

PLAINTIFF'S EXHIBIT

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Properties and uses of Glycols



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PROPERTIES AND USES OF GLYCOLS

Glycols are aliphatic organic compounds having two hydroxyl groups per molecule. The glycols resemble water in that they are essentially clear, colorless liquids with practically no odor. However, they are heavier and more viscous than water at any given temperature and their boiling points are much higher.

Many of the uses for the glycols depend on the fact that they are excellent solvents for many organic compounds and are completely water soluble. Since they can undergo chemical reactions on one or both hydroxyl groups, they are important as chemical intermediates.

The wide range of practical applications for the glycols accounts for their great industrial importance. They are found in such widely diverse products as dynamite, shampoos, cigarettes, printing ink, antifreeze formulations, and glue. It is hoped that the data contained in this booklet will assist you in developing further products and improving present ones.

Seven glycols are discussed in this booklet, but The Dow Chemical Company's interest in this type of compound does not end here. Dow also produces a series of polyethylene and polypropylene glycols, and welcomes inquiries on these or any other glycol derivatives which may be of interest to you.

SEVEN GLYCOLS ARE DISCUSSED IN THIS BOOK

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Physical properties of GLYCOLS

	ETHYLENE GLYCOL	DIETHYLENE GLYCOL	TRIETHYLENE GLYCOL	TETRAETHYLENE GLYCOL	PROPYLENE GLYCOL†	DIPROPYLENE GLYCOL	TRIPROPYLENE GLYCOL
FORMULA	C ₂ H ₆ O ₂	C ₄ H ₁₀ O ₃	C ₆ H ₁₄ O ₄	C ₈ H ₁₈ O ₅	C ₃ H ₈ O ₂	C ₆ H ₁₄ O ₃	C ₉ H ₂₀ O ₄
MOLECULAR WEIGHT	62.1	106.1	150.2	194.2	76.1	134.2	192.3
BOILING POINT* AT 760 mm Hg °F	387.1	472.6	545.9	597.2	369.0	447.8	514.4
BOILING POINT* AT 760 mm Hg °C	197.3	244.8	288	327	187.2	231.0	268.0
VAPOR PRESSURE* AT 77°F (25°C) mm Hg	0.12	<0.01	<0.01	<0.01	0.22	0.03	<0.01
DENSITY AT 77°F (25°C)	1.110	1.113	1.119	1.120	1.033	1.023	1.016
AT 140°F (60°C)	1.085	1.088	1.092	1.092	1.007	0.996	0.992
POUNDS PER GALLON AT 77°F (25°C)	9.26	9.29	9.34	9.34	8.62	8.54	8.51
FREEZING POINT, °F	8	17	19	22	Supercools	Supercools	Supercools
POUR POINT, °F	—	— 65	— 73	— 42	— 71	— 38	— 42
VISCOSITY IN CENTIPOISES AT 77°F (25°C)	16.5	28.2	37.3	44.6	44.0	74.1	56.2
AT 140°F (60°C)	4.68	6.99	8.77	10.2	8.50	11.1	9.80
SURFACE TENSION AT 77°F (25°C) DYNES/CM	47	44	45	45	36	33	34
REFRACTIVE INDEX AT 77°F (25°C)	1.430	1.446	1.454	1.457	1.431	1.439	1.442
SPECIFIC HEAT AT 77°F (25°C) B.T.U./LB./°F	0.58	0.55	0.53	0.52	0.60	0.58	0.51
FLASH POINT, °F (C.O.C.)‡	240	280	320	365	215	260	285
FIRE POINT, °F (C.O.C.)‡	245	290	330	375	220	260	310

† Note: These properties are laboratory results on pure compounds or typical of the product, but should not be confused with, or regarded as, specifications.

* Pure Compound

† Available in Industrial and U.S.P. Grades

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SOME COMMERCIAL USES OF DOW GLYCOLS

ETHYLENE GLYCOL

Many of the present uses for ethylene glycol are based on its properties as a freezing point depressant, but this compound is also valuable in numerous applications which depend upon one or more additional properties. The ease with which it reacts with other chemical intermediates plus its solvent, lubricant, plasticizing, and hygroscopic properties—all are likewise responsible for its popularity as an industrial raw material.

One of the major applications for ethylene glycol is as the prime ingredient of permanent-type automotive antifreeze formulations. It is also employed as an antifreeze agent in de-icing formulations for aircraft and automatic fire-sprinkler systems. Incorporated in latex paint, glass cleaners, dyes, waxes and other products damaged by freezing, ethylene glycol gives dependable cold weather protection.

Ethylene glycol is also used as a solvent for stains, dyes and resins and is a mutual solvent or coupling agent in inks, soluble oils, hydraulic fluids and textile-processing chemicals.

The chemical reactivity of ethylene glycol is used in the production of an extensive series of esters. One of the more important esters is ethylene glycol dinitrate, an essential component of low-freezing gelatin dynamites. Another group of important glycol-derived products is the alkyd resins, which are used in paints, enamels and varnishes.

A synthetic rubber with high resistance to chemicals, petroleum products and abrasion plus high tensile strength is obtained by reacting ethylene glycol and other glycols with adipic acid followed by cross-linking with diisocyanates.

Ethylene glycol is permitted in various indirect additive food uses under paragraphs 121.2514; 121.2526; 121.2559; 121.2519; 121.2520; 121.2522; 121.2548; 121.2576; 121.2569 of the Food Additive Regulations under the Federal Food, Drug and Cosmetic Act.

Polyester resins, prepared by reacting ethylene glycol with polybasic acids, rep-

resent still another fairly of highly important glycol-derived products. The uses for polyester resins are extremely varied. They are employed in molding boat hulls, for preparing sheet and board used by the building industry for roofing, fencing, flashing, copings, cornices, gutters and downspouts, in the manufacture of automobile and airplane bodies and components; and for molding luggage, motor housings, pipes, tanks, ducts, dies, and a variety of household furniture and appliances. The polyester produced from ethylene glycol and terephthalic acid is used to produce packaging films as well as a very useful and popular textile fiber. Further information concerning the manufacture and uses of these products may be found in the Dow booklet, "Polyester Resins", which is available upon request.

Because of its hygroscopic properties and compatibility, ethylene glycol functions effectively as a plasticizer for cellophane. It has also proven to be an excellent and economical mold lubricant in manufacturing heavy asphalt objects, such as burial vaults. Ethylene glycol finds additional use as an intermediate to the electrolyte in dry capacitors and as a solvent and coupling agent in numerous other applications.

Because they have properties similar to those of ethylene glycol, many of the higher glycols also find use in these same applications. In each instance the exact range of properties which the particular application demands will determine which glycol can be used most advantageously.

DIETHYLENE GLYCOL

Diethylene glycol is similar to ethylene glycol in many respects but has a higher boiling point, viscosity and specific gravity—as might be predicted from its higher molecular weight. Its properties are sufficiently different from those of ethylene glycol to make it a more desirable material in many applications.

The affinity of diethylene glycol for water makes it an excellent material for dehydrating natural gas. Drying this gas eliminates freezing of moisture in transmission lines and the formation of hydrocarbon hydrates which foul instruments and reduce the capacity of the lines. Diethylene glycol is also employed as a humectant in the foundry sand used for magnesium molding. Less water is necessary to make the treated sand workable and as a result there is less magnesium-water reaction to cause imperfect castings.

Diethylene glycol is completely miscible with water yet dissolves many organic chemicals. This property makes it suitable as a solvent and coupling agent in textile lubricants, cutting oils, drycleaning soaps and hand soaps. It is also a good solvent for many dyes and for the resins in the steam-set inks used in modern high-speed printing presses.

Diethylene glycol has been widely accepted as a plasticizer and softener for paper, cellophane, glue, cork, and numerous other materials. Its high boiling point, low volatility, hygroscopicity and wide range of compatibility all play a part in its selection for this purpose. Diethylene glycol is also valuable as an intermediate in the production of plasticizers for these and other applications.

Diethylene glycol is permitted in indirect food use under paragraphs 121.2514; 121.2519; 121.2520; 121.2526; 121.2534; 121.2548; 121.2550; 121.2554; 121.2559; 121.2569 and 121.2576 of the Food Additive Regulations under the Federal Food, Drug and Cosmetic Act.

TRIETHYLENE GLYCOL

Being less volatile than either ethylene glycol or diethylene glycol, triethylene glycol is suitable for many applications in which these other materials will not perform satisfactorily. Its high boiling point and excellent solubility properties, coupled with low volatility and low toxicity have led to its use as a high-boiling solvent and plasticizer.

Triethylene glycol is especially effective as a plasticizer in products made from ground cork held together by a binder. Unless the binder is plasticized, the product will be brittle and, therefore, weak. Triethylene glycol not only imparts the required resiliency, but also permits longer retention of the desired properties than do the lower-boiling glycols. Triethylene glycol likewise shows utility as a plasticizer in many glues and resins and, in addition, is a valuable

intermediate in the production of other plasticizers.

Triethylene glycol is receiving increasing attention as a dehumidifying agent for air and natural gas. Its superiority over other products in these applications stems from its hygroscopicity and higher boiling point. Triethylene glycol is also incorporated as a resin solvent into steam-set printing inks. Many of the resins used in these inks are soluble in Triethylene Glycol but unaffected by mixtures of glycol with water.

Triethylene glycol is permitted in indirect food uses under paragraphs 121.2507; 121.2511; 121.2514; 121.2520; 121.2526; 121.2531; 121.2543; 121.2548; 121.2550; 121.2559; 121.2567 of the Food Additive Regulations under the Federal Food, Drug and Cosmetic Act, and other petitions are pending.

TETRAETHYLENE GLYCOL

Tetraethylene glycol is of special interest as a plasticizer and solvent where a high boiling point and low volatility are important. It is completely miscible with water and a wide range of organic solvents, but has only a very slight affinity for certain aliphatic hydrocarbons—a fact which may be used to advantage in some applications.

The producers of textile lubricants and formulations, in which water soluble and insoluble compounds must be mixed, have found tetraethylene glycol an effective coupling agent. It may also be reacted with fatty acids to produce emulsifiers useful in the textile and agricultural chemical fields.

Tetraethylene glycol is also a suitable plasticizer for cork products, glues, and similar products in which a long shelf life is highly desirable. It may also be reacted with dibasic acids to produce a series of plasticizers having a wide range of usefulness.

PROPYLENE GLYCOL

Propylene glycol is unique among the glycols in that its very low toxicity permits it to be taken internally. Because of this fact, Dow offers propylene glycol in two grades—Propylene Glycol, U.S.P. for foods, pharmaceuticals, cosmetics and other applications involving possible ingestion or absorption through the skin, and Propylene glycol, Industrial for other uses. In common with the other glycols, propylene glycol is odorless and colorless, and has a wide range of solvency for organic materials, plus being completely water soluble.

It is permissible to use propylene glycol as a direct or indirect food additive under

paragraphs 121.101, 121.102, 121.1122, 121.2514, 121.2519, 121.2520, 121.2522, 121.2526, 121.2534, 121.2548, 121.2550, 121.2551, 121.2559, 121.2562, 121.2576 of the Food Additive Regulations under the Federal Food, Drug and Cosmetic Act and by the Meat Inspection Division of the U.S. Department of Agriculture for several uses.

Propylene glycol, U.S.P. is an important solvent for aromatics in the flavor concentrate industry, enabling manufacturers to produce low-cost flavor concentrates of high quality. It is also an excellent wetting agent for natural gums, greatly simplifying the compounding of citrus and other emulsified flavors. Propylene glycol, U.S.P. finds additional use as a solvent in elixirs and pharmaceutical preparations containing some water-soluble ingredients, and as a solvent and coupling agent in the formulation of sun screen lotion, shampoos, shaving creams and other similar products. Certain esters of propylene glycol such as propylene glycol monostearate, are also popular as emulsifiers in cosmetic and pharmaceutical creams.

Propylene Glycol, Industrial, is an important intermediate in the production of alkyd resins used in paints and varnishes. When reacted with dibasic acids, styrene or vinyltoluene, and other glycols, propylene glycol, Industrial forms a series of polyester resins which are increasing in importance as laminating, coating and potting resins (see p. 3).

Propylene Glycol, U.S.P. is also valuable as a low temperature heat-transfer medium in brewing and dairy cooling systems and in other refrigeration equipment having cooling coils which are in direct contact with beverages and liquid foods. In aqueous solution it displays excellent antifreeze properties.

Used in hydraulic fluids, Propylene Glycol, Industrial functions as a solvent and coupling agent and inhibits the rubber swelling caused by other components of the fluid. Propylene glycol is also valuable as a humectant and preservative in tobacco, a foam stabilizer in shaving creams, a solvent for printing inks, and a solvent and coupling agent in many other applications.

Further information concerning the use of this product in foods, pharmaceuticals, and cosmetics may be found in the bulletin, "Dow Propylene Glycol, U.S.P.," available upon request.

DIPROPYLENE GLYCOL

Dipropylene glycol is similar to the other glycols in general properties and its fields

of use are comparable. However, its greater solvency for certain materials, coupled with a higher surface tension and viscosity, makes it of interest in certain applications for which the other glycols are not so well suited.

The great solvency of dipropylene glycol for castor oil indicates its usefulness as a component of hydraulic brake-fluid formulations, while its affinity for certain other oils has likewise led to its use in cutting oils, textile lubricants and industrial soaps.

Dipropylene glycol is permitted as an indirect additive under paragraphs 121.2520, 121.2526, 121.2531, 121.2557, 121.2571, 121.2576, 121.2569 of the Food Additive Regulations under the Federal Food, Drug and Cosmetic Act.

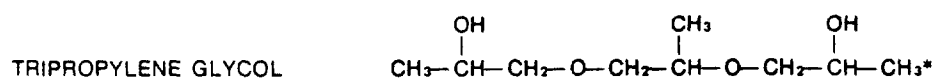
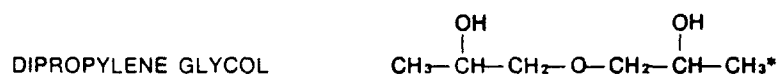
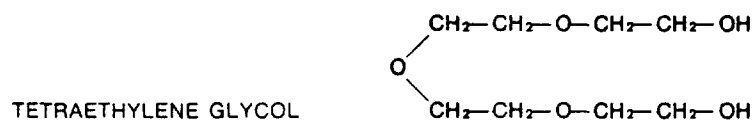
TRIPROPYLENE GLYCOL

Tripropylene glycol is an excellent solvent in many applications where other glycols fail to give satisfactory results. Its ability to solubilize printing-ink resins is especially marked; so much so that it finds its way into creams designed to remove ink stains from the hands. A combination of water solubility and good solvent power for many organic compounds plus low volatility and high boiling point also has led to its use by formulators of textile soaps and lubricants, cutting-oil concentrates and many similar products.

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CHEMISTRY OF THE GLYCOLS

The formulas of the GLYCOLS discussed in this booklet are:



* And Other Isomers

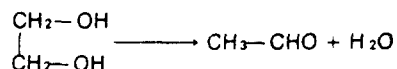
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The chemistry of the glycols centers on the two hydroxyl (OH) groups which characterize them as glycols. Glycols are therefore intermediate in their properties between the alcohols with their single hydroxyl group and glycerine with its three hydroxyl groups. Likewise, the solubility characteristics of the glycols tend to be intermediate between those of the alcohols and glycerine.

Like glycerine, glycols are normally quite stable in air under the usual conditions of storage. At high temperatures they tend to oxidize in air, giving rise to a wide variety of oxidation products such as aldehydes and acids. This oxidation can be practically eliminated by the use of stabilizers so that the glycols may be used as heat transfer media at relatively high temperatures.

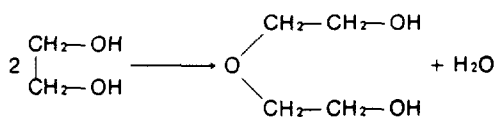
Under suitable dehydrating conditions, glycols can be made to split out water in these three ways:

- 1 One molecule of water from one molecule of glycol to form aldehydes



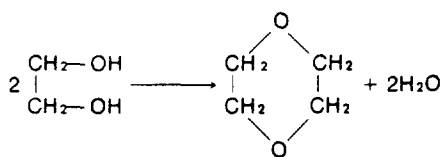
ETHYLENE GLYCOL $\longrightarrow$ ACETALDEHYDE + WATER

- 2 One molecule of water from two molecules of glycol to form a polyglycol



ETHYLENE GLYCOL $\longrightarrow$ DIETHYLENE GLYCOL + WATER

- 3 Two molecules of water from two molecules of glycol to form cyclic ethers.

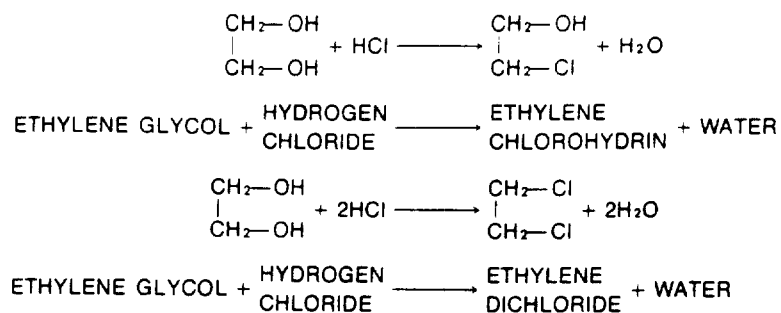


ETHYLENE GLYCOL $\longrightarrow$ DIOXANE + WATER

This reaction can be carried out stepwise, diethylene glycol being the intermediate product.

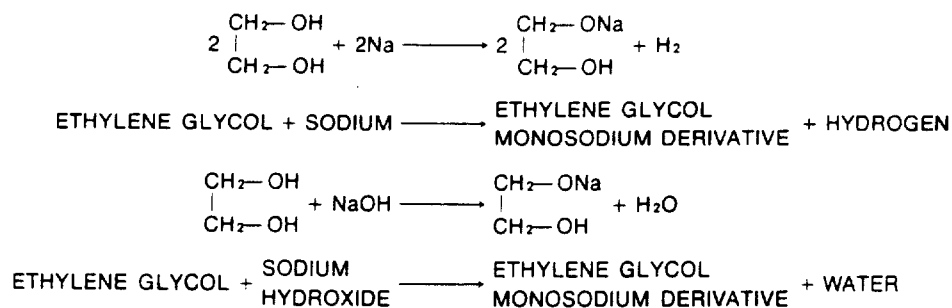
Glycols, like alcohols, react with hydrogen halides (HCl, etc.) or with phosphorous halides (PCl₃, etc.) to replace one or both of the hydroxyls with halogen

4



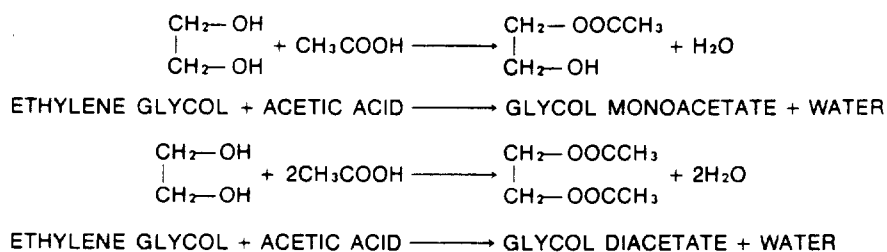
The hydrogens in either or both of the hydroxyl groups can be replaced by an alkali metal either by direct reaction or by splitting out water from the corresponding alkali metal hydroxide

5



Glycols readily form mono- and diesters by reaction with acids, acid halides or acid anhydrides.

6



PHYSICAL PROPERTIES OF GLYCOLS

SOLUBILITY

The glycols discussed here possess the property common to all low-molecular-weight alcohols of being soluble in all proportions in water. In addition, many water-immiscible materials can be carried into clear water solutions by means of the coupling action of the mutually-soluble glycols.

As a general rule, propylene glycol is a better solvent for oils and organic chemicals than ethylene glycol. The polyethylene and polypropylene glycols show increased solvency over the monoglycols. Tripropylene glycol, for example, has the most extensive solvent properties of the entire group.

This relationship is well demonstrated by Figure 1, which illustrates the relative solvent properties of glycols for a number of oils and other organic substances.

Saturated hydrocarbon oils are virtually insoluble in these glycols. The ester or acid type oils and gums are soluble to some extent in all the glycols but are most soluble in tripropylene glycol.

Aromatic compounds in general have appreciable solubility in the glycols, while alcohols and aromatic hydroxy compounds, such as phenols and resorcinol, are readily soluble and most are miscible in all proportions.

The effect of glycols on rubber and synthetic rubber is shown in Figure 2. A value of more than 0.2% shows definite action of the glycol on the rubber. Any value of 0.2% or less indicates that solvent action is ques-

tionable. Although the glycols became discolored through contact with GN-427T1, there appeared to be no effect on the flexibility or strength of any of the rubber samples.

Ethyl cellulose and cellulose acetate are completely insoluble in all glycols, as shown by Figure 3. Cellulose nitrate swells in ethylene glycol and propylene glycol and shows distinct solubility in the polyglycols.

Small amounts of ethylene, polyethylene or propylene glycol can be tolerated in clear ethyl cellulose and cellulose nitrate films. Slightly larger amounts produce hazy or opaque films. Large amounts of dipropylene glycol are compatible in all three cellulose films. Cellulose acetate shows compatibility for substantial quantities of all glycols.

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**SOLUBILITIES
OF MATERIALS IN GLYCOLS
(Per Cent By Weight)**

FIGURE 1

S = Completely Soluble I = Insoluble < = Less Than > = Greater Than	ETHYLENE GLYCOL	DIETHYL- ENE GLYCOL	TRI- ETHYL- ENE GLYCOL	TETRA- ETHYLENE GLYCOL	PROPYL- ENE GLYCOL	DI- PROPYL- ENE GLYCOL	TRI- PROPYL- ENE GLYCOL
Benzene	5.7	31.3	S	S	19.2	S	S
Carbon Tetrachloride *	6.2	26.2	33.6	62	23.4	S	S
Dibutyl Phthalate	0.5	10.6	16.5	S	8.1	S	S
Dichloroethyl Ether *	10.6	S	S	S	37.1	S	S
Drethanolamine *	S	S	S	S	S	S	S
DOWANOL * PM * Glycol Ether	S	S	S	S	S	S	S
DOWANOL * DPM * Glycol Ether	S	S	S	S	S	S	S
Ethyl Alcohol	S	S	S	S	S	S	S
Ethyl Ether	8.2	16.3	16.9	20	S	S	S
Methyl Alcohol	S	S	S	S	S	S	S
Methyl Isobutyl Carbinol	S	S	S	S	S	S	S
Methyl Isobutyl Ketone	12	S	S	S	S	S	S
Monochlorobenzene *	5.7	S	S	S	22.5	S	S
Monoethanolamine *	S	S	S	S	S	S	S
ortho-Dichlorobenzene *	4.5	48.4	S	S	19.4	S	S
Perchloroethylene *	0.7	10.7	15.0	19.0	14.5	S	S
Phenol *	S	S	S	S	S	S	S
Styrene *	3.4	36	S	S	15	S	S
Toluene	2.9	17.2	24.8	89	12.3	S	S
Urea	48	30	37	28	29	12	10
Castor Oil	1	<0.5	<0.5	<1	0.8	S	S
Coconut Oil	1	1	1	<1	1	1	3
Cottonseed Oil	1	1	1	<1	1	1	<1
Hydrous Wool Fat	<0.5	<0.5	<0.5	<1	<0.5	<0.5	<1
Lard Oil	1	1	1	<1	1	1	<1
Linseed Oil	1	1	1	<1	1	1.4	2.5
Onitica Oil	<1	<1	<1	<1	<1	<1	<1
Olive Oil	1	1	1	<1	1	0.7	1.5
Pine Oil	S	S	S	S	S	S	S
Soya Bean Oil	1	1	1	<1	1	1	<1
Sperm Oil	1	1	1	<1	1	1	<1
Tall Oil	<1	<1	<1	<1	<1	S	S
Tung Oil	1	1	1	<1	1	1	<1
Turkey Red Oil	<1	<1 **	1 **	1 **	<1 **	3 **	4 **
Paraffin Oil	1	1	1	<1	1	1	<1
SAE No 10 Oil	1	1	1	<1	1	1	<1
VMP Naphtha	<1	<1	<1	1	1	10	14
Animal Glue (Dry)	<0.5	<0.5	<0.5	<1	<0.5	<0.5	<1
Dextrin	<1	<1	<1	<1	<1	<1	<1
Gum Damar	<0.5	<0.5	<0.5	<1	<0.5	<0.5	<1
Kauri Gum	<0.5	<0.5	<0.5	>16 ***	< 5	< 5	>16 ***
Sudan III	<0.5	<0.5	<0.5	<1	<0.5	<0.5	<1
Shellac	<0.5	<0.5	<0.5	<1	<0.5	<0.5	<1

* Product of The Dow Chemical Company

** Forms stable emulsion from this concentration to 100%

*** Becomes too viscous to stir beyond 16%

FIGURE 2 EFFECT OF VARIOUS GLYCOLS ON SYNTHETIC RUBBER SAMPLES RESULTS REPORTED AS % VOLUME AND % WEIGHT INCREASE

GLYCOL	GN-427T1		GRS-53115T		FA-THIOLKOL		GUM RUBBER	
	% VOL.	% WT.	% VOL.	% WT.	% VOL.	% WT.	% VOL.	% WT.
3 DAYS IMMERSION								
ETHYLENE	-.2	-.2	-.1	-.5	.5	.2	2	.2
DIETHYLENE	-.12	-.2	-.1	-.5	3	0	1	0
TRIETHYLENE	-.1	-.1	-.1	-.5	.5	1	3	1
PROPYLENE	-.2	-.2	1	-.3	3	0	2	0
DIPROPYLENE	-.1	-.2	0	-.5	3	-.1	1	1
10 DAYS IMMERSION								
ETHYLENE	-.2	-.2	-.3	-.7	3	2	3	5
DIETHYLENE	-.3	-.3	-.2	-.8	3	0	-.2	0
TRIETHYLENE	0	-.1	-.1	-.6	.6	.3	.0	.1
PROPYLENE	-.1	-.1	-.3	-.7	.0	-.1	-.1	0
DIPROPYLENE	.1	-.2	-.1	-.6	.1	-.2	.0	.1

FIGURE 3 A. SOLUBILITY OF CELLULOSE DERIVATIVES IN GLYCOLS

GLYCOL	50 CPS. ST. E/C	1/2 SECOND CELLULOSE NITRATE	CELLULOSE ACETATE FM 3
ETHYLENE	Insoluble	Swelled	Insoluble
DIETHYLENE	Insoluble	> 20% Soluble	Insoluble
TRIETHYLENE	Insoluble	> 20% Soluble	Insoluble
PROPYLENE	Insoluble	Swelled	Insoluble
DIPROPYLENE	Insoluble	> 20% Soluble	Insoluble

B. COMPATIBILITY OF FILM CAST FROM 80/20 = TOLUENE/ALCOHOL. TABLE SHOWS % GLYCOL IN FILM WITH THE PROPERTIES SHOWN.

GLYCOL	50 CPS. ST. E/C			1/2 SECOND CELLULOSE NITRATE			CELLULOSE ACETATE FM 3		
	CLEAR	HAZE	OPAQUE	CLEAR	HAZE	OPAQUE	CLEAR	HAZE	OPAQUE
ETHYLENE	1%	3%	10%	3%	5%	10%	>10	20	...
DIETHYLENE	1%	3%	10%	1%	5%	10%	>20	30	...
TRIETHYLENE		1%	3%	1%	3%	15%	>20	30	...
PROPYLENE	1%	3%	10%	1%	3%	10%	>10	20	...
DIPROPYLENE	20%	25%	30%	>50%			>40	50	...

HYGROSCOPICITY

The glycols are hygroscopic. If placed in an atmosphere containing water vapor, they will pick up and retain moisture. This property is responsible for the many applications of glycols as humectants and dehydrating agents. In many of these applications, glycol-water solutions are used. Since the addition of water modifies the properties of the glycols, data on such solutions are needed. The

properties of both anhydrous glycols and glycol-water solutions are presented in this booklet.

The relative humectant value of the glycols is influenced by humidity and temperature variations. These variations for a range of temperatures and humidities frequently encountered in humectant problems are shown in Figure 4, which may be used to determine the amount of glycol needed to condition a given quantity of a product requiring a humectant.

FIGURE 4 RELATIVE HUMECTANT VALUES*

TEMPERATURE OF AIR °F	GLYCOL	RELATIVE HUMIDITIES								
		10%	20%	30%	40%	50%	60%	70%	80%	90%
20	ETHYLENE	97.5	93.4	89.3	85.7	82	78	72	63	48
	DIETHYLENE	97.8	95.1	92.0	89.0	86	83	78	68	52
	TRIETHYLENE	98.5	96.8	94.0	91.1	89	83	78	66	51
	PROPYLENE	96.8	91.4	90.0	84.6	77	73	68	55	40
	DIPROPYLENE	98.5	97.0	95.1	92.6	89	85	79	67	51
40	ETHYLENE	97.3	93.2	89.1	85.4	82	76	69	60	42
	DIETHYLENE	97.7	95.0	92.0	89.0	86	82	77	67	50
	TRIETHYLENE	98.4	96.5	93.8	91.0	88	83	77	65	51
	PROPYLENE	97.0	92.3	90.2	85.2	78	74	68	55	40
	DIPROPYLENE	98.4	96.9	95.0	92.5	89	85	79	67	51
60	ETHYLENE	97.1	93.0	88.9	85.0	81	75	66	57	37
	DIETHYLENE	97.7	95.0	92.0	89.0	86	82	76	66	48
	TRIETHYLENE	98.2	96.2	93.6	90.8	86	82	77	65	50
	PROPYLENE	97.1	92.9	90.4	85.8	80	74	68	55	40
	DIPROPYLENE	98.4	96.8	94.8	92.4	89	85	79	67	51
80	ETHYLENE	96.8	92.8	88.6	84.7	80	73	64	55	36
	DIETHYLENE	97.6	94.9	92.0	89.0	85	81	75	65	47
	TRIETHYLENE	98.1	96.0	93.4	90.7	85	82	76	64	50
	PROPYLENE	97.1	93.5	90.5	86.3	81	75	68	55	40
	DIPROPYLENE	98.3	96.7	94.7	92.3	89	85	79	67	51
100	ETHYLENE	96.6	92.7	88.4	84.3	79	72	63	53	35
	DIETHYLENE	97.6	94.8	92.0	89.0	85	81	74	64	46
	TRIETHYLENE	98.0	95.7	93.2	90.6	84	82	76	64	49
	PROPYLENE	97.2	93.9	90.6	86.6	82	75	68	55	40
	DIPROPYLENE	98.3	96.6	94.6	92.1	89	85	79	67	51
120	ETHYLENE	96.4	92.5	88.2	84.0	78	71	62	51	34
	DIETHYLENE	97.6	94.8	92.0	89.0	85	80	73	63	45
	TRIETHYLENE	97.8	95.4	93.0	90.5	83	82	75	63	49
	PROPYLENE	97.2	94.3	90.7	86.7	83	76	68	55	40
	DIPROPYLENE	98.2	96.5	94.5	92.0	89	85	79	67	51

* Note. Values are given as the percent by weight of glycol in water solutions, required to maintain equilibrium in contact with air of various temperatures and humidities

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For Example . . .

If six pounds of water is required to condition 100 pounds of product, and propylene glycol is chosen as the humectant, the following calculation can be made from Figure 4. With a 60% relative humidity and at 80° F, a 75% propylene glycol solution in water is indicated in the table. Since six pounds of water is required, 6 divided by 0.25 equals 24 pounds of solution needed. Subtracting the 6 pounds of water, the total amount of propylene glycol required is 18 pounds.

It should be borne in mind that a product will normally contain a certain amount of moisture, the exact amount depending on prevailing conditions of temperature and humidity. Therefore, in calculating the quantity of conditioner required, only moisture other than that normally present need be considered. It should also be assumed that the presence of a moisture is at least partially desirable because of its plasticizing effect. Propylene glycol will also have a plasticizing effect, therefore much smaller amounts of total conditioner are usually required.

A natural gas producer wishes to depress the dew point of the gas before turning it

into the transmission lines in order to prevent the formation of hydrates that may plug the lines. The natural gas is introduced into the contactor in which the glycol solution is contained. The solution temperature is 80° F. It is desirable to depress the dew point of the gas to 50° F. Assume that diethylene glycol is being used as the dehydrating medium. Turn to Figure 6 and locate 80° F on the horizontal scale entitled "Solution Temperature, Degrees Fahrenheit". Follow this line vertically up the scale until it intersects the 50° F line of the vertical scale entitled "Water Vapor Dew Point, Degrees Fahrenheit". The point thus found falls between the 90% by weight solution line and the 92% by weight solution line, but is nearer the 90% line. By estimation, approximately 91% diethylene glycol solution would be required. Substituting the other glycols in the same example. Figure 5 shows that 86% ethylene glycol solution would be needed. Figure 7 shows that 92% triethylene glycol solution would be necessary. Figure 8 indicates that 88% propylene glycol solution would be called for, and Figure 9 shows that 93.5% dipropylene glycol solution would be required.

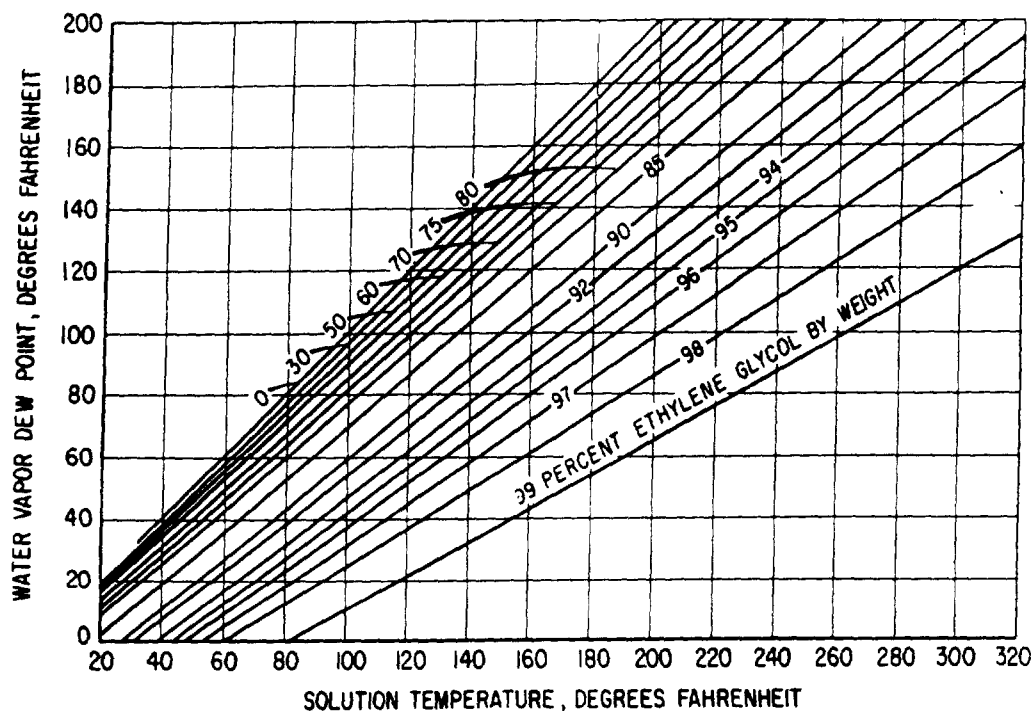
When glycols are used for dehydration of gases, the dew point or temperature at which the water will condense from the gas is used as a measure of the amount of water vapor present in the gas. Thus the dew point is depressed as water vapor is removed from the gas. Gases may be dried by bringing them in contact with glycol-water solutions. The glycol solutions will draw out the moisture until a state of equilibrium is reached. Water vapor dew points for gases in equi-

librium with glycol-water solutions are given in Figure 5 for ethylene glycol, Figure 6 for diethylene glycol, Figure 7 for triethylene glycol, Figure 8 for propylene glycol and Figure 9 for dipropylene glycol. The graphs extend over the range of temperatures most commonly encountered, from 20° to 320° F and may be used to calculate dew point depressions of gases at equilibrium with the glycol solution at atmospheric pressure.

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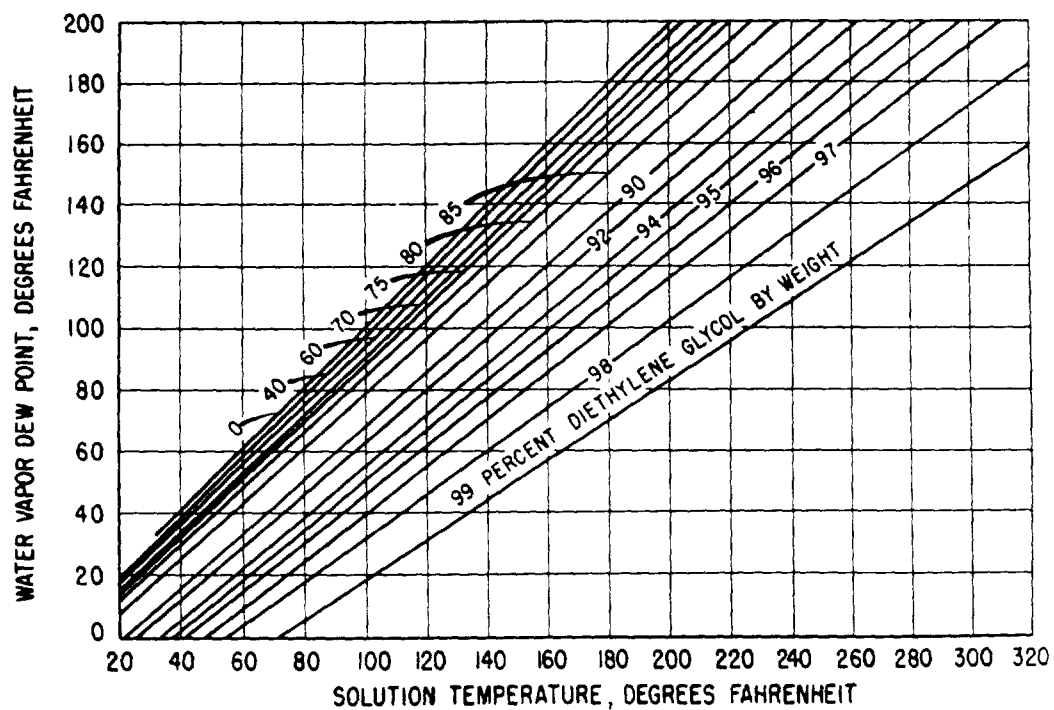
**WATER VAPOR DEW POINTS OVER
AQUEOUS ETHYLENE GLYCOL SOLUTIONS**

FIGURE 5



**WATER VAPOR DEW POINTS OVER
AQUEOUS DIETHYLENE GLYCOL SOLUTIONS**

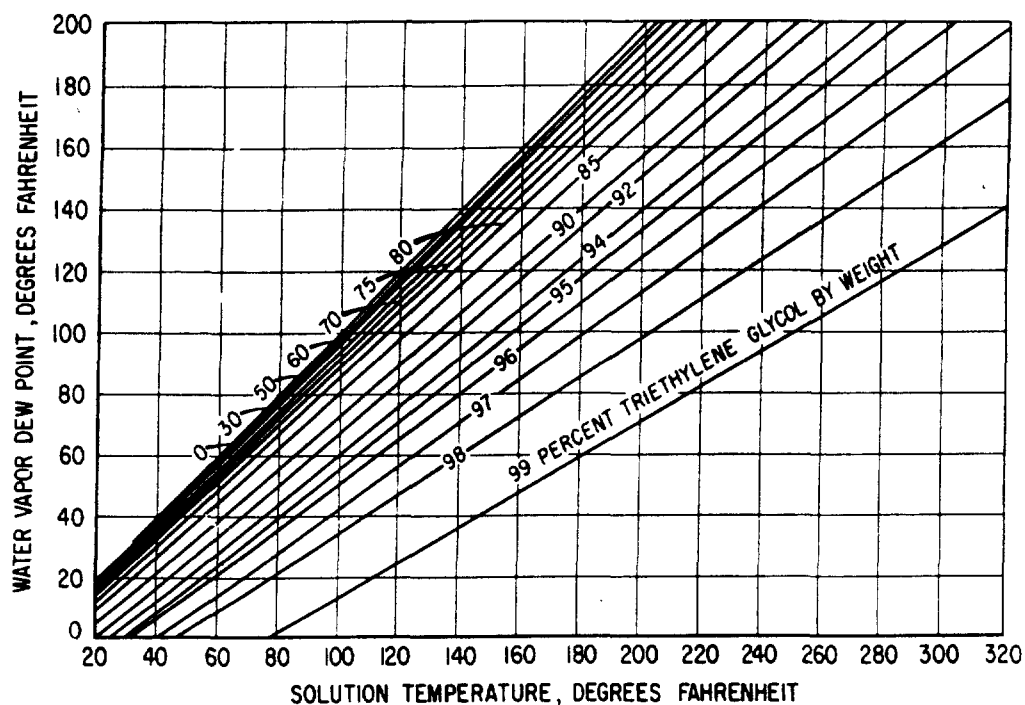
FIGURE 6



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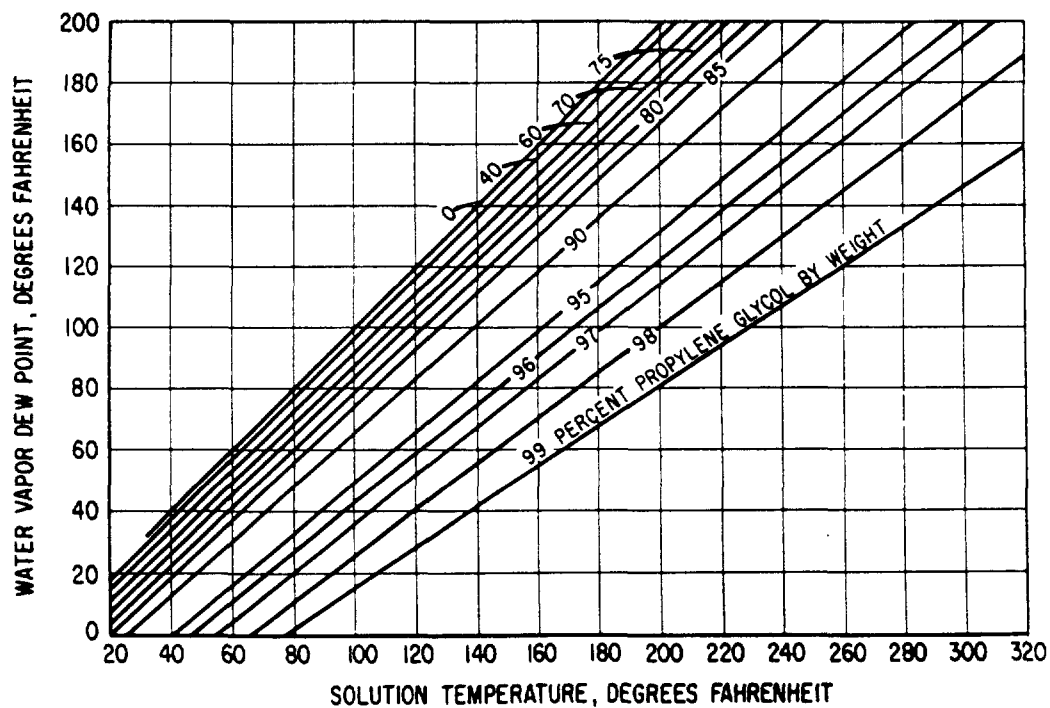
WATER VAPOR DEW POINTS OVER AQUEOUS TRIETHYLENE GLYCOL SOLUTIONS

FIGURE 7



WATER VAPOR DEW POINTS OVER AQUEOUS PROPYLENE GLYCOL SOLUTIONS

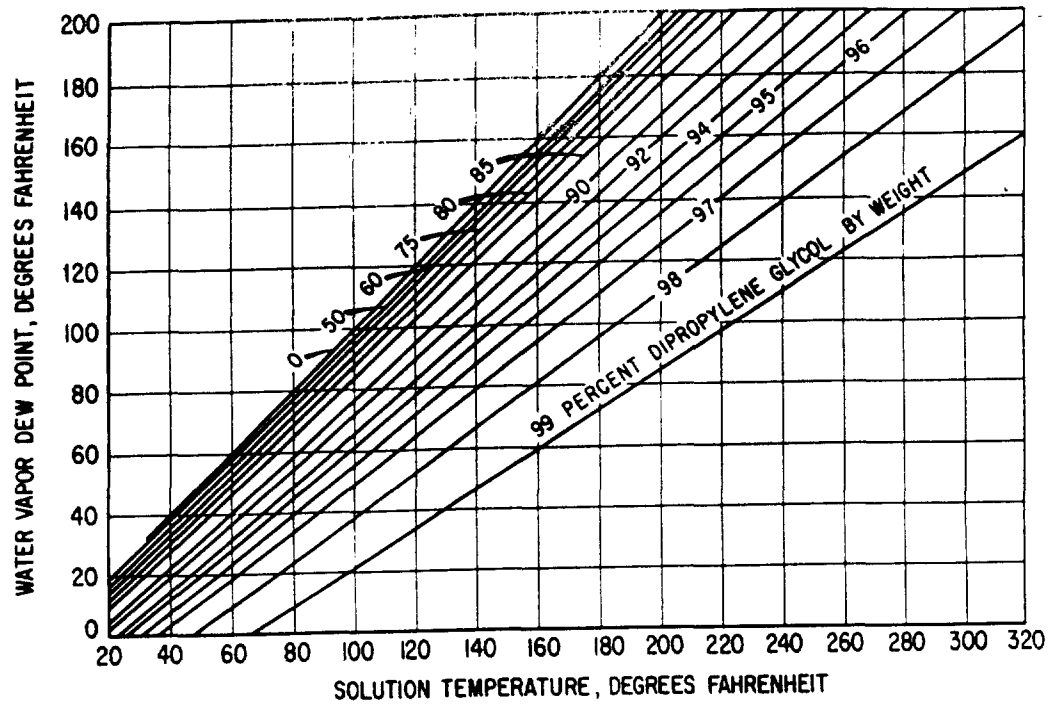
FIGURE 8



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WATER VAPOR DEW POINTS OVER AQUEOUS DIPROPYLENE GLYCOL SOLUTIONS

FIGURE 9



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VAPOR PRESSURE AND BOILING POINT

All liquids form vapors which exert pressures characteristic of the materials. The pressure exerted by these vapors in the presence of the liquid is called the vapor pressure. The vapor pressure increases with temperature, as shown by Figures 10, 11, 12, 13, and 14 on pages 18, 19 and 20. The boiling point of a liquid is the temperature at which its vapor pressure is equal to the external pressure on the surface of the liquid. When the liquid is heated in an open vessel, it will boil when its vapor pressure is equal to the atmospheric pressure, which for purposes of physical measurement has been defined as 760 mm Hg. In Figures 10, 11, 12, 13, and 14, heavy lines have been drawn across the curves at 760 mm. The normal boiling points of each of the glycols are the points at which the glycol vapor-pressure curves cross these heavy lines. The glycols have lower vapor pressures than water and their boiling points are above the boiling point of water. If the external pressure is reduced, the glycols will boil at lower temperatures, as shown in Figures 10, 11, 12, 13, and 14, where the vapor pressures of the glycols are equal to the reduced external pressure. The following table lists the boiling points of water and the glycols when the external pressure is reduced to 50 mm Hg.

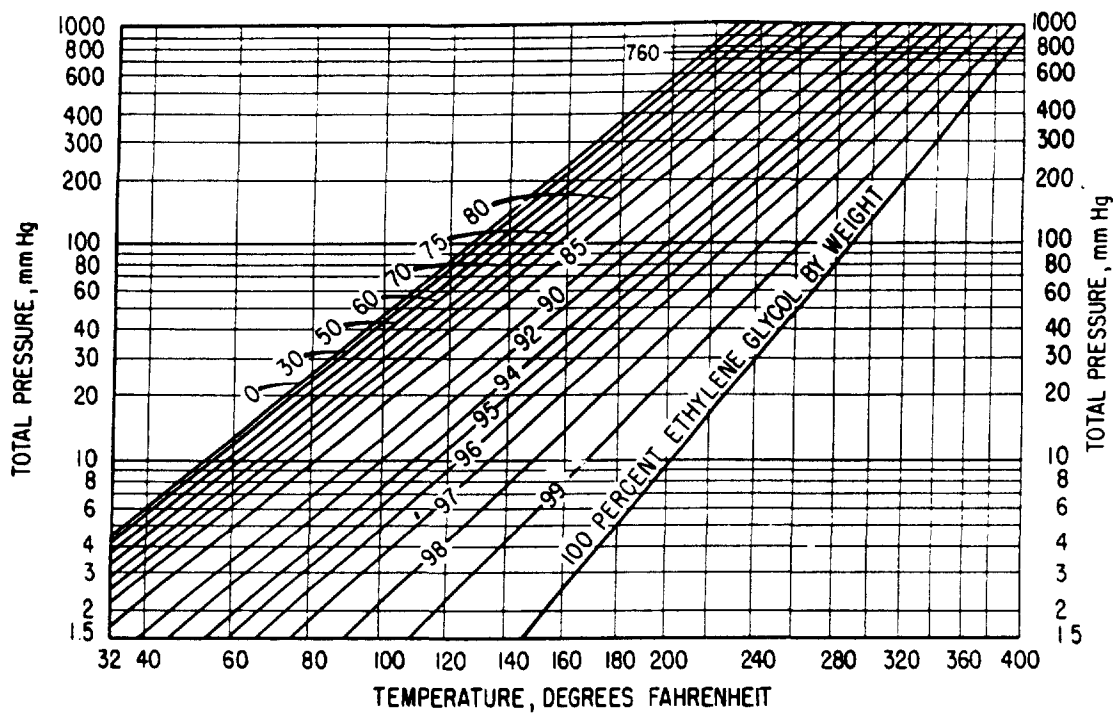
The glycols are considered high boiling point liquids because of their low vapor pressure compared to that of water at any given temperature. It is interesting to note that at 68° F the vapor pressure of water is more than 100 times as great as that of propylene glycol, the most volatile of the glycols listed. This low volatility of the glycols lessens their tendency to evaporate and has led to their use as plasticizers, "permanent" type antifreeze agents, solvent vehicles, hygroscopic agents, and ingredients of brake fluids.

BOILING POINTS AT 50 mm Hg

WATER	100°F
ETHYLENE GLYCOL	258°F
DIETHYLENE GLYCOL	338°F
TRIETHYLENE GLYCOL	387°F
TETRAETHYLENE GLYCOL	453°F
PROPYLENE GLYCOL	240°F
DIPROPYLENE GLYCOL	307°F
TRIPROPYLENE GLYCOL	356°F

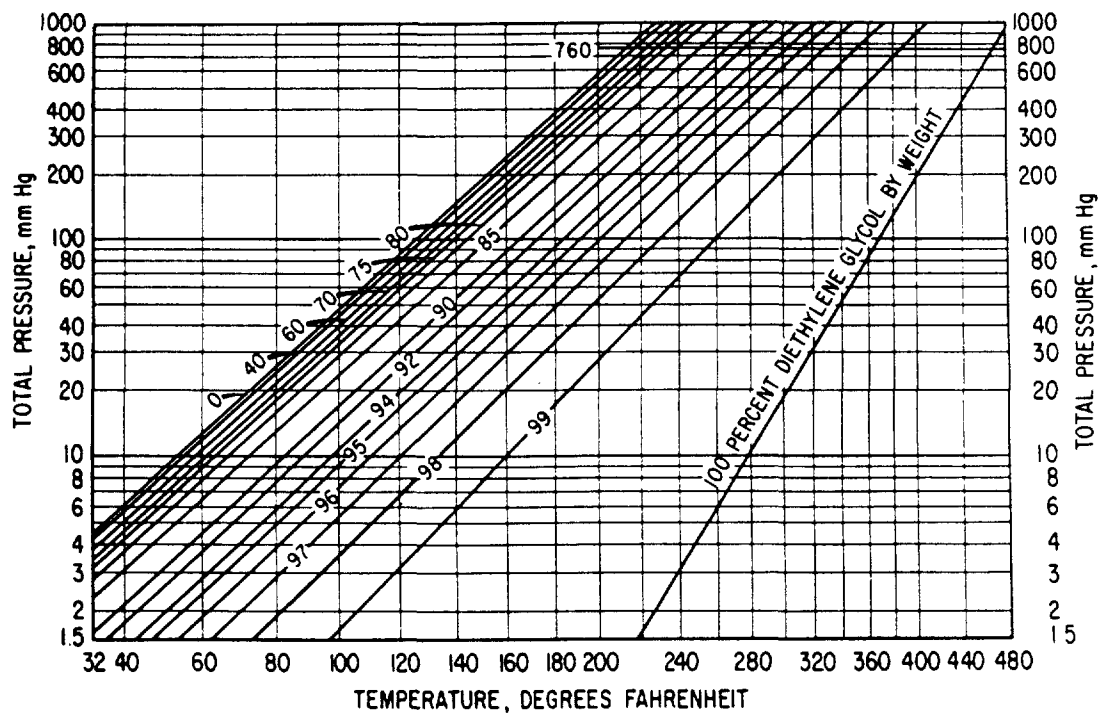
TOTAL PRESSURE OVER AQUEOUS ETHYLENE GLYCOL SOLUTIONS VERSUS TEMPERATURE

FIGURE 10



TOTAL PRESSURE OVER AQUEOUS DIETHYLENE GLYCOL SOLUTIONS VERSUS TEMPERATURE

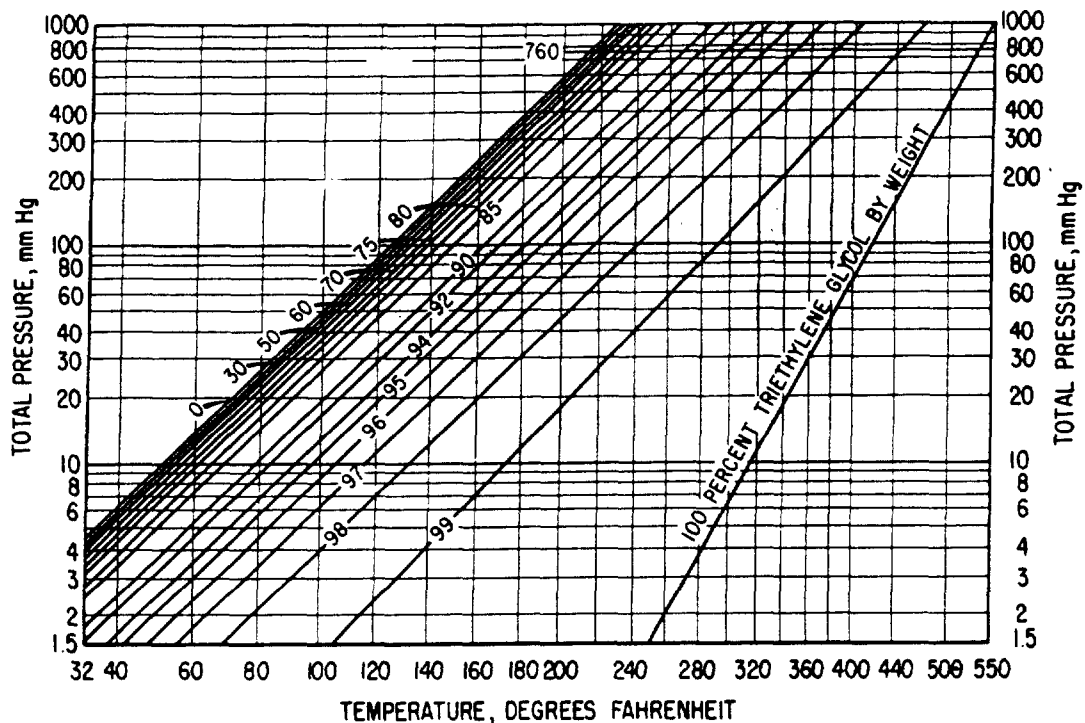
FIGURE 11



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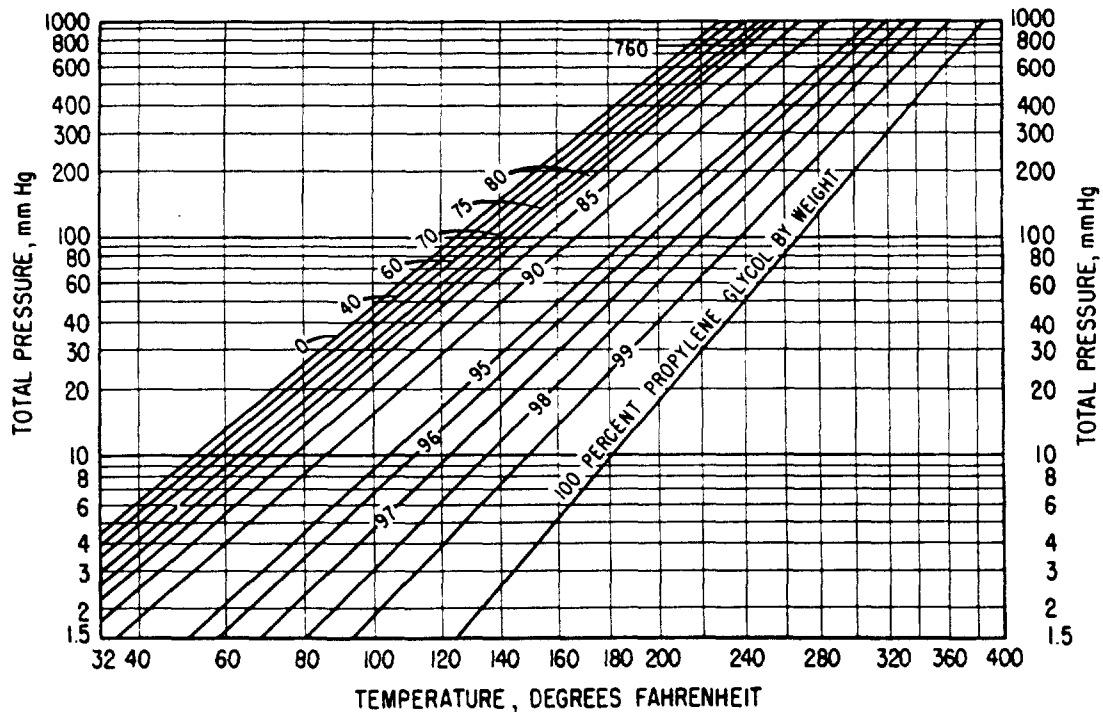
TOTAL PRESSURE OVER AQUEOUS TRIETHYLENE GLYCOL SOLUTIONS VERSUS TEMPERATURE

FIGURE 12



TOTAL PRESSURE OVER AQUEOUS PROPYLENE GLYCOL SOLUTIONS VERSUS TEMPERATURE

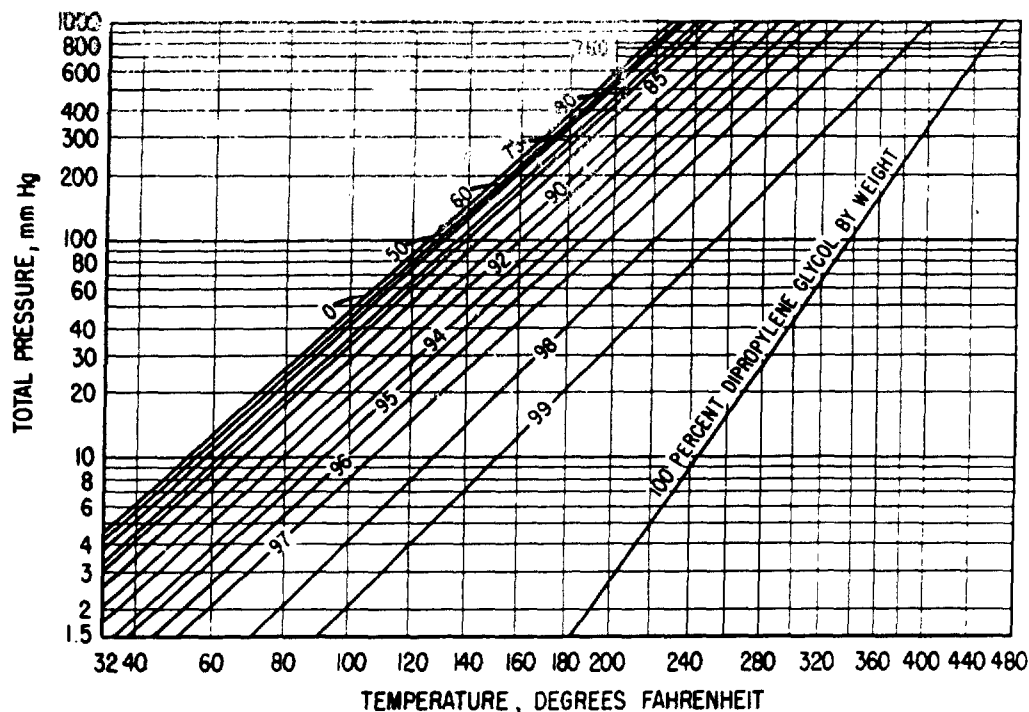
FIGURE 13



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TOTAL PRESSURE OVER AQUEOUS DIPROPYLENE GLYCOL SOLUTIONS VERSUS TEMPERATURE

FIGURE 14



Glycol-water mixtures generally have physical properties between those of water and anhydrous glycols; consequently, the addition of water to a glycol results in a mixture having a boiling point lower than that of the anhydrous glycol. The smaller the concentration of glycol, the lower the boiling point will be. Ethylene glycol-water solution boiling points at pressures of 100, 300 and 600 mm Hg are shown in Figure 15, page 21. The boiling points of aqueous solutions of diethylene, triethylene, propylene and dipropylene glycols are shown in Figures 16 to 19, pages 22-25. To determine the boiling point of an 0.8 molar ethylene glycol-water solution at 600 mm Hg for example, turn to Figure 15 and, on the horizontal scale titled "Mole Fraction Ethylene Glycol", locate the 0.8 molar line. Follow the 0.8 molar line vertically to the point where it intersects the liquid curve for solutions at 600 mm Hg. The boiling point of this solution can then be read off the vertical scale. In this example it is 288° F.

it is often desirable to determine the com-

position of the vapors in equilibrium with any given solution. This information may also be obtained from Figures 15 to 19.

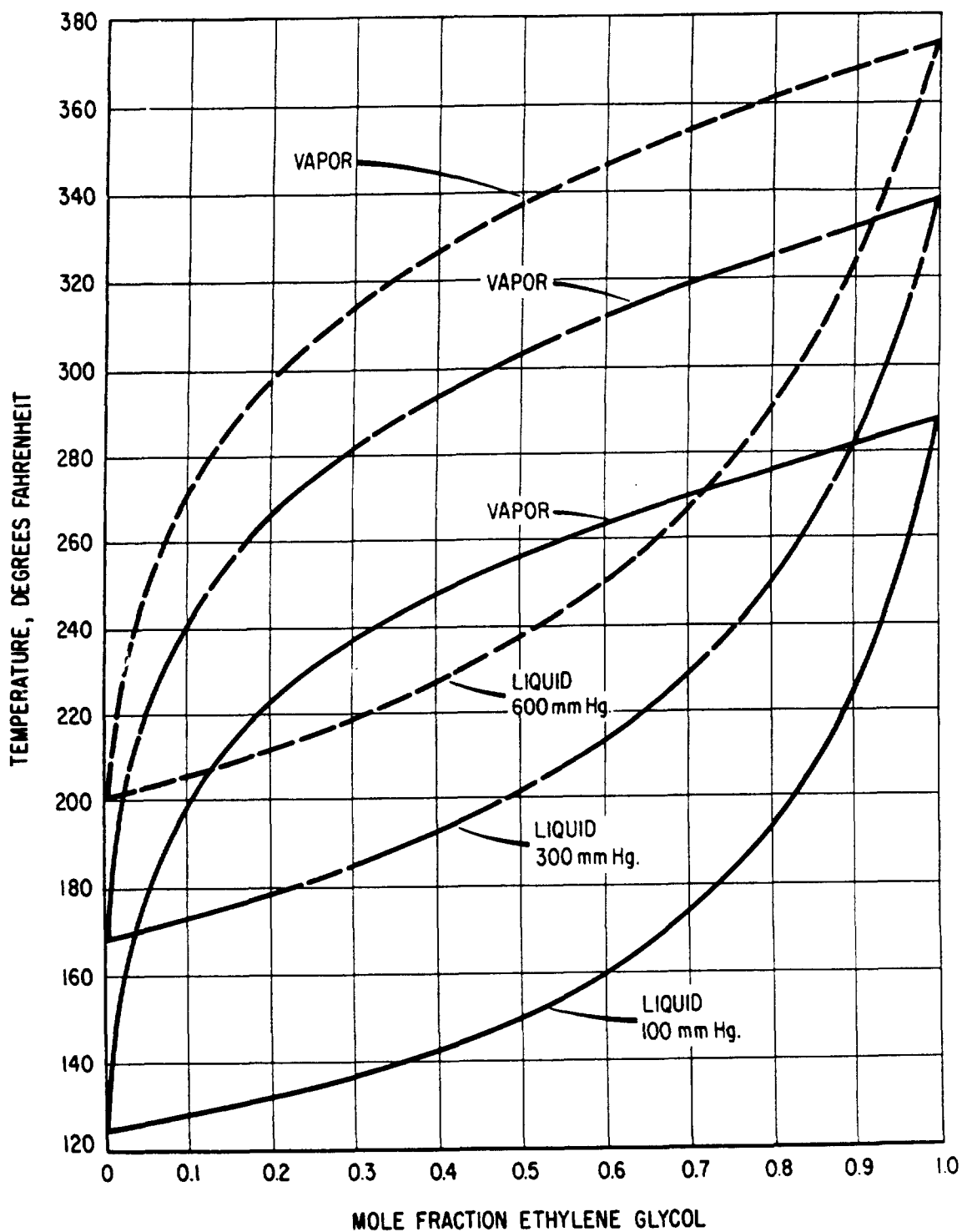
In the example quoted above for an 0.8 molar ethylene glycol solution, the vapor composition is found by reading across the chart on the 288° F line to its point of intersection with the vapor curve—a point which turns out to be directly above 0.156 on the horizontal scale.

It is sometimes desirable to enrich the glycol-water solution periodically by removing part of the water, rather than by adding glycol. These vapor-liquid composition curves are useful in engineering such an operation.

The vapor-liquid equilibrium diagrams presented in this publication are plotted as mole fraction vs. temperature. It is often desirable or necessary to express these values in weight percent or volume percent. Figure A1-A7 in the Appendix can be used for making conversions between mole fraction, weight percent, and volume percent.

VAPOR-LIQUID COMPOSITION CURVES FOR
AQUEOUS ETHYLENE GLYCOL SOLUTIONS

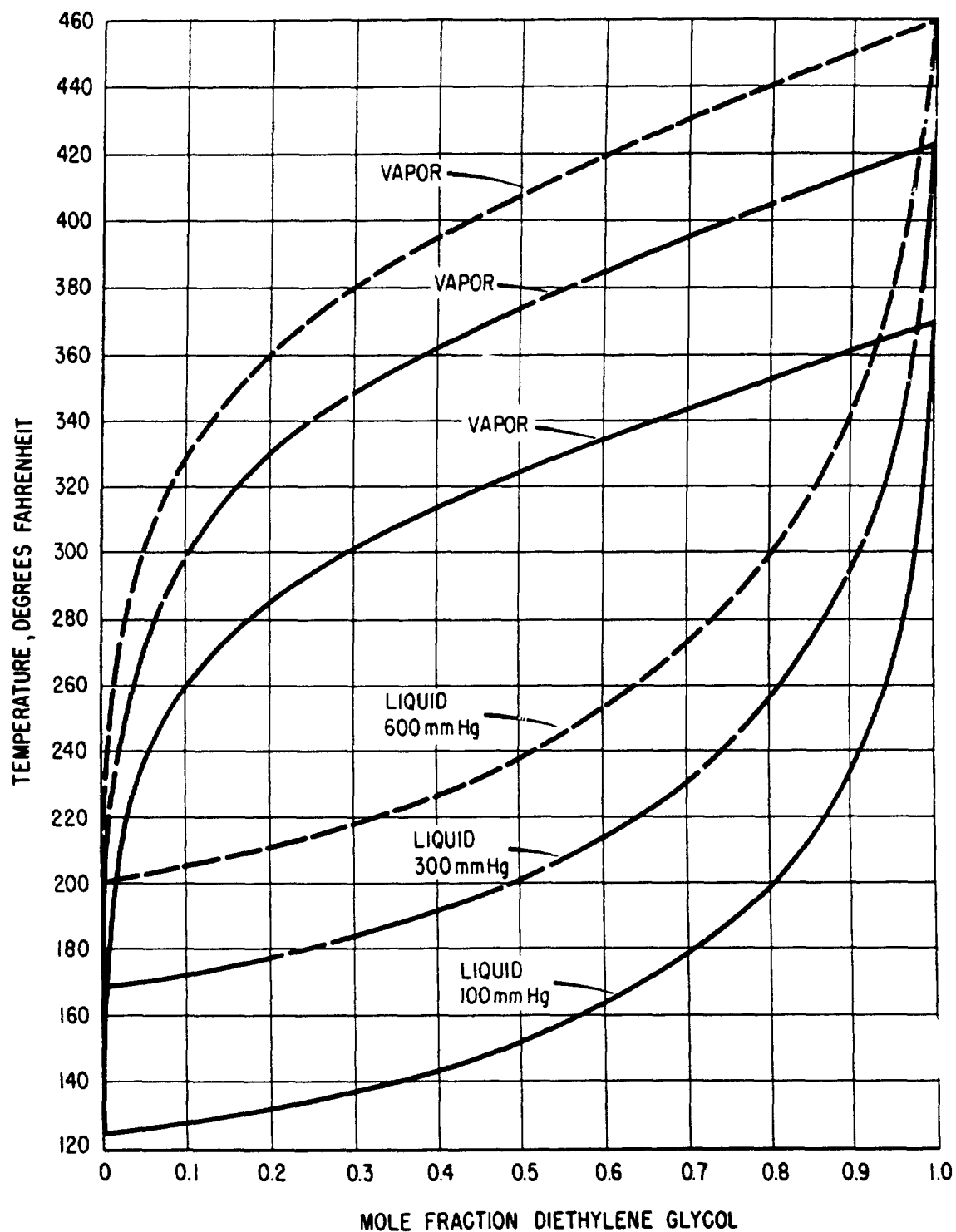
FIGURE 15



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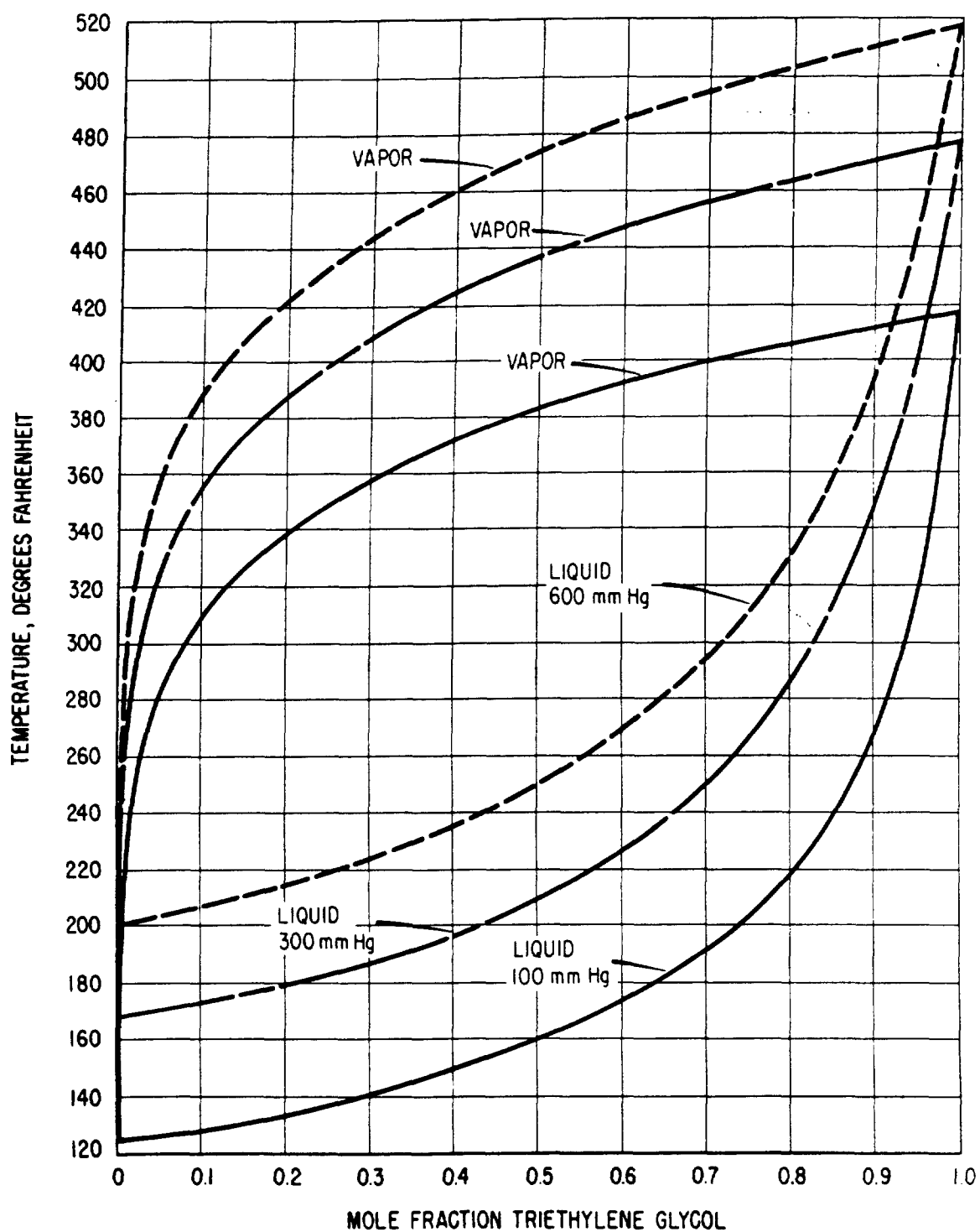
VAPOR-LIQUID COMPOSITION CURVES FOR
AQUEOUS DIETHYLENE GLYCOL SOLUTIONS

FIGURE 16



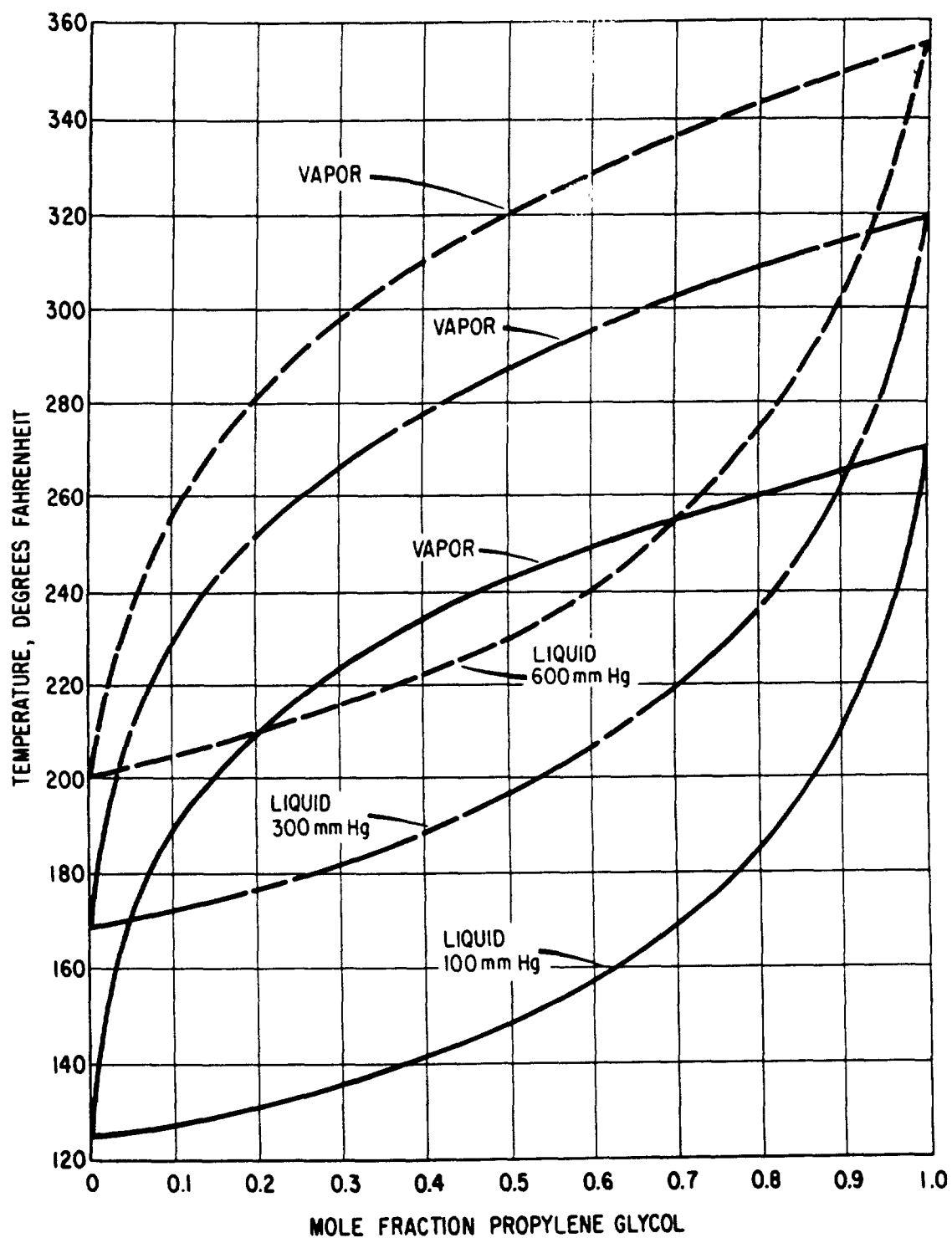
VAPOR-LIQUID COMPOSITION CURVES FOR
AQUEOUS TRIETHYLENE GLYCOL SOLUTIONS

FIGURE 17



VAPOR-LIQUID COMPOSITION CURVES FOR
AQUEOUS PROPYLENE GLYCOL SOLUTIONS

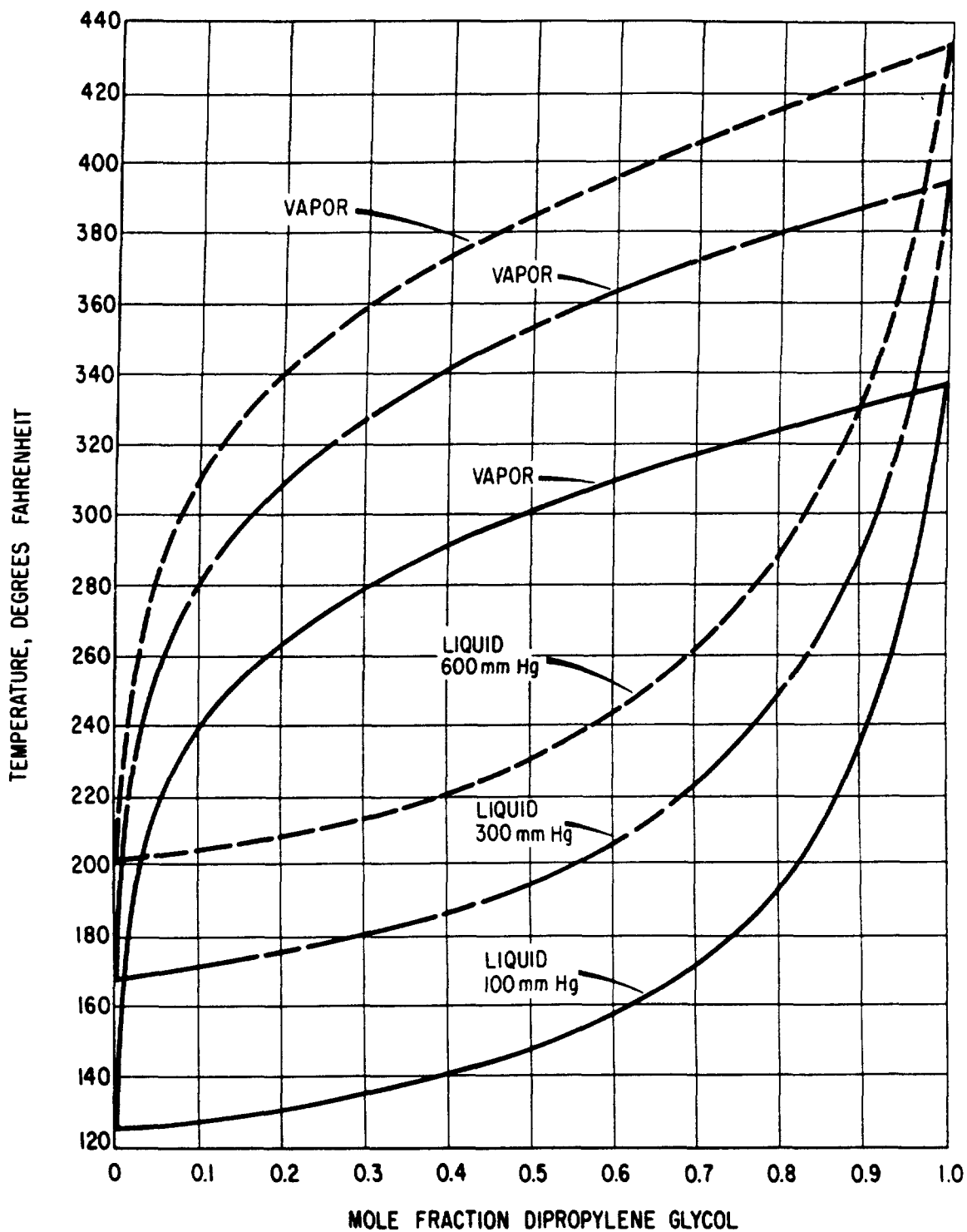
FIGURE 18



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VAPOR-LIQUID COMPOSITION CURVES FOR
AQUEOUS DIPROPYLENE GLYCOL SOLUTIONS

FIGURE 19



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VISCOSITY

Viscosity is a measure of the internal friction of a liquid. As viscosity increases, the tendency to flow decreases. Viscosities of the glycols vary inversely with temperature. Hot glycols flow freely but their viscosities increase as they cool, until they eventually set and fail to flow. The lowest temperature at which a liquid will flow is called the pour

point. The pour points of the glycols are listed below. Ethylene, diethylene, triethylene, and tetraethylene glycols will freeze above their pour points if agitated or seeded.

The viscosities of anhydrous glycols are shown by Figure 20, page 27, and those of aqueous glycol solutions by Figures 21-27, pages 28-31.

GLYCOL	POUR POINT
ETHYLENE GLYCOL	<-75°F
DIETHYLENE GLYCOL	-65°F
TRIETHYLENE GLYCOL	-73°F
TETRAETHYLENE GLYCOL	-42°F
PROPYLENE GLYCOL	-71°F
DIPROPYLENE GLYCOL	-38°F
TRIPROPYLENE GLYCOL	-42°F

These curves are of value where viscosity information is required for pumping, filtering, and piping calculations.

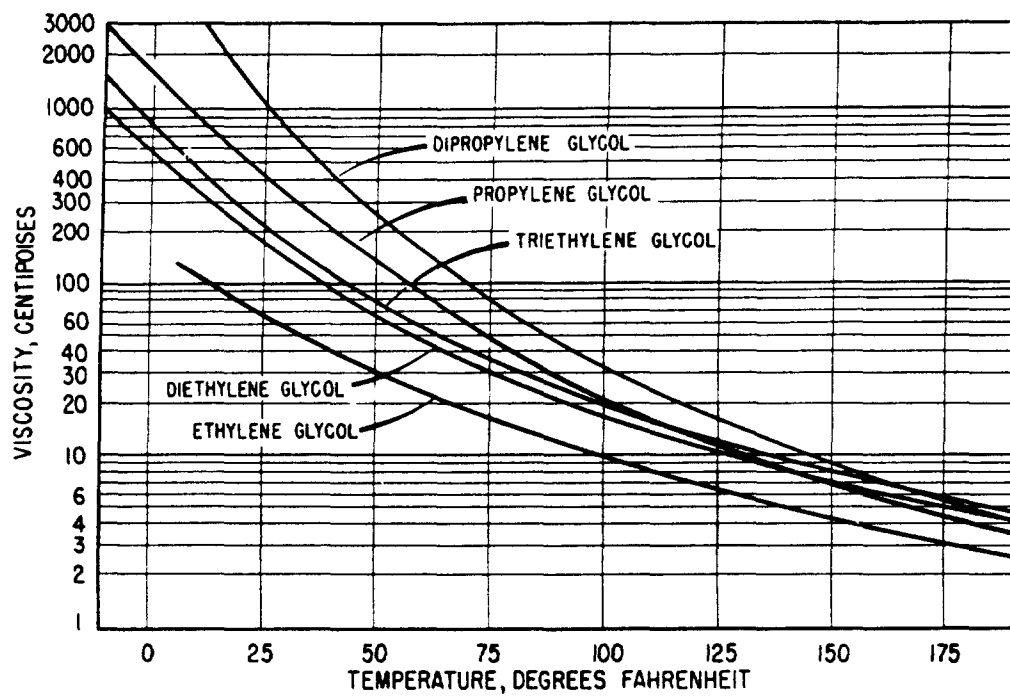
Although the viscosities of the glycols are shown in centipoises, the values can easily be converted to centistokes if desired. To do so, divide centipoises by the density in grams per milliliter at the indicated temperature. The densities of glycols

and aqueous glycol solutions are shown in Figures 31-37, pages 36-42.

The glycols are more fluid than many of the high boiling solvents and plasticizers. For this reason they are often employed, either alone or in combination with other fluids, to reduce the viscosities of compositions with too much body.

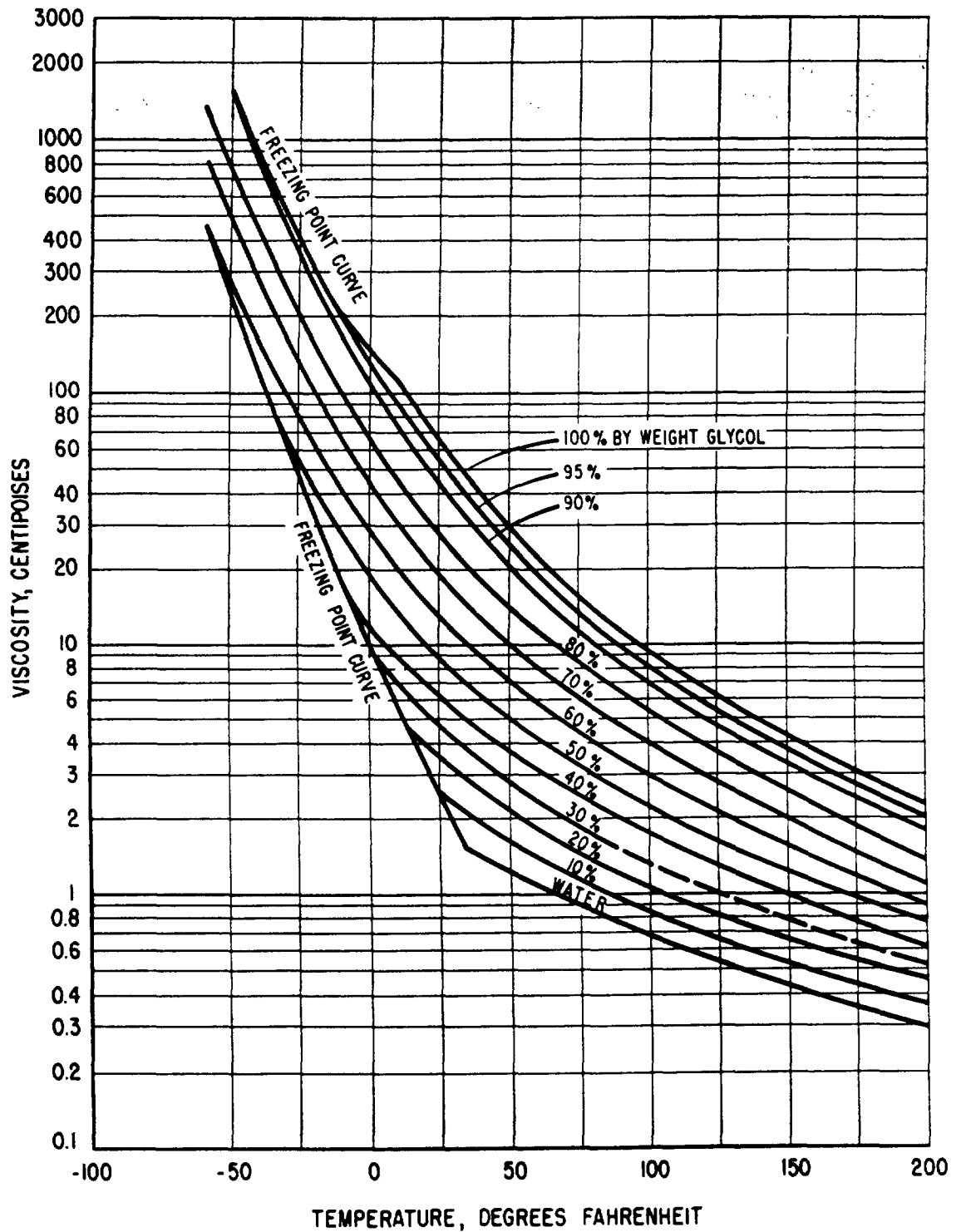
VISCOSITIES OF ANHYDROUS GLYCOLS

FIGURE 20



VISCOSITIES OF AQUEOUS ETHYLENE GLYCOL SOLUTIONS

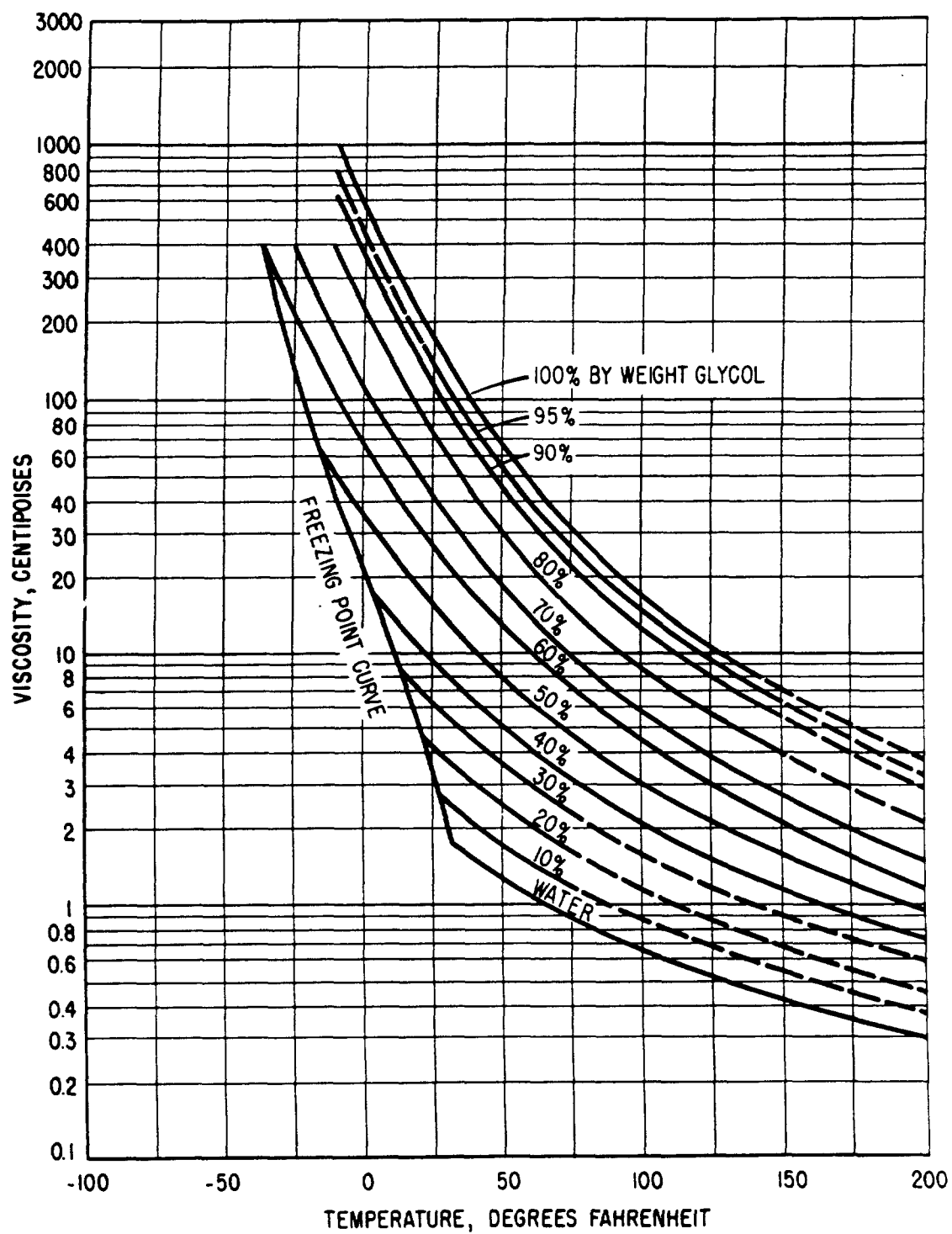
FIGURE 21



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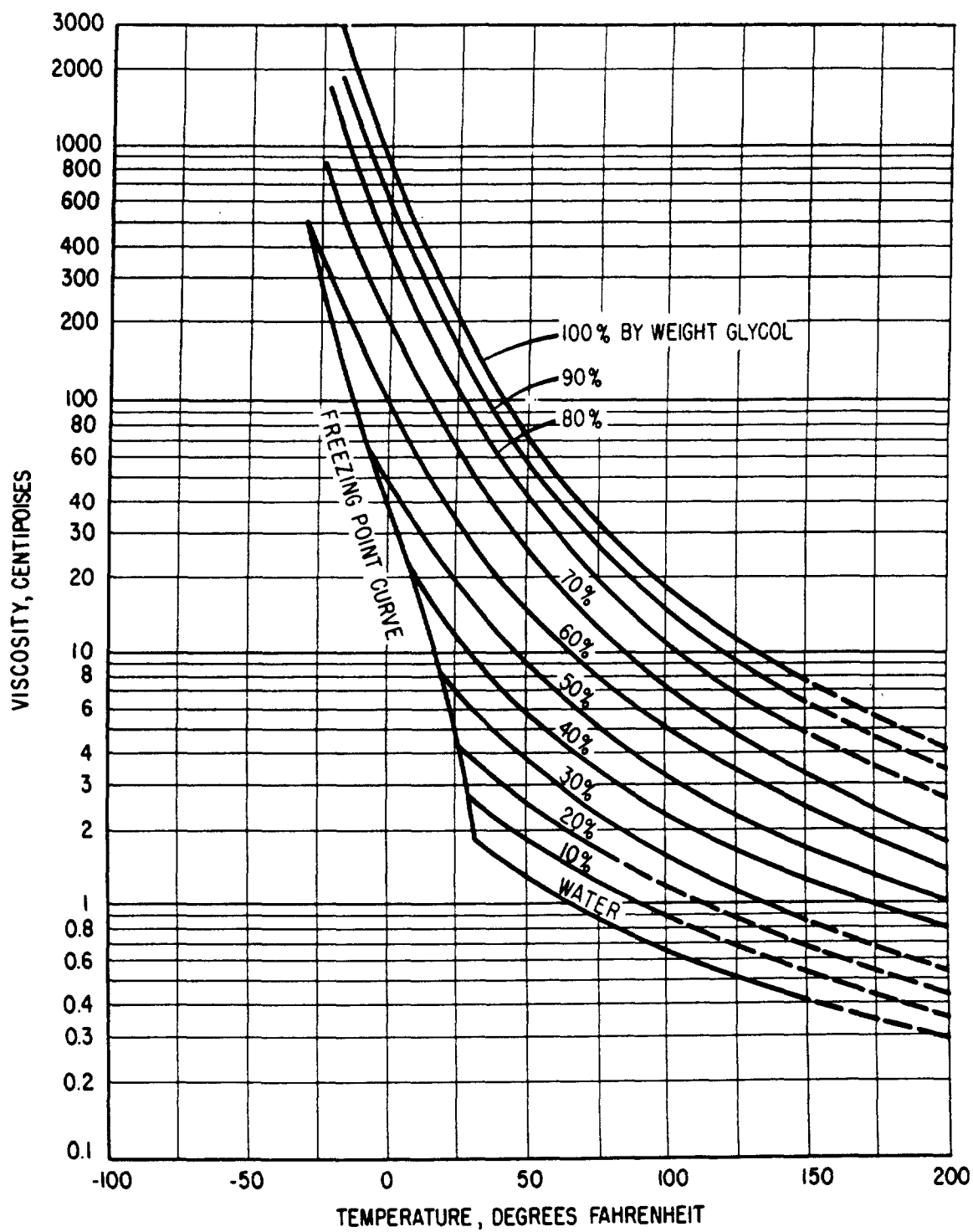
VISCOSITIES OF AQUEOUS DIETHYLENE GLYCOL SOLUTIONS

FIGURE 22



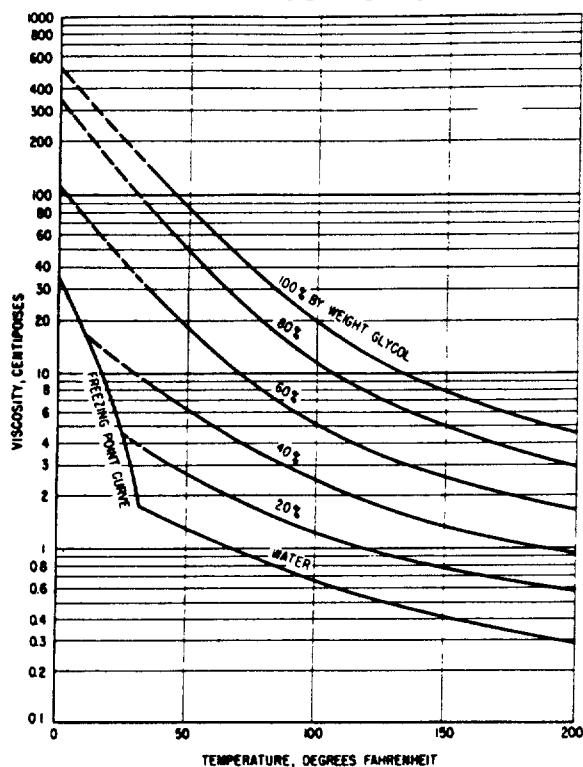
VISCOSITIES OF AQUEOUS TRIETHYLENE GLYCOL SOLUTIONS

FIGURE 23

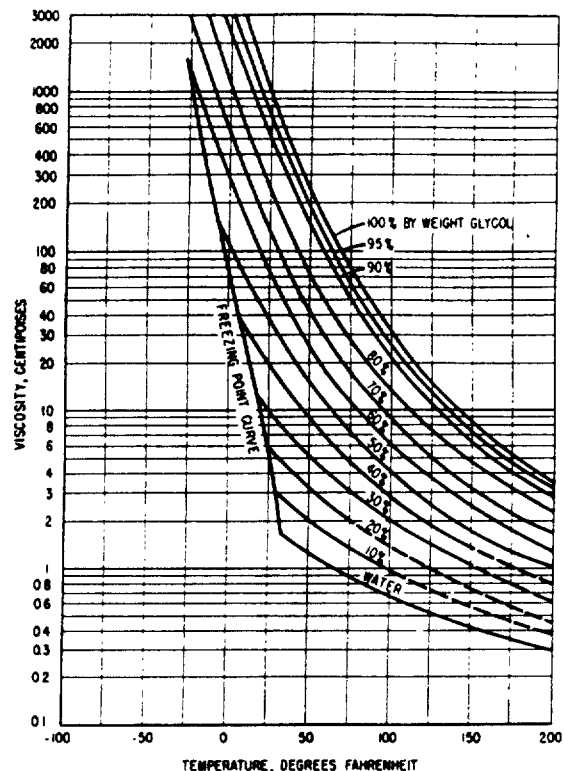


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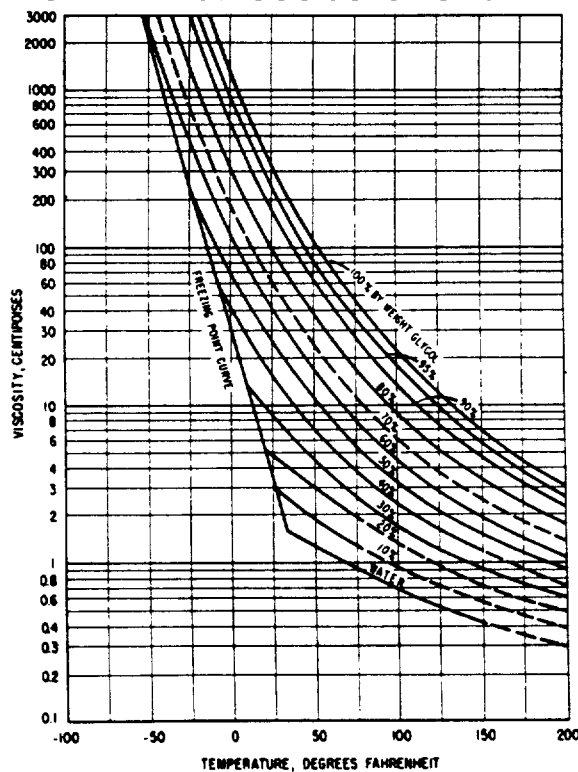
VISCOSITIES OF AQUEOUS TETRAETHYLENE GLYCOL SOLUTIONS FIGURE 24



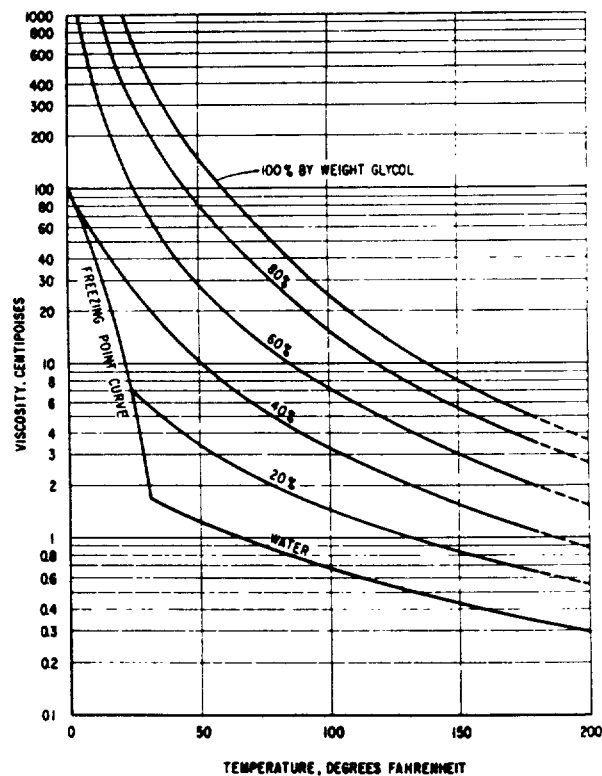
VISCOSITIES OF AQUEOUS DIPROPYLENE GLYCOL SOLUTIONS FIGURE 26



VISCOSITIES OF AQUEOUS PROPYLENE GLYCOL SOLUTIONS FIGURE 25



VISCOSITIES OF AQUEOUS TRIPROPYLENE GLYCOL SOLUTIONS FIGURE 27



FREEZING POINT

When liquids are cooled they eventually either crystallize like ice or become increasingly viscous until they fail to flow and set up like glass. The first type of behavior represents true freezing, the second is known as supercooling.

The glycols do not have sharp freezing points. Under normal conditions, ethylene glycol and the other members of the ethylene series supercool rather than freeze; however, freezing points can be obtained if seeding and agitation are properly employed.

Propylene glycol and its homologs likewise set to glass-like solids, rather than freezing.

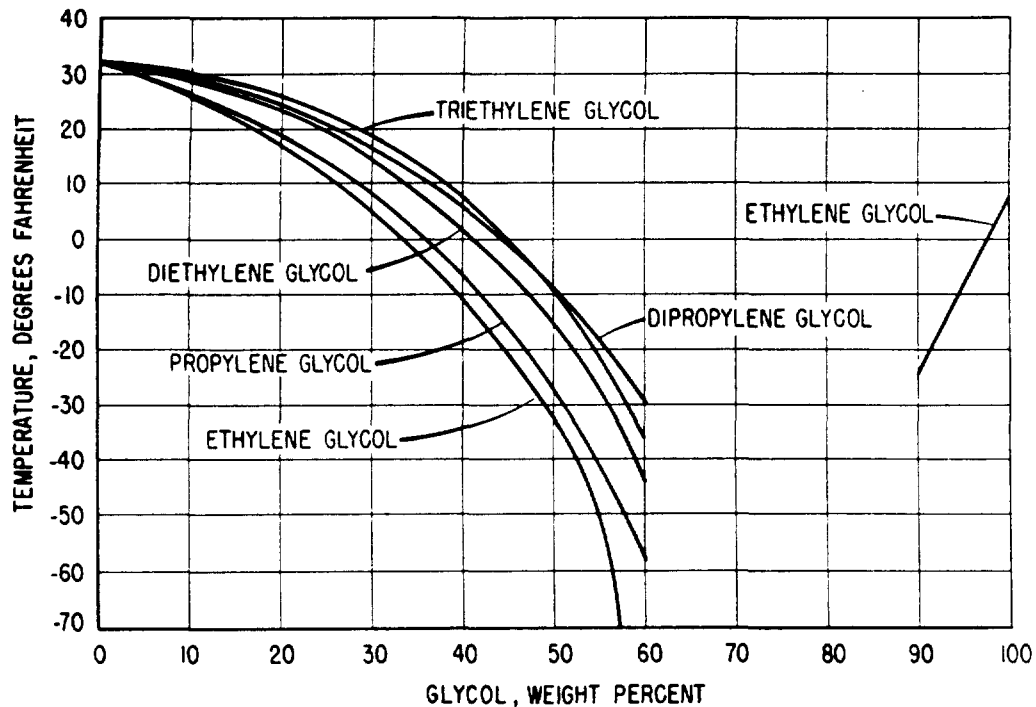
The addition of water to a glycol yields a

solution with a freezing point below that of water. This has led to the extensive use of glycol-water solutions as cooling media at temperatures appreciably below the freezing point of water. Instead of having sharp freezing points, glycol-water solutions become slushy during freezing. As the temperature is lowered, the slush becomes more and more viscous and finally fails to flow.

Freezing points of glycol-water solutions are shown in Figure 28, below. It should be remembered that the freezing points are the temperatures at which the first crystals form, and that even below these temperatures, a slushy solution exists which will still flow.

FREEZING POINTS OF
AQUEOUS GLYCOL SOLUTIONS

FIGURE 28



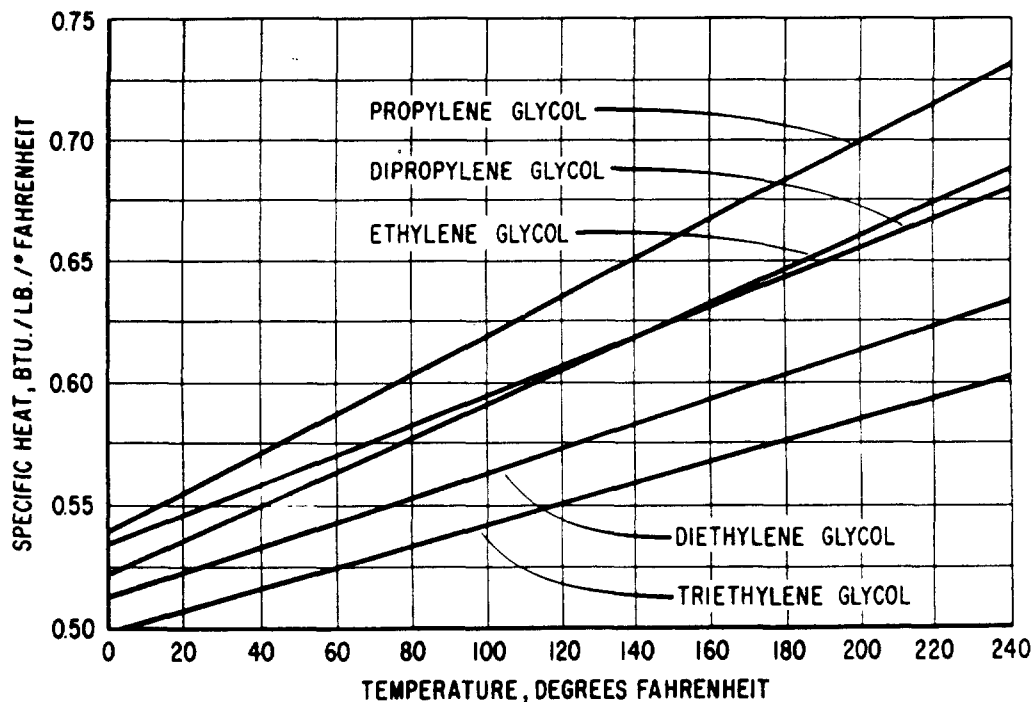
SPECIFIC HEAT

Specific heat is the amount of heat required to raise a unit weight of substance one degree in temperature. It can be expressed either as calories per gram per degree Centigrade, or as British Thermal Units per pound per degree Fahrenheit, and the expressions are numerically equal. The specific heat of water is approximately 1 at ordinary temperatures. Specific heat varies with temperature, and the specific heats of the glycols are shown in Figure 29, below for temperatures from 0° F to 240° F.

Specific heats of glycol-water solutions are shown in Figure 30. As would be expected, the addition of water to a glycol increases the specific heat. This is important whenever glycol solutions are considered for use as heat transfer media. A liquid with a high specific heat will do more work per unit weight than one with a low specific heat if all other factors are equal.

SPECIFIC HEAT OF
ANHYDROUS GLYCOLS

FIGURE 29



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**SPECIFIC HEATS OF AQUEOUS GLYCOL
SOLUTIONS (Btu/lb/°F)**

FIGURE 30

GLYCOL, % BY WEIGHT							Temp. °C
Temp. °F	100	80	60	40	20	10	
ETHYLENE GLYCOL							
60	.563	.660	.757	.855	.940	.976	15.6
80	.576	.673	.769	.864	.942	.977	26.7
100	.590	.685	.780	.872	.944	.978	37.8
120	.604	.697	.792	.880	.946	.979	48.9
140	.618	.710	.803	.888	.948	.980	60.0
160	.632	.722	.814	.896	.950	.981	71.1
180	.646	.735	.825	.905	.952	.982	82.2
200	.660	.748	.837	.914	.954	.982	93.3
220	.674	.761	.849	.922	.956	.983	104.4
240	.688	.774	.861	.930	.958	.984	115.5
DIETHYLENE GLYCOL							
60	.543	.631	.736	.849	.922	.949	15.6
80	.555	.645	.749	.855	.927	.954	26.7
100	.565	.659	.762	.861	.932	.960	37.8
120	.575	.672	.774	.868	.937	.965	48.9
140	.583	.686	.787	.874	.943	.970	60.0
160	.593	.700	.800	.880	.948	.975	71.1
180	.603	.714	.813	.886	.954	.980	82.2
200	.613	.728	.826	.893	.960	.985	93.3
220	.623	.742	.839	.900	.965	.990	104.4
240	.634	.756	.852	.907	.971	.995	115.5
TRIETHYLENE GLYCOL							
60	.525	.637	.749	.866	.935	.979	15.6
80	.534	.648	.758	.872	.938	.980	26.7
100	.540	.659	.768	.878	.941	.981	37.8
120	.550	.669	.777	.884	.944	.981	48.9
140	.562	.680	.787	.890	.946	.982	60.0
160	.569	.690	.796	.895	.949	.983	71.1
180	.577	.701	.806	.901	.952	.984	82.2
200	.586	.711	.815	.907	.955	.985	93.3
220	.595	.722	.825	.913	.957	.985	104.4
240	.605	.732	.834	.919	.960	.986	115.5
PROPYLENE GLYCOL							
60	.587	.687	.795	.900	.970	.985	15.6
80	.603	.702	.808	.907	.972	.986	26.7
100	.619	.717	.821	.913	.975	.988	37.8
120	.635	.733	.833	.919	.977	.990	48.9
140	.651	.748	.846	.925	.980	.991	60.0
160	.667	.763	.857	.930	.983	.992	71.1
180	.683	.778	.871	.936	.984	.994	82.2
200	.699	.794	.882	.944	.987	.995	93.3
220	.715	.809	.895	.949	.990	.996	104.4
240	.731	.824	.907	.954	.993	.998	115.5
DIPROPYLENE GLYCOL							
60	.570	.687	.801	.900	.967	.985	15.6
80	.582	.698	.810	.905	.970	.986	26.7
100	.594	.708	.819	.910	.972	.988	37.8
120	.606	.718	.828	.915	.974	.990	48.9
140	.618	.728	.836	.920	.976	.991	60.0
160	.631	.739	.845	.924	.978	.993	71.1
180	.644	.749	.854	.929	.980	.995	82.2
200	.656	.760	.863	.934	.983	.997	93.3
220	.668	.770	.872	.939	.985	.998	104.4
240	.680	.781	.881	.944	.988	.999	115.5

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DENSITY

Density is the weight per unit volume of a mass. Density varies with temperature and the graphs on Pages 36-42 show the densities of Dow glycols and glycol-water solutions over a range of temperatures. Figures 35 and 36 show that the densities of propylene glycol-water solutions and dipropylene glycol-water solutions may be the same for two concentrations. Therefore, density alone is not a reliable method of testing for solutions concentration.

Although the graphs in this booklet show the densities of the glycols and glycol-water solutions, it may sometimes be desirable to know the specific gravities at certain temperatures. The specific gravity can be obtained by dividing the density of the glycol or glycol-water solution by the density of water. Densities, and therefore specific gravities, vary with temperature hence it is necessary to indicate the temperatures of both the glycol and water. A specific gravity of ethylene glycol, the density of which is 1.1097 at 77°F, when compared to water, which has a density of 0.9970 at 77°F, could be calculated as follows:

Specific Gravity of Ethylene Glycol at

$$77^{\circ}\text{F}/77^{\circ}\text{F} = \frac{1.1097}{0.9970} = 1.1130$$

Specific gravities may be expressed at various temperatures, as follows:

$$\begin{aligned} &\text{Specific Gravity of} \\ &\text{Ethylene Glycol at } "x" ^{\circ}\text{F} / "y" ^{\circ}\text{F} * = \\ &\frac{\text{Density of Ethylene Glycol at } "x" ^{\circ}\text{F}}{\text{Density of Water at } "y" ^{\circ}\text{F}} \end{aligned}$$

* "x" and "y" may be the same or different numbers

The weight per gallon of a glycol or aqueous glycol solution is determined as follows:

$$\text{Density at } t^{\circ}\text{C} \times 8.345 = \text{lb./gal. at } t^{\circ}\text{C}$$

Weight per Gallon at 77°F

Ethylene Glycol.....	9.26 lb
Diethylene Glycol.....	9.29 lb
Triethylene Glycol.....	9.34 lb
Tetraethylene Glycol.....	9.34 lb
Propylene Glycol.....	8.62 lb
Dipropylene Glycol.....	8.54 lb
Tripropylene Glycol.....	8.51 lb

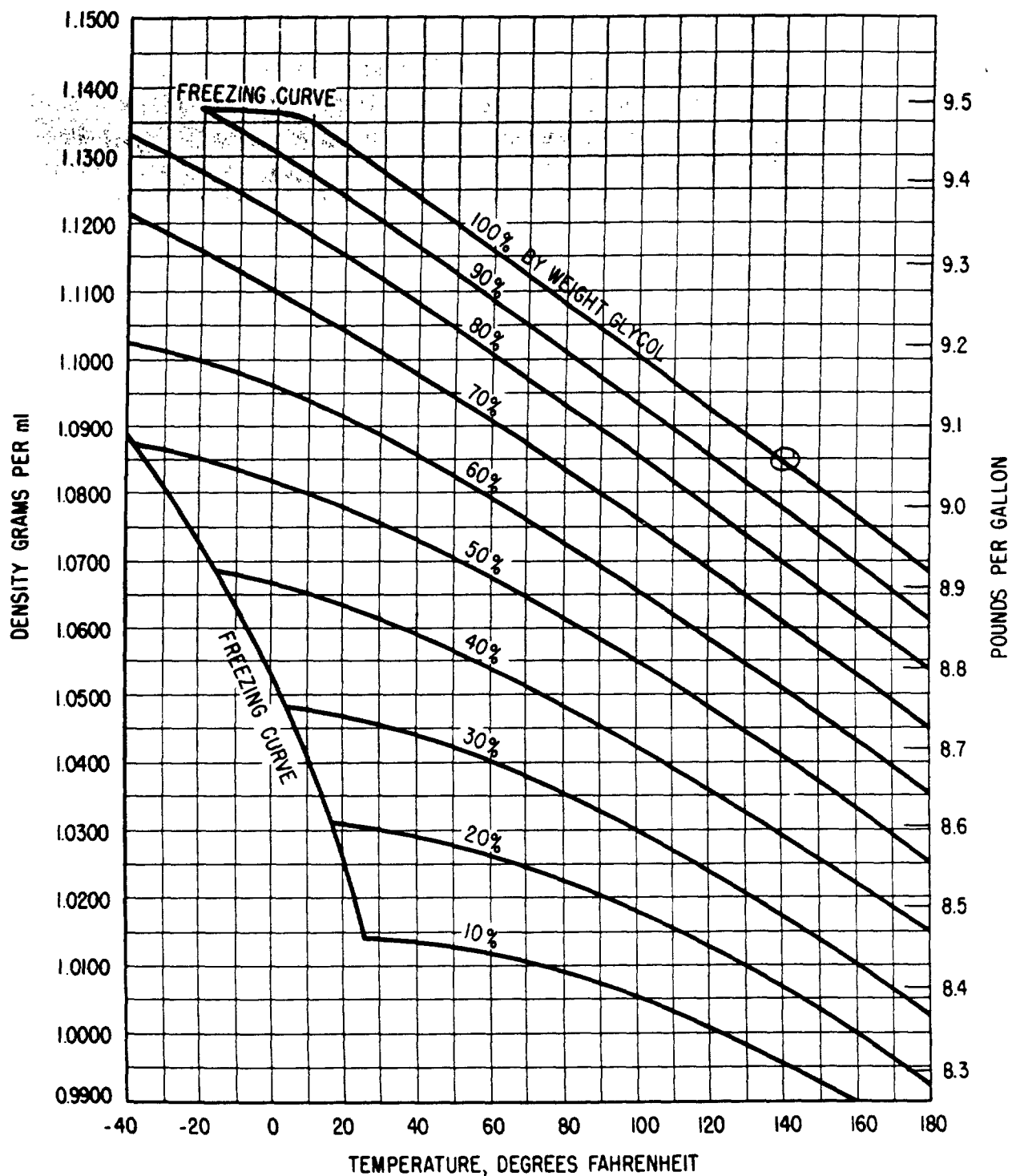
Volume changes resulting from heating or cooling glycols or glycol-water solutions may be readily calculated from the data presented in Figures 31-37. For example, in heating 10,000 lb. of ethylene glycol from 77°F to 140°F, the increase in volume will be:

$$\frac{10,000}{9.05} - \frac{10,000}{9.26} = 1105 - 1080 = 25 \text{ gal}$$

(140°F) (77°F)

DENSITIES OF AQUEOUS
ETHYLENE GLYCOL SOLUTIONS
(PERCENT BY WEIGHT)

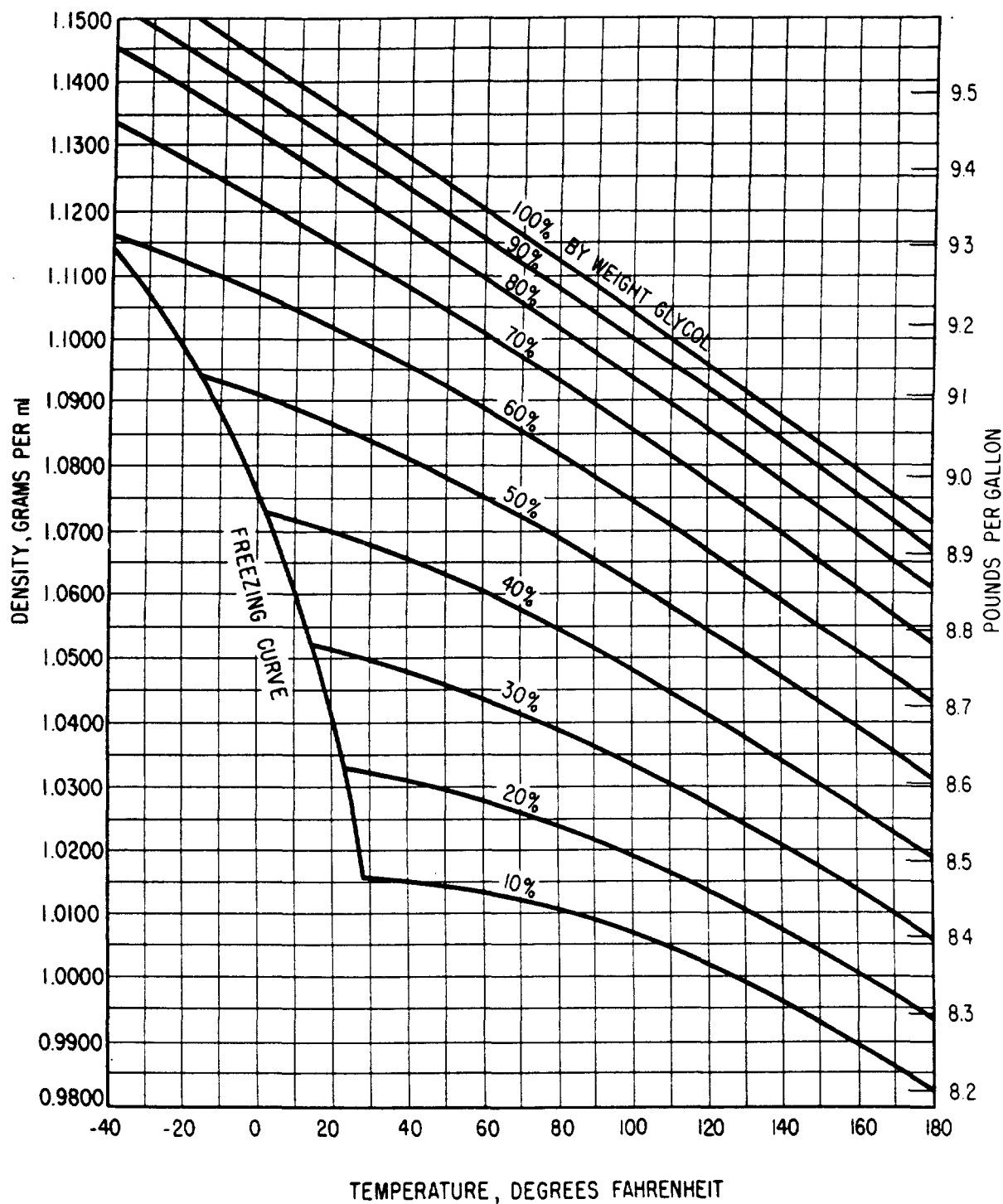
FIGURE 31



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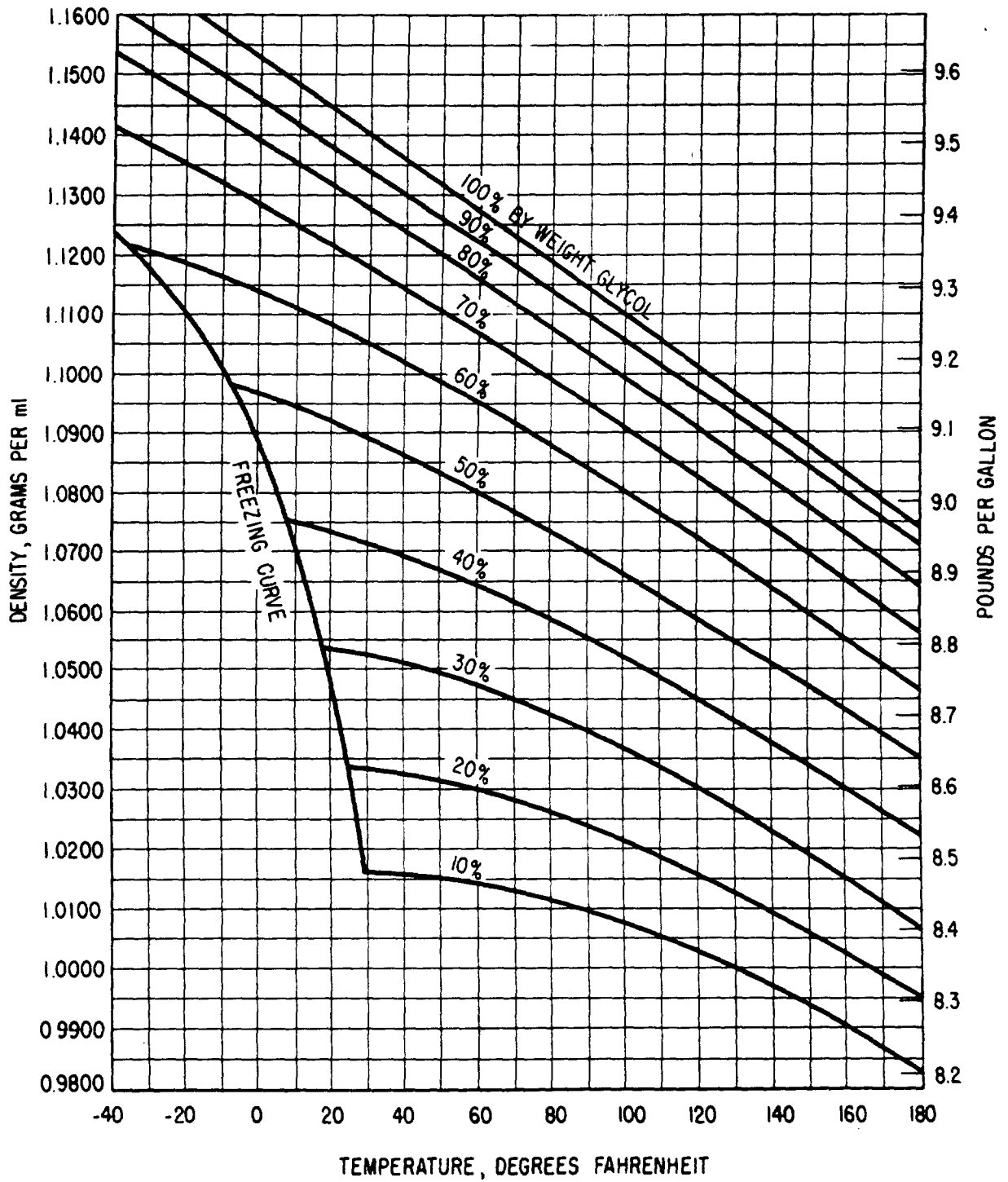
DENSITIES OF AQUEOUS
DIETHYLENE GLYCOL SOLUTIONS
(PERCENT BY WEIGHT)

FIGURE 32



DENSITIES OF AQUEOUS
TRIETHYLENE GLYCOL SOLUTIONS
(PERCENT BY WEIGHT)

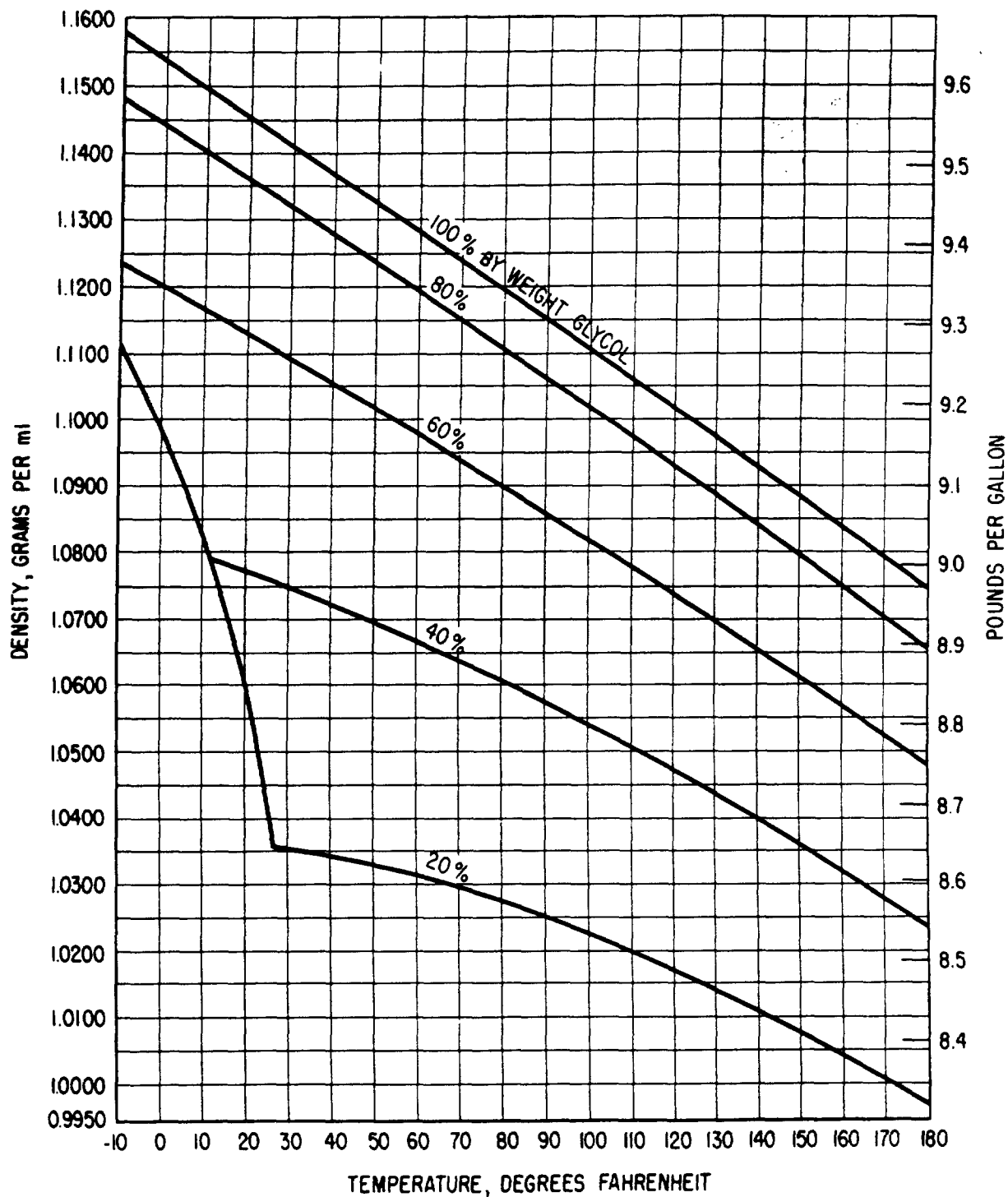
FIGURE 33



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DENSITIES OF AQUEOUS
TETRAETHYLENE GLYCOL SOLUTIONS
(PERCENT BY WEIGHT)

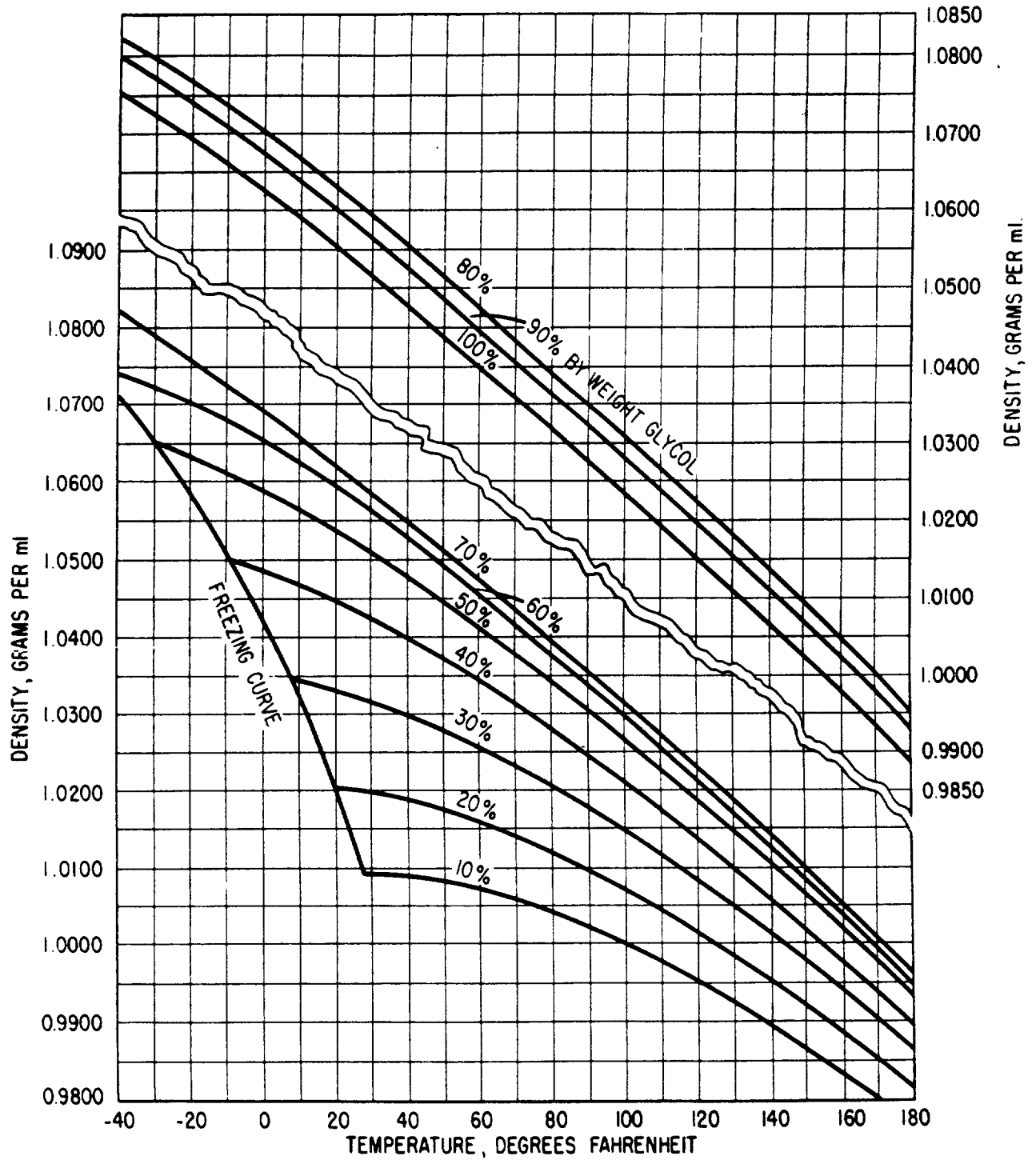
FIGURE 34



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**DENSITIES OF AQUEOUS
PROPYLENE GLYCOL SOLUTIONS
(PERCENT BY WEIGHT)**

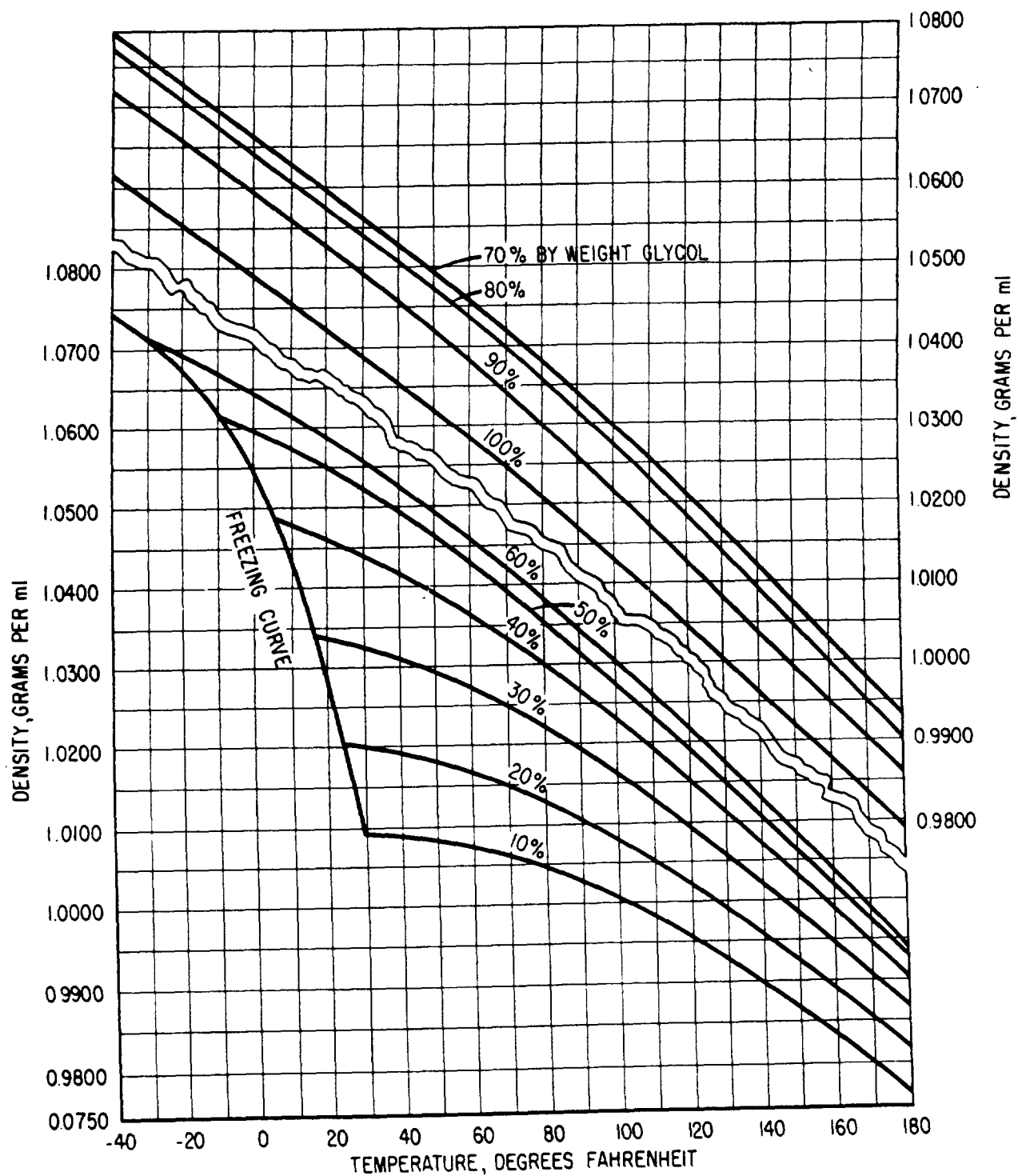
FIGURE 35



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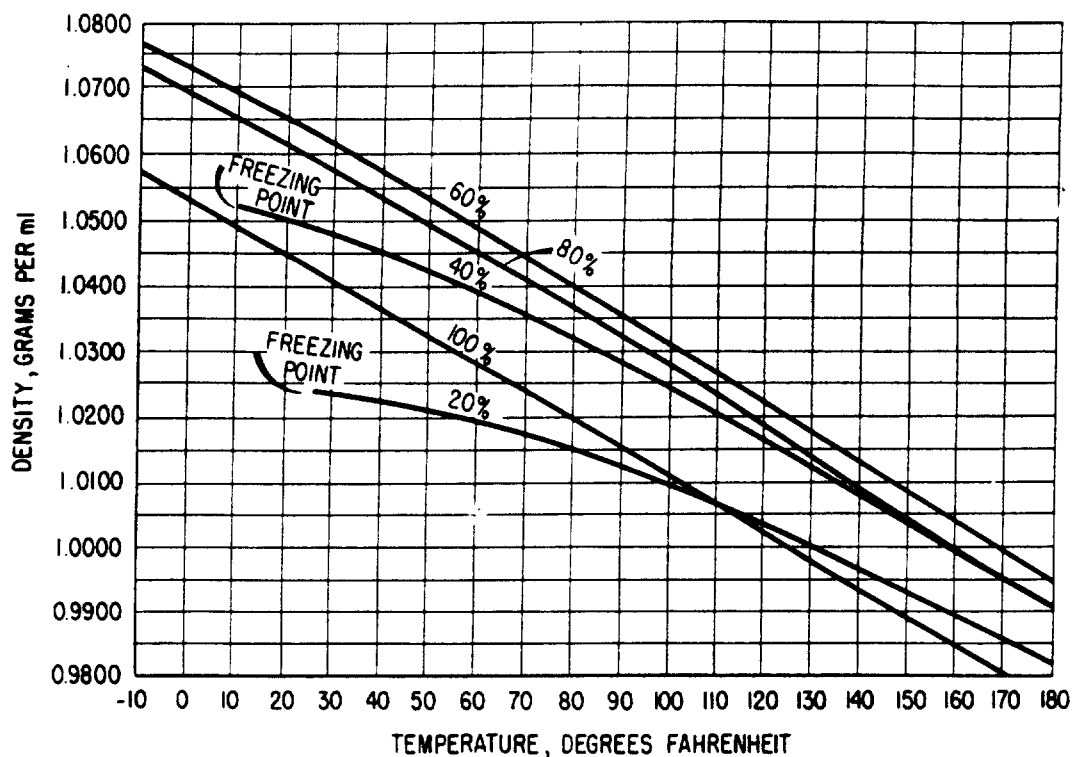
DENSITIES OF AQUEOUS
DIPROPYLENE GLYCOL SOLUTIONS
(PERCENT BY WEIGHT)

FIGURE 36



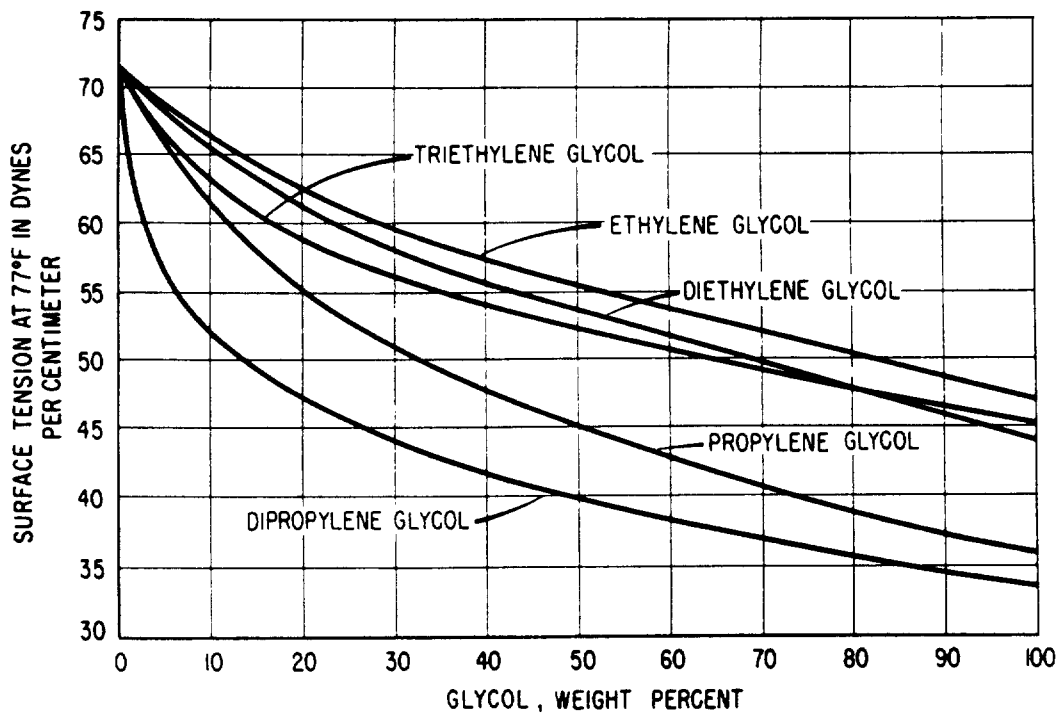
**DENSITIES OF AQUEOUS
TRIPROPYLENE GLYCOL SOLUTIONS
(PERCENT BY WEIGHT)**

FIGURE 37



**SURFACE TENSIONS OF AQUEOUS
SOLUTIONS OF GLYCOLS AT 77°F**

FIGURE 38



SURFACE TENSION

Surface tension is that force on the surface of a liquid which tends to diminish the surface area to the minimum. It is an important property when the wetting or penetrating ability of a liquid is considered.

Surface tensions of the glycols are lower than that of water. Solutions of glycol and water have varying surface tensions, de-

pending on the concentration of glycol in the solution. This is illustrated by Figure 38, page 42.

When heat is applied to liquids their surface tension is reduced. In the case of glycols, however, heat does not affect the surface tension materially except near the boiling points.

FLAMMABILITY

The flash and fire points of the seven glycols are above the boiling point of water. For this reason the glycols present practically no

fire hazard in storage or handling. Flash and fire points determined by the ASTM Cleveland Open Cup method are as follows:

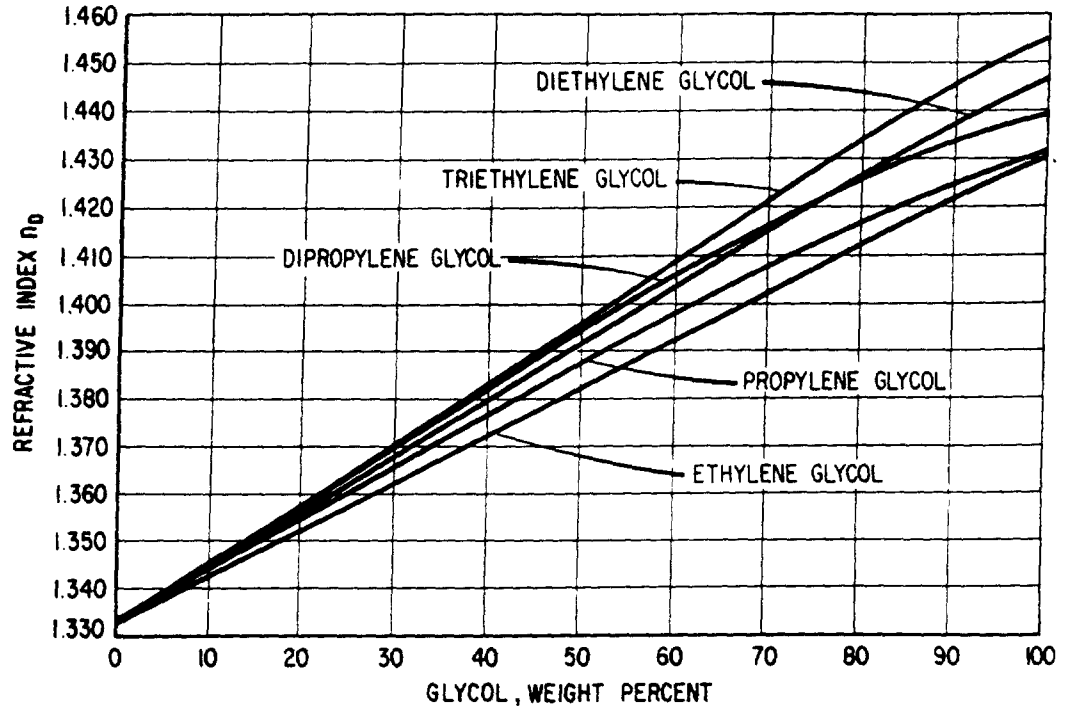
GLYCOL	FLASH POINT		FIRE POINT	
	°F	°C	°F	°C
ETHYLENE GLYCOL	240	116	245	119
DIETHYLENE GLYCOL	280	138	290	142
TRIETHYLENE GLYCOL	320	160	330	166
TETRAETHYLENE GLYCOL	365	185	375	191
PROPYLENE GLYCOL	215	102	220	104
DIPROPYLENE GLYCOL	260	127	260	127
TRIPROPYLENE GLYCOL	285	141	310	154

Note: These properties are laboratory results on pure compounds or typical of the product but should not be confused with or regarded as specifications.

STANDARD

REFRACTIVE INDICES OF AQUEOUS GLYCOL SOLUTIONS AT 77°F

FIGURE 39



REFRACTIVE INDEX

The refractive index of a material is an optical measurement of its ability to bend a beam of light entering it. The refractive index may be used to determine the purity of

the material. Figure 39, above, shows the refractive indices of the glycols and their aqueous solutions at 77°F

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TOXICOLOGICAL CONSIDERATIONS

ACUTE ORAL TOXICITY

All of the glycols considered in this booklet display a low acute oral toxicity. The accompanying table lists the LD₅₀ values obtained when the various glycols are fed in single oral doses to rats.

Glycol	LD ₅₀ , gm/kg
Ethylene.....	5.5
Diethylene.....	14.8
Triethylene.....	22.0
Tetraethylene.....	32.8
Propylene.....	32.5
Dipropylene.....	14.8
Tripropylene.....	3.0*

* Largest dose survived by all rats tested. 10.0 gm/kg caused the death of all the rats tested.

Human experience indicates that man seems to be more susceptible to injury caused by ethylene glycol and diethylene glycol than laboratory animals. The lethal dose for humans for ethylene glycol appears to be about 1.4 ml./kg. and for diethylene glycol about 1.0 ml./kg.

CHRONIC ORAL TOXICITY

The glycols vary considerably in chronic oral toxicity. Propylene glycol is especially low in this respect; studies in which rats were fed drinking water containing as much as 10 percent propylene glycol over a period of 140 days showed no apparent ill effects, while other investigations have revealed that rats can tolerate up to 4.9 percent propylene glycol in the diet for 24-month periods without significant effect on growth rate. However, minor liver damage was observed. Because of its low chronic oral

toxicity, propylene glycol is considered safe for use in foods and pharmaceuticals. Since 1942, it has been included in *New and Non-Official Remedies* as a proper ingredient for pharmaceutical products and is listed in the *United States Pharmacopoeia*. It is widely used and accepted as an ingredient of dental preparations and is considered generally recognized as safe for use in foods if used in accordance with good manufacturing practices.

Triethylene glycol and tetraethylene glycol are likewise low in chronic oral toxicity. The first of these has been fed in the drinking water of rats at 4 percent concentration and over a two-year period with no apparent ill effect. Similarly, no adverse effects have been evidenced in rats fed diets containing 2.5 percent of the second material for 90 days. Because of their low chronic oral toxicity, triethylene glycol and tetraethyl-

ene glycol have been adjudged safe for many applications where intake is limited.

In contrast, ethylene glycol and diethylene glycol are regarded as too toxic for applications where there is a possibility of ingestion. The feeding of rats for two years on diets containing 0.5 and 1.0 gm./kg. of ethylene glycol caused a toxic action centered chiefly in the kidneys. The ethylene glycol shortened the life span of the rats, produced calcium oxalate bladder calculi, severe renal tubular atrophy, and fatty degeneration in the liver. With diethylene glycol, two-year feeding studies revealed that one-percent concentrations retarded growth slightly and produced a low incidence of calcium oxalate bladder calculi accompanied by slight kidney and infrequent liver damage.

Sufficient studies have not been carried out on dipropylene glycol and tripropylene glycol to permit conclusions to be drawn regarding their suitability for uses involving ingestion, although they are permitted in various indirect additive food uses under the Food Additive Regulations under the Federal Food, Drug and Cosmetic Act.

SKIN IRRITATION AND ABSORPTION

The glycols produce a negligible degree of irritation when applied to the skin and there is no evidence to indicate that they are absorbed through the skin in quantities sufficient to produce systemic injury. A slight macerating action comparable to that caused by glycerine may result from very

severe prolonged exposures to ethylene glycol and diethylene glycol under severe conditions of exposure, such as actually bathing the body with ethylene glycol or diethylene glycol for prolonged periods of time, it is possible that enough of the material might be absorbed to cause systemic injury. Because of these considerations, the use of glycols—other than propylene glycol and possibly triethylene glycol and tetraethylene glycol—in preparations intended to be applied over extensive areas of the body is considered unwise.

VAPOR INHALATION

Inhalation of the vapors of the glycols appears to present no significant hazard in ordinary applications. Atmospheric concentrations of ethylene glycol vapors in the order of 0.35 to 0.40 mg./liter (140-160 ppm.) for 80 periods of 8 hours each during 16 weeks caused no injury in mice or rats. However, it would seem wise to avoid inhaling vapors rising from heated material, particularly if exposure is prolonged and repeated. Limited human experience indicates that breathing of mists of these glycols may be harmful, therefore, it would seem wise to avoid breathing spray mists of these materials. Prolonged inhalations of saturated vapors of triethylene glycol and propylene glycol have produced no ill effects. Very little work has been done on the vapor toxicity of the other glycols; however, because of their very low vapor pressures and low systemic toxicities, it is very unlikely that injury would occur due to vapor inhalation.

GENERAL CONCLUSION: The glycols discussed in this book have a relatively low degree of toxicity and present no serious hazard insofar as their normal industrial handling and use are concerned.

The toxicological information on these glycols has been reviewed and summarized in *Patty's Industrial Hygiene and Toxicology*, second revised edition, Volume II, 1962, Chapter 35, which is published by Interscience Publishers, a division of John Wiley and Sons, New York.

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STORAGE OF GLYCOLS

INTRODUCTION

The storage of glycols presents no unusual problems. A tank truckload can be emptied into available drums or tanks and kept with little difficulty since glycols do not readily solidify, can easily be handled without hazard of toxicity, and are noncorrosive. However, if more elaborate storage facilities are required for ease of handling or to maintain purity, special precautions should be taken. The following information is presented as a guide to trouble-free storage of glycols.

STORAGE TANKS

Ordinary steel tanks are normally satisfactory for glycol storage. However, during extended storage in such tanks, a slight coloration may develop due to iron contamination. This problem can be avoided by using stainless steel or aluminum tanks, or by coating an ordinary steel tank with a vinyl or phenolic resin. Satisfactory vinyl resins include Durakon¹, Lankote², and Amercoat 23³ resins. Among phenolic materials, Heresite⁴ resin has met with approval.

¹ Product of United Paint & Chemical Company, Highland Park, Mich.

² Product of J. Landau Company, Newark, New Jersey.

³ Product of Amercoat Corporation, Evanston, Illinois.

⁴ Product of Heresite Chemical Company, Manitowoc, Wisconsin.

Before a storage tank is coated, all rough spots caused by welding and machining must be completely removed until the surface is perfectly smooth. If this is not done, pinholes may form in the coating. Then the tank must be carefully cleaned. Usually five or six coats of resin are necessary to insure good protection and each coat should be thoroughly dried before the next is applied. Warm air can be used to hasten drying.

Both vertical and horizontal tanks are available for storage. Vertical tanks are more economical to install and occupy less space, while horizontal tanks are easier to maintain and repair. If future compartmentation of the tank is likely, a horizontal tank should be chosen since it is easier to modify. Usually, however, the decreased maintenance generally required with horizontal tanks does not offset their higher cost and greater space requirements; hence vertical tanks are generally recommended.

Vertical tanks should be diked and all vegetation in the vicinity should be removed to reduce the possibility of fire.

Storage tanks located on the ground are recommended in preference to underground tanks because above-ground installation and maintenance are cheaper and less troublesome. With underground storage, gauging and pumping are also more difficult. In addition, leakage is more difficult to detect and usually more expensive to correct.

For continuous storage of glycols at low

temperatures, to prevent pumping problems due to high viscosity and freezing, insulation and heat are required. Ethylene, diethylene and triethylene glycols should not be permitted to drop below 25°F, while tetraethylene, propylene, dipropylene and tripropylene glycols should be maintained at temperatures above 35°F. If storage temperatures only occasionally drop slightly below these prescribed limits, steam heating coils alone will prevent freezing or excessive viscosity of the glycols. However, if the low temperatures are sustained, both heating coils and insulation are necessary for satisfactory storage. A 1-inch to 1½-inch layer of magnesia asbestos has served satisfactorily as an insulating material. Heating coils should be of stainless steel if even slight coloration of the glycol is undesirable, otherwise ordinary steel coils are satisfactory. Either a pencil-type coil or a return-bend coil can be used if it provides the required heating surface. This coil should be removable for cleaning and maintenance. Normally, 10 to 30 pound steam is satisfactory for heating.

Storage tanks should be provided with a manhole or some other means of entry to facilitate cleaning.

The tanks should be vented to prevent excess pressure buildup and to facilitate the discharge of the glycol. Use of a pressure-vacuum relief valve is recommended for this purpose. Glycols will not deteriorate in an atmosphere of air at normal storage temperatures, therefore, air—which, because of the hygroscopic nature of the glycols, must be dry—is satisfactory for padding the tank. The opening in the vent should be downward so that rain and dust cannot get into the tank and contaminate the glycol.

Flake calcium chloride is an efficient and inexpensive desiccant for drying the air used for padding. The trap containing the desiccant should be inspected periodically, cleaned and recharged with fresh, dry material to keep it from becoming plugged with dissolved calcium chloride. If the trap does become plugged, the pad system will be inoperative and the tank will be able to breathe only through the relief valve.

PUMPS, FITTINGS AND VALVES

Centrifugal pumps are commonly used in glycol service but reciprocating pumps are used when glycols must be pumped at high heads. Pumps can be made of ordinary steel if slight coloration of the glycol is not objectionable, otherwise stainless steel pumps should be employed.

Piping valves and fittings can also be of ordinary steel unless coloration of the glycol is objectionable, in which case stainless steel should be used. Regardless of the metal used, schedule-ten piping, which will withstand normal pumping pressures, is recommended.

PUMP PACKING AND GASKETS

Glycols are difficult materials to contain and are prone to leak past any defective fittings or packing. Consequently, the installation of all fittings, packings and gaskets should be done with the utmost care.

Pipe dopes that have been used successfully include a mixture of graphite and cutting oil, formulated into a thick paste and applied directly.

Asbestos-base materials are recommended for gaskets and packing in glycol service. With centrifugal pumps, Johns-Manville C-7¹ shaft packing and Crane² asbestos shaft packing are recommended. Garlock 900³ and Johns-Manville 60 gasket material are recommended for flange gaskets.

Whenever reciprocating pumps are used, Johns-Manville No. 60 gaskets are recommended. Among packing materials Palmento No. 1200⁴ Packing has served satisfactorily.

¹ Product of Johns-Manville Company, Manville, New Jersey.

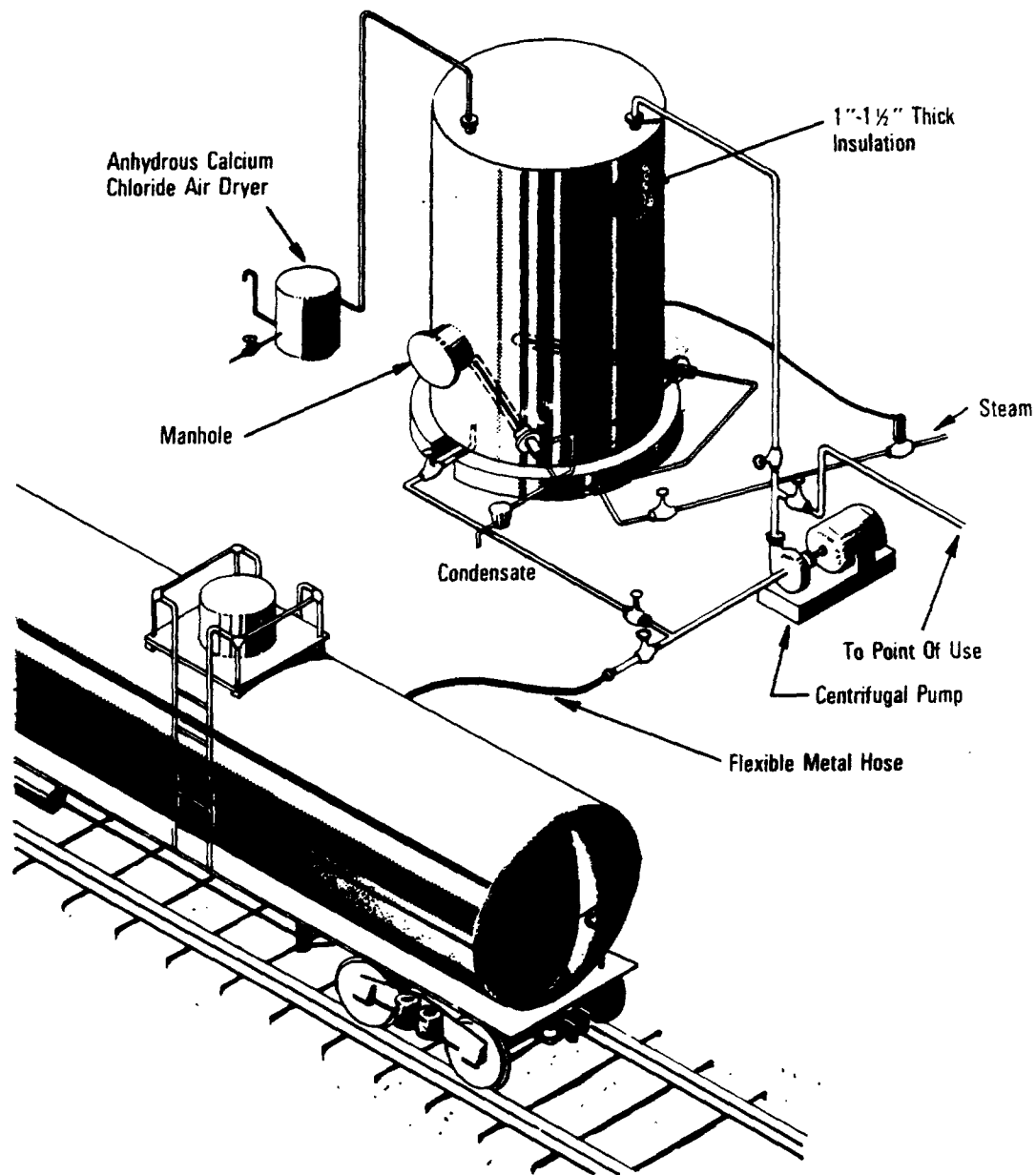
² Product of Crane Packing Company, Morton Grove, Illinois.

³ Product of Garlock Packing Company, Palmyra, New York.

⁴ Product of Green Tween & Company, North Wales, Pennsylvania.

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DIAGRAM OF VERTICAL STORAGE TANK FOR ETHYLENE GLYCOL



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ANALYTICAL METHODS FOR DOW GLYCOLS

SCOPE

This general method is applicable to the analysis of ethylene, diethylene, triethylene, tetraethylene, propylene, dipropylene, and tripropylene glycols. Procedures are given for the determination of distillation range, specific gravity, acidity, inorganic chlorides, water, and color. Specific methods are available for each glycol separately covering its specification items.

SAMPLING

1. **APPLICATION** This procedure is applicable to the sampling of glycol in tanks, tank cars, and tank trucks.

2. **APPARATUS** Use a suitable weighted bottle with a $\frac{3}{4}$ -inch diameter opening fitted with a cork stopper. See Figure 2 of ASTM D 270.

3. **PROCEDURE** (a) Lower the weighted, stoppered bottle as near as possible to the draw-off level. Pull out the stopper with a sharp jerk of the cord, and raise the bottle at such a rate that it is nearly (but not completely) full as it emerges from the liquid.

(b) Stopper the bottle and wash off all traces of the glycol. Label the bottle and deliver to the laboratory for analysis.

DISTILLATION RANGE

4. **PRINCIPLE** The distillation range is determined essentially by ASTM Designation D 1078. The procedure is empirical and will give reproducible results only if the specified conditions are employed.

5. **APPARATUS** The apparatus as specified under ASTM Designation D 1078 is used with the following modifications:

(a) **Distillation flask.** Use a standard 100-ml Engler distillation flask for ethylene, propylene and dipropylene glycols and a standard 125-ml Engler distillation flask for diethylene, triethylene, tetraethylene and tripropylene glycols.

(b) **Thermometer.** For all glycols except triethylene and tetraethylene glycols, this should be one such as ASTM 2C, 76-mm immersion, temperature range to include -5 to 300°C , graduated in 1°C . An MCA R4 should be used in case of question or where greater accuracy is desired. Optionally, a platinum resistance thermometer may be used.

For triethylene and tetraethylene glycols, a thermometer such as ASTM 3C, 76 mm immersion, temperature range to 400°C , graduated in 1°C should be used.

6. **PROCEDURE** Follow ASTM Designation D 1078 with two modifications:

(a) **Source of heat.** When a gas burner is used, the flame shall never be so large that it spreads over a circle greater than $3\frac{1}{2}$ inches on the under surface of the asbestos board.

(b) **Dry point.** Adjust the heat input if necessary so that the time required to reach the dry point after the liquid residue in the flask is approximately five ml does not exceed five minutes.

7. **NOTE** For correction of the boiling point for barometric pressure, the value of K is as follows:

Ethylene glycol	0.042°C per mm
Diethylene glycol	0.049°C per mm
Triethylene glycol	0.054°C per mm
Tetraethylene glycol	0.043°C per mm
Propylene glycol	0.042°C per mm
Dipropylene glycol	0.050°C per mm
Tripropylene glycol	0.055°C per mm

SPECIFIC GRAVITY

8. PRINCIPLE The specific gravity in air at 20 or 25°C is determined by weighing a known value of sample in a Lipkin bicapillary pycnometer. For a complete description of apparatus and procedure, see ASTM Designation D 941.

9. APPARATUS

- (a) Pycnometer, Lipkin bicapillary
- (b) Constant temperature bath, controlled to 20.00 or 25.00 ± 0.05°C. Sargent S-84805, or equivalent.
- (c) Analytical balance, sensitivity of 0.05 to 0.10 milligrams, either one or two pan type.
- (d) Analytical weights, Class S. These are calibrated and checked periodically against National Bureau of Standards weights. If a one pan balance is used, no weights are necessary.

10. PROCEDURE (a) Pour approximately 15 ml. of sample into a clean, dry, shallow dish (approximately 15 ml capacity), placed near the edge of the working desk to facilitate filling the pycnometer. Submerge the curved end of the pycnometer in the liquid. Carefully and slowly apply suction to the other opening and fill to the necessary volume, about "3 to 5 stem reading." To accomplish this, release suction just before the bulb of the pycnometer is filled, then remove the filling tip of the pycnometer from the sample just as the liquid begins to enter the second column.

(b) Hold the pycnometer in a vertical position and be sure there are no entrapped air bubbles in either the bulb or the calibrated stems. Place the pycnometer in a constant temperature bath for at least 20 minutes. Hold the bath temperature to 20.00 or 25.00 ± 0.05°C during the determination (see 12a).

(c) While the pycnometer is still in the bath, take readings and record. Dip the pycnometer in an acetone bath, then allow it to dry for five minutes and weigh. Run all determinations in duplicate. The results should not differ more than 0.0002 units.

11. CALCULATION

$$(a) \text{ Sp. gr. at } 20/20^{\circ}\text{C} = \frac{\text{grams of sample}}{\text{ml of sample} \times 0.99823}$$

$$(b) \text{ Sp. gr. at } 25/25^{\circ}\text{C} = \frac{\text{grams of sample}}{\text{ml of sample} \times 0.99707}$$

12. NOTES (a) A calibrated mercury thermometer should be used for reading the temperature of the constant temperature bath. The thermometer should have 0.1°C graduations.

(b) Optionally, a standard pycnometer may be used. See Method C of ASTM Designation D 891.

ACIDITY

13. PRINCIPLE The free acidity is titrated with a standard solution of sodium hydroxide and calculated as acetic acid.

14. REAGENTS (a) Sodium hydroxide, standard 0.01 N solution. This solution is standardized against hydrochloric acid.

(b) Phenol red indicator, 0.05% solution. Dissolve 1.1 gm. of the sodium salt of phenolsulfonephthalein (Eastman No. 6131) and dilute to two liters with water.

15. PROCEDURE Dilute 50 ml of sample with 50 ml of distilled water in an Erlenmeyer flask. Then add four to six drops of phenol red and titrate the solution with 0.01 N NaOH to a permanent pink color which persists for 15 seconds.

16. CALCULATION

$$\frac{(\text{ml of } 0.01 \text{ N NaOH}) \times 0.00060 \times 100}{(\text{ml of sample}) \times \text{sp. gr.}} = \% \text{ acetic acid}$$

INORGANIC CHLORIDES

17. PRINCIPLE The inorganic chlorides are titrated with a standard solution of silver nitrate by the Volhard procedure.

18. REAGENTS (a) Nitric acid, 1:10 solution in distilled water.

(b) Silver nitrate, standard 0.01 N solution. Dissolve 1.7 grams of reagent grade silver nitrate in water and dilute to one liter. Standardize against a standard solution of hydrochloric acid by the Volhard method.

(c) Ammonium thiocyanate, standard 0.01 N solution. Dissolve 0.761 gram of recrystallized ammonium thiocyanate in water and dilute to one liter. Standardize this solution against the 0.01 N silver nitrate solution.

(d) Volhard indicator. Dissolve 100 grams of ferric ammonium sulfate, $\text{Fe}_2(\text{NH}_4)_2(\text{SO}_4)_4 \cdot 24\text{H}_2\text{O}$, with 15 ml of concentrated nitric acid and dilute with water to one liter.

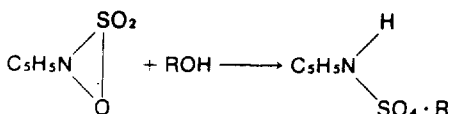
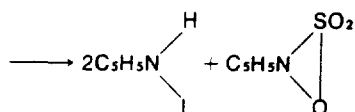
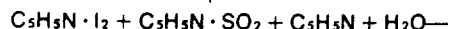
19. PROCEDURE Pipet 50 ml of sample into a clean 250-ml Erlenmeyer flask and dilute with 50 ml of distilled water. Add about one to two ml of dilute nitric acid from a dropping bottle. Add approximately one ml of Volhard indicator and one ml of 0.01 N ammonium thiocyanate from a buret. Titrate to a white end-point with silver nitrate. Add about two ml in excess and back titrate with 0.01 N ammonium thiocyanate until the first appearance of a pink color which remains for one minute. The total ml of 0.01 N silver nitrate, minus the total ml of 0.01 N ammonium thiocyanate, is equivalent to the chlorides present in the sample. This is the net ml of 0.01 N silver nitrate.

20. CALCULATION

$$\frac{(\text{net ml N/100 AgNO}_3) \times 3.55}{\text{ml of sample} \times \text{sp. gr.}} \times 100 = \% \text{ chlorides}$$

WATER

21. **PRINCIPLE** In an alcohol-pyridine solution, iodine is not reduced by sulfur dioxide unless water is present. Karl Fischer reagent, which contains all of these components except water, can be used for titrating the latter. The brown iodine color of the reagent changes to yellow as long as water is available to permit the reaction to proceed. The determination is based on the following reaction in solution and appears to take place in two distinct steps:



22. **REAGENTS** (a) Methanol (anhydrous).

(b) Solution W, water-in-methanol standard. Pipet 2.5 ml of water into a liter volumetric flask. Dilute to the mark with anhydrous methanol and mix well.

(c) Karl Fischer reagent can be obtained from laboratory supply houses. It is prepared as follows:

(1) Dissolve 127 grams of finely granulated iodine in 1200 ml of anhydrous methanol (less than 0.05% water) contained in a two-liter, brown, glass-stoppered bottle. Add 395 grams of anhydrous pyridine and mix thoroughly.

(2) Connect a sulfur dioxide cylinder to the reagent bottle through a one-gallon bottle arranged as a trap. Use glass delivery tubing with rubber connectors.

(3) Place the reagent bottle on a large solution balance, and add 95 grams of sulfur dioxide in small increments. Cool the solution. Dilute to volume with methanol and mix thoroughly. This reagent loses strength gradually. It must be standardized daily.

23. **APPARATUS** Any suitable Karl Fischer apparatus for water determinations including automatic 25-ml burets of a type which minimizes errors due to reaction of the reagents with atmospheric moisture. See ASTM D 1123. Optionally, an instrument for detection of the "dead-stop" end-point such as the Beckman Aquameter may be used.

24. STANDARDIZATION OF REAGENTS

(a) Add an excess of Fischer reagent to 25 ml of methanol. Back-titrate to the end-point with solution W. This procedure will remove the last traces of water from the methanol and leave it neutral with respect to Fischer reagent.

(b) Add an excess of three to five ml of Fischer reagent to the dry methanol, and record the exact amount.

(c) Titrate the excess Fischer reagent with solution W. Repeat several times and compute the average equivalence ratio between the Fischer reagent and solution W:

$$F_a = \frac{\text{ml of Fischer reagent}}{\text{ml of solution W}}$$

(d) Add an excess of Fischer reagent to 25 ml of methanol and back-titrate to the end-point with solution W.

(e) Add approximately 0.05 gram of water to the dried methanol. Record the exact weight to the nearest 0.1 mg. Use a Lunge pipet or a one-ml syringe and needle.

(f) Add an excess of two ml of Fischer reagent. Record the exact amount.

(g) Back-titrate with solution W. Compute the water equivalent (Ff) in grams of water per ml of Fischer reagent:

$$F_f = \frac{\text{gm of water added}}{(\text{ml of Fischer}) - F_a(\text{ml of solution W})}$$

25. **PROCEDURE** (a) Add an excess of two to five ml of Fischer reagent to about 25 ml of methanol.

(b) Back-titrate to the end-point with solution W.

(c) Add a 50-ml sample to the neutralized methanol.

(d) Add an excess of two ml of Fischer reagent. Record the exact amount.

(e) Back titrate the excess Fischer reagent with solution W. Record the titration.

26. CALCULATION

Where:

net ml of Fischer =

(ml of Fischer) - F_a(ml of solution W),

then

$$\frac{(\text{net ml of Fischer}) \times F_f}{(\text{ml of sample}) \times \text{sp. gr.}} \times 100 = \% \text{ water.}$$

APHA COLOR

27. **PRINCIPLE** A sample is compared with APHA standards. The APHA color number of a standard which most nearly matches the sample is reported as the color of the sample.

28. **APPARATUS** (a) Nessler tube, 100-ml, matched.

(b) Hellige comparator, with color disc 0-50, color disc 0-100, two comparator tubes and plungers.

29. **REAGENT** Platinum-cobalt color standard. This standard is useful where a Hellige comparator is unavailable. Dissolve 1.245 grams of potassium chloroplatinate (K₂PtCl₆), containing 0.500 gram of platinum, and one gram of crystallized cobaltous chloride (CoCl₂ · 6H₂O), containing about 0.25 gram of cobalt, in water with 100 ml of concentrated hydrochloric acid. Dilute to one liter with distilled water. This solution has an APHA color of 500.

30. PROCEDURE (Using the Hellige Comparator) Fill the tube on the left side of the comparator with distilled water and insert the plunger. Put the sample in the tube on the right and close the instrument. Compare the colors by rotating the color wheel on the instrument. Read the closest matching color from the circular opening beneath the prism housing within the light shield. Record this as the APHA color.

31. PROCEDURE (Using Solution Color Standards) (a) Prepare standards having APHA colors of 5, 10, 15, . . . , 30, etc., by diluting 1.0, 2.0, 3.0 . . . , 6.0 ml., etc., of the above solution in Nessler tubes to 100 ml with water. Stopper the tubes when not in use to prevent evaporation and dust contamination.

(b) Pour the sample into a clean, dry Nessler tube to the 100-ml mark and compare with the standard by looking down through the Nessler tubes against a white background. Report as the APHA color the number of the standard which most nearly matches the sample.

REFERENCES

32. LITERATURE REFERENCES (a) Lipkin, M. R., Davison, J. A., Harvey, W. T., and Kurtz, S. S., "Pycnometer for Volatile Liquids," *Ind. Engr. Chem., Anal. Ed.*, **16**, 55 (1944).

(b) Almy, E. G., Griffin, W. C., and Wilcox, C. S., "Fischer Volumetric Determination of Water," *Ind. Eng. Chem., Anal. Ed.*, **12**, 392-396 (1940).

(c) Mitchell, J., and Smith, D. M., "Aquametry," Chapter 2, Interscience Publishers, New York, N. Y.

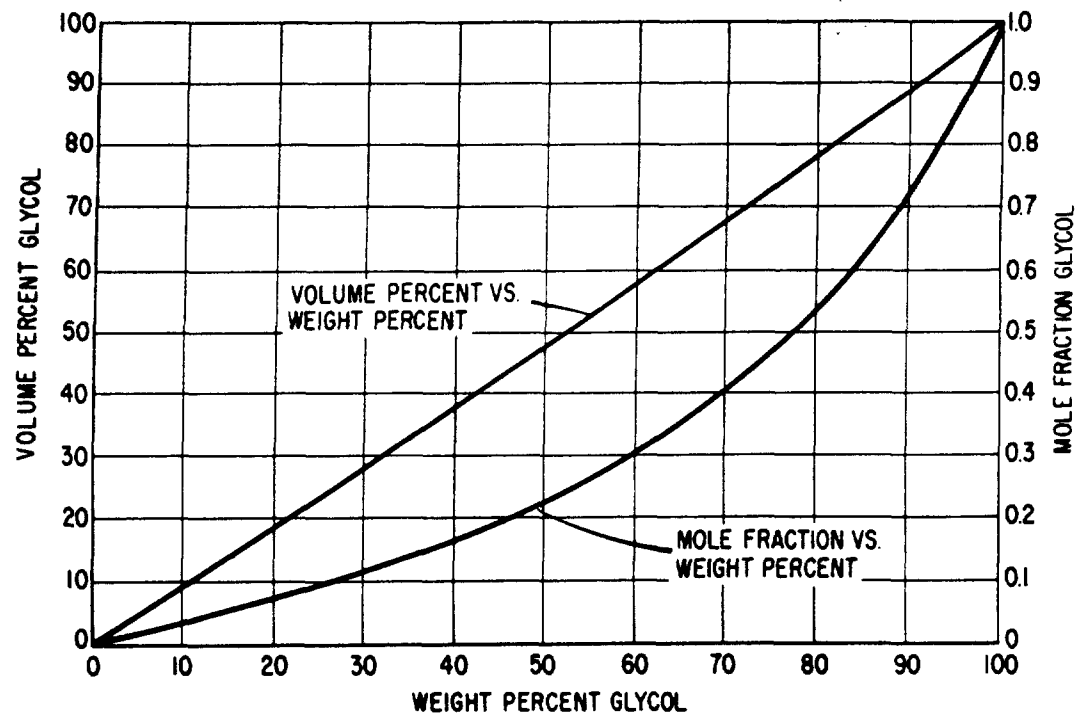
(d) American Society for Testing and Materials, 1916 Race Street, Philadelphia 3, Pa.: "Distillation Range of Lacquer Solvents and Diluents," D 1078; "Density and Specific Gravity of Hydrocarbon Liquids by the Lipkin Bicapillary Pycnometer," D 941; "Specific Gravity of Industrial Aromatic Hydrocarbons," D 891; "Color of Clear Liquids (Platinum-Cobalt Scale)," D 1209; "Sampling Petroleum and Petroleum Products," D 270.

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APPENDIX

CONVERSION CHART FOR AQUEOUS
ETHYLENE GLYCOL SOLUTIONS

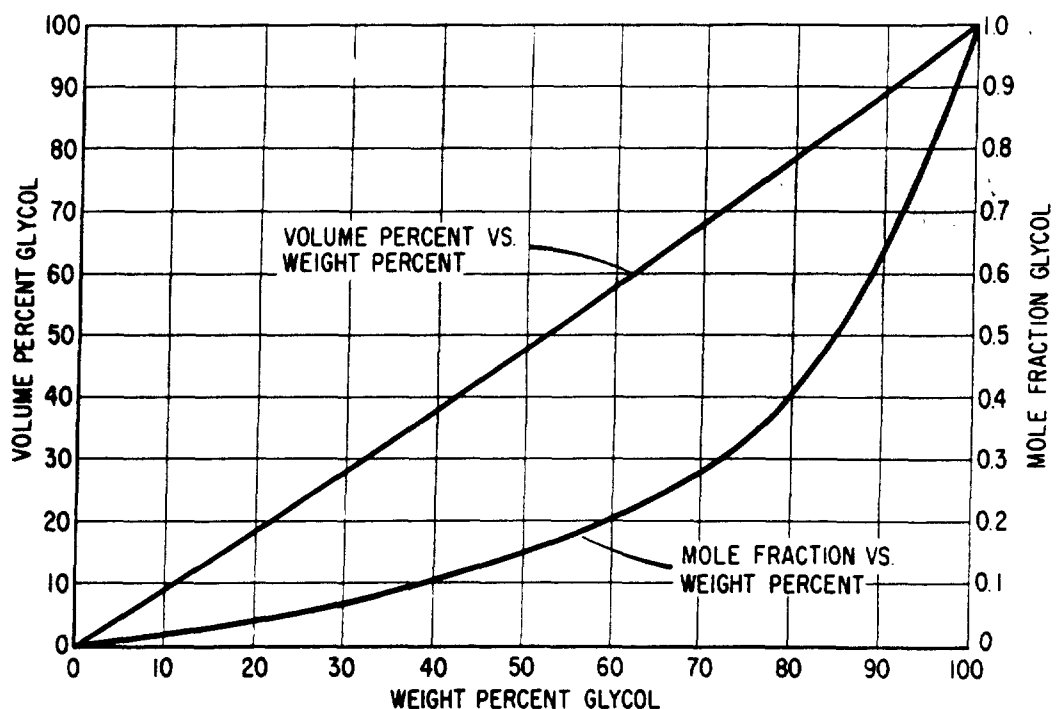
FIGURE A-1



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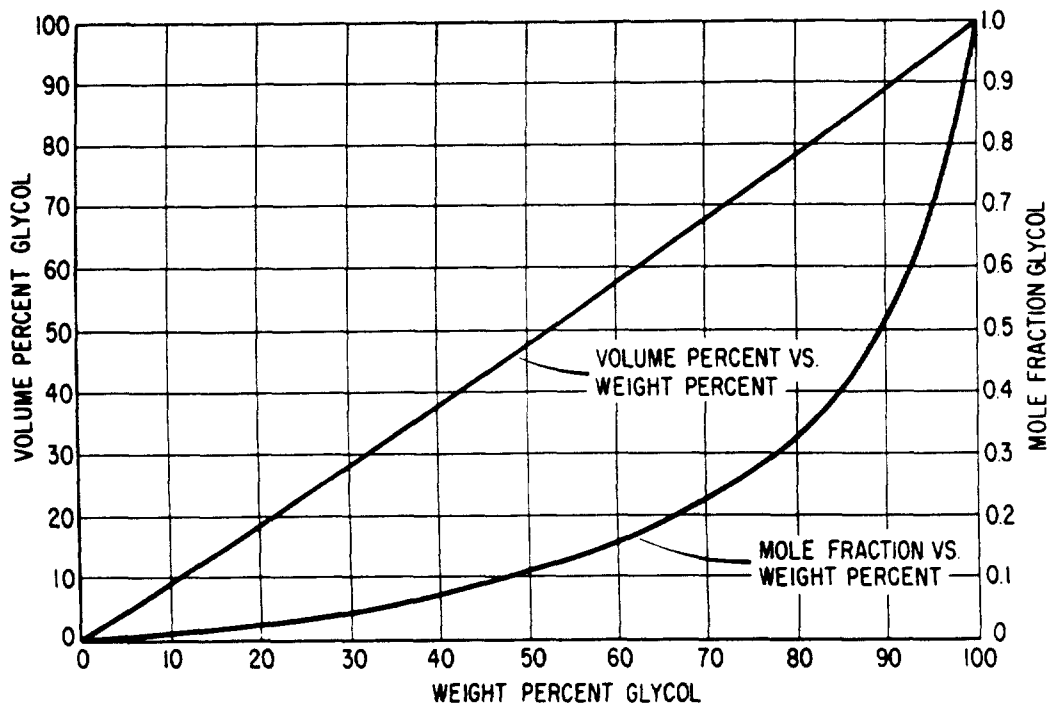
**CONVERSION CHART FOR AQUEOUS
DIETHYLENE GLYCOL SOLUTIONS**

FIGURE A-2



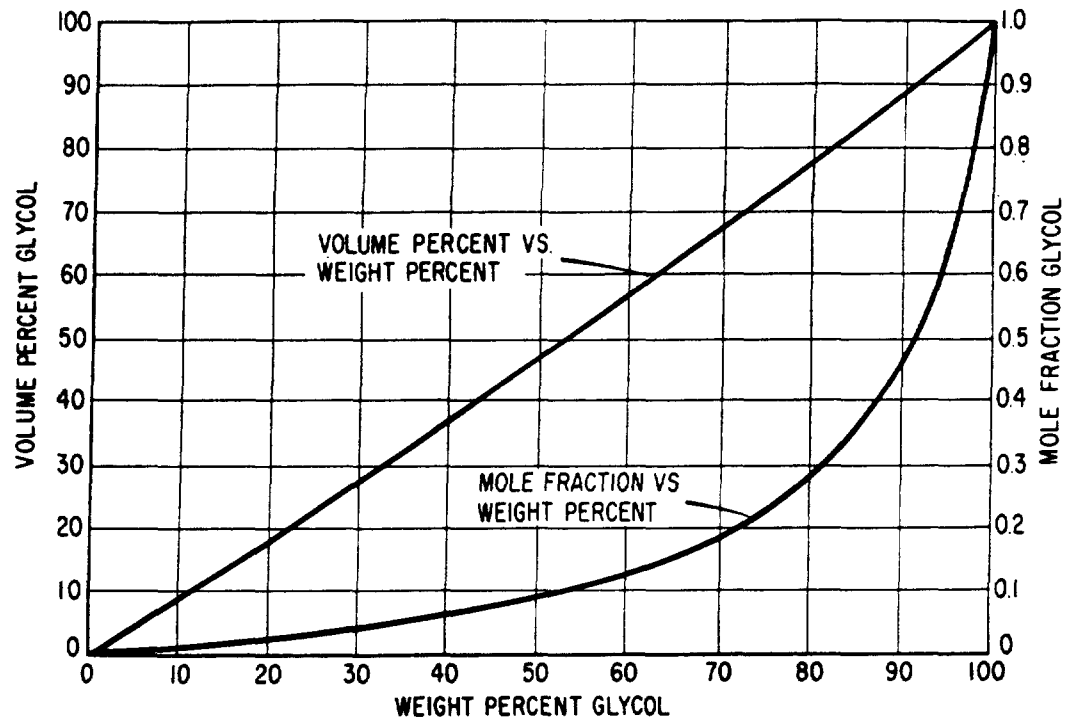
**CONVERSION CHART FOR AQUEOUS
TRIETHYLENE GLYCOL SOLUTIONS**

FIGURE A-3



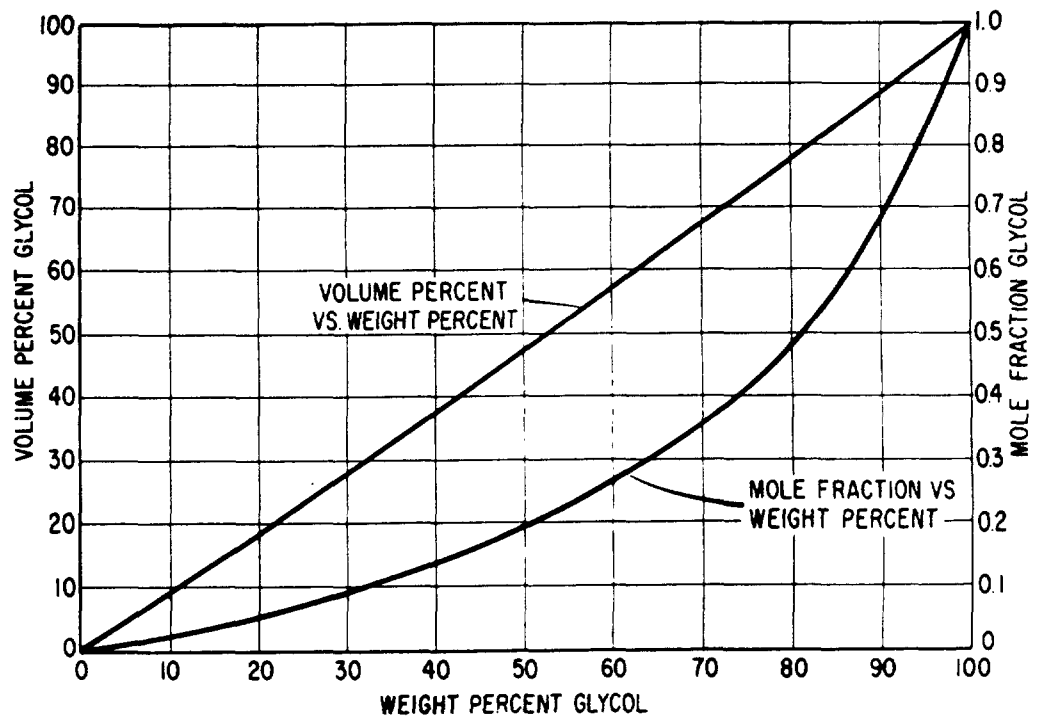
**CONVERSION CHART FOR AQUEOUS
TETRAETHYLENE GLYCOL SOLUTIONS**

FIGURE A-4



**CONVERSION CHART FOR AQUEOUS
PROPYLENE GLYCOL SOLUTIONS**

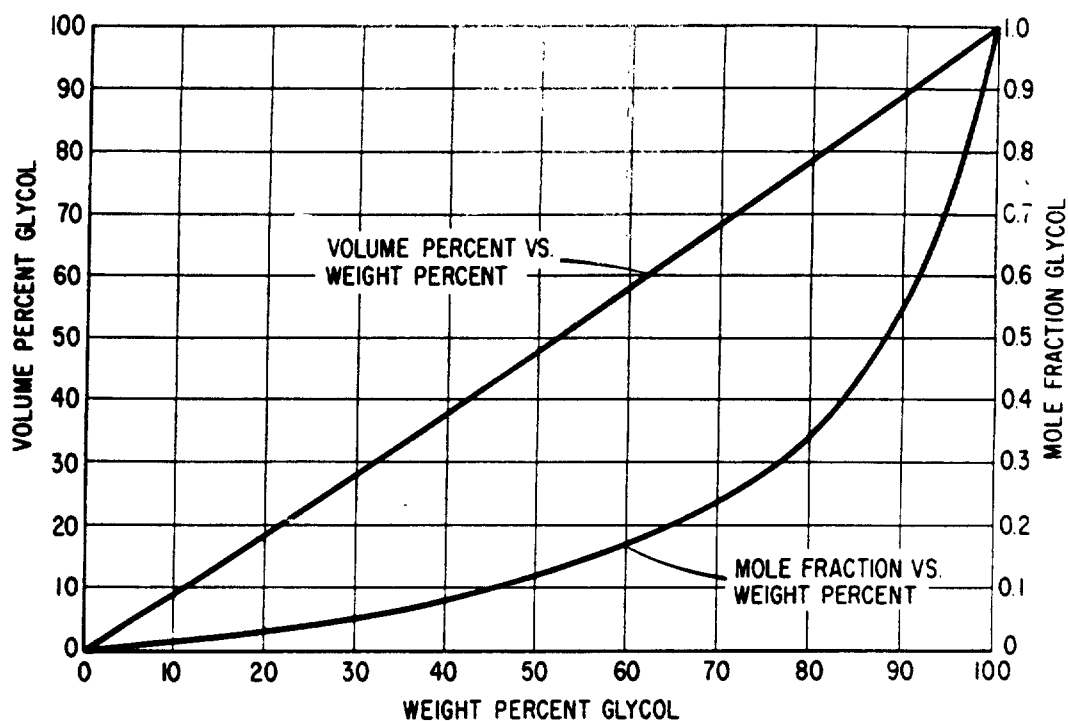
FIGURE A-5



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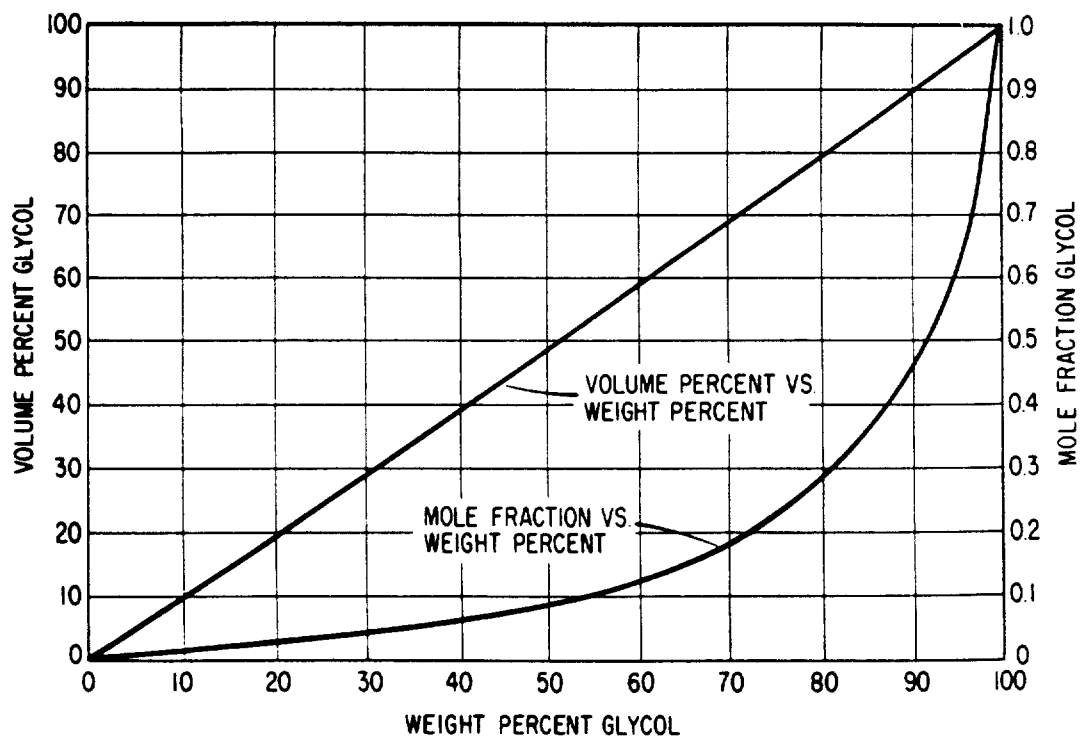
**CONVERSION CHART FOR AQUEOUS
DIPROPYLENE GLYCOL SOLUTIONS**

FIGURE A-6



**CONVERSION CHART FOR AQUEOUS
TRIPROPYLENE GLYCOL SOLUTIONS**

FIGURE A-7



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Properties and uses of Glycols

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AG-ORGANICS DEPARTMENT

MIDLAND, MICHIGAN 48640



TEMPERATURE CONVERSION DATA

FIGURE A-8

°F	TEMP.	°C	°F	TEMP.	°C	°F	TEMP.	°C
-94.0	-70	-56.67	+104.0	+40	+ 4.44	+302.0	+150	+65.56
-76.0	-60	-51.11	+105.8	+41	+ 5.00	+320.0	+160	+71.11
-58.0	-50	-45.56	+107.6	+42	+ 5.56	+338.0	+170	+76.67
-40.0	-40	-40.00	+109.4	+43	+ 6.11	+356.0	+180	+82.22
-22.0	-30	-34.44	+111.2	+44	+ 6.67	+374.0	+190	+87.78
- 4.0	-20	-28.89	+113.0	+45	+ 7.22	+392.0	+200	+93.33
- 2.2	-19	-28.34	+114.8	+46	+ 7.78	+410.0	+210	+98.89
- 0.4	-18	-27.78	+116.6	+47	+ 8.33	+428.0	+220	+104.44
+ 1.4	-17	-27.23	+118.4	+48	+ 8.89	+446.0	+230	+110.00
+ 3.2	-16	-26.67	+120.2	+49	+ 9.44	+464.0	+240	+115.56
+ 5.0	-15	-26.12	+122.0	+50	+10.00	+482.0	+250	+121.11
+ 6.8	-14	-25.56	+123.8	+51	+10.56	+500.0	+260	+126.67
+ 8.6	-13	-25.00	+125.6	+52	+11.11	+518.0	+270	+132.22
+10.4	-12	-24.44	+127.4	+53	+11.67	+536.0	+280	+137.78
+12.2	-11	-23.89	+129.2	+54	+12.22	+554.0	+290	+143.33
+14.0	-10	-23.33	+131.0	+55	+12.78	+572.0	+300	+148.89
+15.8	- 9	-22.78	+132.8	+56	+13.33	+590.0	+310	+154.44
+17.6	- 8	-22.22	+134.6	+57	+13.89	+608.0	+320	+160.00
+19.4	- 7	-21.67	+136.4	+58	+14.44	+626.0	+330	+165.56
+21.2	- 6	-21.11	+138.2	+59	+15.00	+644.0	+340	+171.11
+23.0	- 5	-20.56	+140.0	+60	+15.56	+662.0	+350	+176.67
+24.8	- 4	-20.00	+141.8	+61	+16.11	+680.0	+360	+182.22
+26.6	- 3	-19.44	+143.6	+62	+16.67	+698.0	+370	+187.78
+28.4	- 2	-18.89	+145.4	+63	+17.22	+716.0	+380	+193.33
+30.2	- 1	-18.33	+147.2	+64	+17.78	+734.0	+390	+198.89
+32.0	0	-17.78	+149.0	+65	+18.33	+752.0	+400	+204.44
+33.8	+ 1	-17.22	+150.8	+66	+18.89	+770.0	+410	+210.00
+35.6	+ 2	-16.67	+152.6	+67	+19.44	+788.0	+420	+215.56
+37.4	+ 3	-16.11	+154.4	+68	+20.00	+806.0	+430	+221.11
+39.2	+ 4	-15.56	+156.2	+69	+20.56	+824.0	+440	+226.67
+41.0	+ 5	-15.00	+158.0	+70	+21.11	+842.0	+450	+232.22
+42.8	+ 6	-14.44	+159.8	+71	+21.67	+860.0	+460	+237.78
+44.6	+ 7	-13.89	+161.6	+72	+22.22	+878.0	+470	+243.33
+46.4	+ 8	-13.33	+163.4	+73	+22.78	+896.0	+480	+248.89
+48.2	+ 9	-12.78	+165.2	+74	+23.33	+914.0	+490	+254.44
+50.0	+10	-12.22	+167.0	+75	+23.89	+932.0	+500	+260.00
+51.8	+11	-11.67	+168.8	+76	+24.44	+950.0	+510	+265.56
+53.6	+12	-11.11	+170.6	+77	+25.00	+968.0	+520	+271.11
+55.4	+13	-10.56	+172.4	+78	+25.56	+986.0	+530	+276.67
+57.2	+14	-10.00	+174.2	+79	+26.11	+1004.0	+540	+282.22
+59.0	+15	- 9.44	+176.0	+80	+26.67	+1022.0	+550	+287.78
+60.8	+16	- 8.89	+177.8	+81	+27.22	+1040.0	+560	+293.33
+62.6	+17	- 8.33	+179.6	+82	+27.78	+1058.0	+570	+298.89
+64.4	+18	- 7.78	+181.4	+83	+28.33	+1076.0	+580	+304.44
+66.2	+19	- 7.22	+183.2	+84	+28.89	+1094.0	+590	+310.00
+68.0	+20	- 6.67	+185.0	+85	+29.44	+1112.0	+600	+315.56
+69.8	+21	- 6.11	+186.8	+86	+30.00			
+71.6	+22	- 5.56	+188.6	+87	+30.56			
+73.4	+23	- 5.00	+190.4	+88	+31.11			
+75.2	+24	- 4.44	+192.2	+89	+31.67			
+77.0	+25	- 3.89	+194.0	+90	+32.22			
+78.8	+26	- 3.33	+195.8	+91	+32.78			
+80.6	+27	- 2.78	+197.6	+92	+33.33			
+82.4	+28	- 2.22	+199.4	+93	+33.89			
+84.2	+29	- 1.67	+201.2	+94	+34.44			
+86.0	+30	- 1.11	+203.0	+95	+35.00			
+87.8	+31	- 0.56	+204.8	+96	+35.56			
+89.6	+32	+ 0.00	+206.6	+97	+36.11			
+91.4	+33	+ 0.56	+208.4	+98	+36.67			
+93.2	+34	+ 1.11	+210.2	+99	+37.22			
+95.0	+35	+ 1.67	+212.0	+100	+37.78			
+96.8	+36	+ 2.22	+213.8	+110	+43.33			
+98.6	+37	+ 2.78	+215.6	+120	+48.89			
+100.4	+38	+ 3.33	+217.4	+130	+54.44			
+102.2	+39	+ 3.89	+219.2	+140	+60.00			

INTERPOLATION FACTORS		
°F	TEMP.	°C
1.8	1	0.56
3.6	2	1.11
5.4	3	1.67
7.2	4	2.22
9.0	5	2.78
10.8	6	3.33
12.6	7	3.89
14.4	8	4.44
16.2	9	5.00
18.0	10	5.56

CONVERSION FORMULAE		
°F = (1.8 × °C) + 32		
°C = (°F - 32) / 1.8		

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