc., GF Plastic Systems, Santa Ana, California. Not dated.

GSR Fluid Handling, Thermoplastic Piping Systems, Sun Valley, California. (1978).

Hatayama, H.K., Chen, J.J., deVera, E.R., Stephens, R.D., Storm, D.L., A Method for Determining the Compatibility of Hazardous Wastes, Municipal Environmental Research Laboratory, Office of Research and Development, U.S. Environmental Protection Agency, Cincinnati, Ohio. (April, 1980).

Hesse, P.R., A Textbook of Soil Chemical Analysis, Chemical Publishing Co. Inc., New York, New York, p. 321. (1972).

Huibregtse, K.R. et al., Manual for the Control of Hazardous Material Spills - Volume One - Spill Assessment and Water Treatment Techniques, U.S. Environmental Protection Agency, National Environmental Research Center, Cincinnati, Ohio, EPA-600/2-77-227. (November, 1977).

Hussar, R.B. et al. (ed.), Sulphur in the Atmosphere, United Nations Environment Program, Pergamon Press, Elmsford, New York, p. 55. (1978).

Hydraulic Institute, Hydraulic Institute Standards, 12th Edition, New York, New York. (1969).

International Technical Information Institute, Toxic and Hazardous Industrial Chemicals Safety Manual for Handling and Disposal with Toxicity and Hazard Data, Japan. (1981).

Jenkins Brothers, Jenkins Corrosion Resistant Stainless Steel Valves, New York, New York. (1979).

Lang, D.S., Effects of Sulphuric Acid Aerosols on Vegetation, Prepared for the U.S. Environmental Protection Agency, Washington, D.C., EPA-600/3-79-002. (1979).

Lefèvre, M.J., Becker, E.O., First Aid Manual for Chemical Accidents - For Use with Nonpharmaceutical Chemicals, Dowden, Hutchinson, and Ross Inc., Stroudsburg, Pennsylvania. (1980).

Liekauf, G., Yeates, D.B., Wales, K.A., Spektor, D., Albert, R., Lippmann, M., "Effects of Sulphuric Acid Aerosol on Respiratory Mechanics and Mucociliary Particle Clearance in Healthy Non-Smoking Adults", American Industrial Hygiene Association Journal, Vol. 42, No. 4, pp. 273-282.

Lewis, R.J., Tatken, R.L., Registry of Toxic Effects of Chemical Substances, 1979, Vols. 1 and 2, National Institute for Occupational Safety and Health (NIOSH), Cincinnati, Ohio. (September, 1980).

Lippmann, M., Schlesinger, R.B., Liekauf, G., "Effects of Sulphuric Acid Aerosol Inhalations", American Journal of Industrial Medicine, Vol. 1, No. 3/4, pp. 375-381. (1980).

Manufacturing Chemists Association, Chemical Safety Data Sheet, Washington, D.C. (1963).

McKee, J.E., Wolf, H.W., Water Quality Criteria, Second Edition, Resources Agency of California, State Water Quality Control Board. (1963).

McNeily, R.N., Neimans, V.P., Dwyer, L., Water Quality Sourcebook: A Guide to Water Quality Parameters, Inland Waters Directorate, Water Quality Branch, Environment Canada, Ottawa, Canada. (1979).

National Academy of Sciences, Water Quality Criteria 1972, A Report of the Committee on Water Quality Criteria, Environmental Studies Board, National Academy of Sciences, Washington, D.C. (1972).

National Association of Corrosion Engineers, Corrosion Data Survey, Houston, Texas. (1967).

National Fire Protection Association, Fire Protection Guide on Hazardous Materials, Seventh Edition, Boston, Massachusetts. (1978).

National Institute for Occupational Safety and Health, Registry of Toxic Effects of Chemical Substances, U.S. Department of Health and Human Services. Microfiche. (October, 1981).

National Institute for Occupational Safety and Health, Criteria for a Recommended Standard - Occupational Exposure to Sulphuric Acid, U.S. Department of Health, Education and Welfare, Cincinnati, Ohio, NIOSH 74-128. (1974).

National Institute for Occupational Safety and Health, Manual of Analytical Methods, Second Edition, Vol. 3, S. 174., Cincinnati, Ohio. (April, 1977).

National Research Council of Canada, Sulphur and Its Inorganic Derivatives in the Canadian Environment, NRCC No. 15015, Ottawa, Canada. (1977).

Ontario Ministry of the Environment, Water Management Goals, Policies, Objectives and Implementation Procedures for the Ministry of the Environment, Toronto, Ontario. (November, 1978).

Ontario Ministry of the Environment, "The Environmental Protection Act, Statutes of Ontario 1971", Chapter 86, as amended; and Regulation 15 (general) as amended. (1971).

Patton, W.F., Brink, J.A. Jr., "New Equipment and Techniques for Sampling Chemical Process Gases", JAPCA, Vol. 13, p. 162. (1963).

Perry, R.H., Chilton, C.H. (ed.), Chemical Engineer's Handbook, Fifth Edition, McGraw-Hill Book Company, New York, New York. (1973).

Personal Communication, Saskatchewan Environment, Regina, Saskatchewan. (19 January 1982).

Personal Communication, Environmental Protection Service, Nova Scotia, Environment Canada, Halifax, Nova Scotia. (20 January 1982).

Personal Communication, Marten Wild of Canada, Amherst, Nova Scotia. (21 January 1982).

Pilie, R.J. et al., Methods to Treat, Control and Monitor Spilled Hazardous Materials, U.S. Environmental Protection Agency, National Environmental Research Center, Cincinnati, Ohio, EPA-670/2-75-042. (June, 1975).

Portman, J.E., The Toxicity of 120 Substances to Marine Organisms, Shellfish Information Leaflet, Fisheries Experimental Station, Conway, N. Wales, Ministry of Agriculture, Fisheries and Food. (September, 1970).

Proctor, N.H., Hughes, J.P., Chemical Hazards of the Workplace, J.B. Lippincott Company, Toronto, Ontario. (1978).

Roberts, T.M., Clarke, T.A., Ineson, P. et al., "Effects of Sulphur Deposition on Litter Decomposition and Nutrient Leaching in Coniferous Forest Soils", NATO Conf. Ser. 1: Eff. Acid Precipitation Terr. Ecosyst., Vol. 4, pp. 381-393. (1980).

Rosenstock, H.M., Draxl, K., Steiner, B., Herron, J.T., Energetics of Gaseous Ions, National Bureau of Standards, Washington, D.C. (1977).

Saskatchewan Labour, Occupational Health and Safety Branch, "Occupational Health and General Regulations", Saskatchewan Regulation 55/81, Regina, Saskatchewan. (1981).

Sax, N.I., Dangerous Properties of Industrial Materials, Fifth Edition, Van Nostrand Reinhold Company, New York, New York. (1979).

Scott's Industrial Directory of Ontario Manufacturers, 12th Edition, Penstock Directories Limited, Oakville, Ontario. (1979).

Shreve, R.N., Brink, J.A., Chemical Process Industries, Fourth Edition, McGraw-Hill Book Company, New York, New York. (1977).

Southam Business Publications Ltd., "1981 Chemical Buyers' Guide", Canadian Chemical Processing, Vol. 64, No. 9, Don Mills, Ontario. (December, 1980).

Streeter, V.L., Fluid Mechanics, Fifth Edition, McGraw-Hill Book Company, New York, New York. (1971).

Stull, D.R., Prophet, H., JANAF Thermochemical Tables, Second Edition, Office of Standard Reference Data, U.S. National Bureau of Standards, Washington, D.C. (June 1971).

"Sulphuric Acid", Dangerous Properties of Industrial Materials Report, Vol. 15, No. 5, pp. 80-83. (May/June, 1981).

Summary Report, Cleanup of March 5, 1981 Acid Spill near La Loche, Saskatchewan Environment, Regina, Saskatchewan. (April 16, 1981).

Tang, I.N., Wong, W.T., Munkelwitz, H.R., "Laboratory Study of Sulphuric Acid Spill Characteristics Pertaining to Maritime Accidents", Environmental Science and Technology, Vol. 16, pp. 587-593. (1982).

Tanner, R.L., Leaderer, B.P., Spengler, J.D., "Acidity of Atmospheric Aerosols", Environmental Science and Technology, Vol. 15, No. 10, pp. 1150-1153. (October, 1981).

Toxicology Testing in Progress, Sponsored by Toxicology Information Subcommittee, DHEW Committee to Coordinate Environmental and Related Programs. Available from the National Library of Medicine and NTIS. (1981).

Transport Canada, Transportation of Dangerous Goods Code, Vol. 1 (Lists), Vol. 2, Ottawa, Canada. (June, 1980).

Uniroyal, Guide to Polymer Properties, Uniroyal Inc., Mishawaka, Indiana. Not dated.

U.S. Department of Health and Human Services, Review and Evaluation of Recent Literature, Occupational Exposure to Sulphuric Acid, DHHS (NIOSH), Washington, D.C., NIOSH Publication No. 82-104. (1981).

U.S. Department of Health and Human Services, National Institute for Occupational Safety and Health (NIOSH), U.S. Department of Labor, Occupational Safety and Health Administration (OSHA), Occupational Health Guidelines for Chemical Hazards, NIOSH Publication No. 81-123. (1981).

U.S. Department of Health, Education and Welfare, Pocket Guide to Chemical Hazards, United States Department of Health, Education, and Welfare, and U.S. Department of Labor, Washington, D.C. (1978).

U.S. Department of Health, Education and Welfare, Occupational Diseases. A Guide to Their Recognition, National Institute for Occupational Safety and Health, DHEW NIOSH No. 77-181. (1977).

U.S. Department of Transportation, Emergency Action Guide for Selected Hazardous Materials, U.S. D.O.T. Research and Special Programs Administration, Materials Transportation Bureau, Washington, D.C. (1978).

U.S. Department of Transportation, Hazardous Materials, 1980 Emergency Response Guidebook, U.S. Department of Transportation, Research and Special Programs Administration, Materials Transportation Bureau, Washington, D.C. (1980).

U.S. Department of Transportation, Coast Guard, Chemical Hazards Response Information System (CHRIS), Washington, D.C. (1978).

Weast, R.C. (ed.), CRC Handbook of Chemistry and Physics, 60th Edition, Chemical Rubber Publishing Company, Cleveland, Ohio. (1980).

Wedding, J.B., Ligothke, M., Hess, F.D., "Effects of Sulphuric Acid Mist on Plant Canopies", Environmental Science and Technology, Vol. 13, No. 7, pp. 875-878. (1979).

Wedding, J.N., Ligothke, M.W., Physiological Effects of Sulphuric Acid Mist on Plant Canopies, Prepared for U.S. Government Reports Announcements and Index, No. 23. (1981).

Welcher, F.J., Hahn, R.B., Semimicro Qualitative Analysis, D. Van Nostrand Co., Inc., Princeton, New Jersey, pp. 456-457. (1955).

Wetzel, R., Menear, J., Applications Note No. 8, Dionex Corp., Sunnyvale, California. (May, 1978).

Windholz, M., Budavari, S., Stroumtsos, L.Y., Fertig, M.N. (ed.), The Merck Index, Ninth Edition, Merck & Co. Inc., Rahway, New Jersey. (1976).

EnviroTIPS
Common Abbreviations

BOD	biological oxygen demand	MMAD	mass median aerodynamic diameter
b.p.	boiling point	MMD	mass median diameter
CC	closed cup	m.p.	melting point
cm	centimetre	MW	molecular weight
CMD	count median diameter	N	newton
COD	chemical oxygen demand	NAS	National Academy of Sciences
conc.	concentration	NFPA	National Fire Protection Association
c.t.	critical temperature	NIOSH	National Institute for Occupational Safety and Health
eV	electron volt		
g	gram		
ha	hectare		
Hg	mercury		
IDLH	immediately dangerous to life and health		
Imp. gal.	imperial gallon	nm	nanometre
in.	inch	o	ortho
J	joule	OC	open cup
kg	kilogram	p	para
kJ	kilojoule	P _C	critical pressure
km	kilometre	PEL	permissible exposure level
kPa	kilopascal	pH	measure of acidity/alkalinity
kt	kilotonne	ppb	parts per billion
L	litre	ppm	parts per million
lb.	pound	P _S	standard pressure
LC ₅₀	lethal concentration fifty	psi	pounds per square inch
LC _{LO}	lethal concentration low	s	second
LD ₅₀	lethal dose fifty	STEL	short-term exposure limit
LD _{LO}	lethal dose low	STIL	short-term inhalation limit
LEL	lower explosive limit	T _C	critical temperature
LFL	lower flammability limit	TC _{LO}	toxic concentration low
m	metre	T _d	decomposition temperature
m	meta	TD _{LO}	toxic dose low
M	molar	TL _m	median tolerance limit
MAC	maximum acceptable concentration	TLV	Threshold Limit Value
max	maximum	T _S	standard temperature
mg	milligram	TWA	time weighted average
MIC	maximum immision concentration	UEL	upper explosive limit
min	minute or minimum	UFL	upper flammability limit
mm	millimetre	VMD	volume mean diameter
		v/v	volume per volume
		w/w	weight per weight
μg	microgram		
μm	micrometre		
°Be	degrees Baumé (density)		