A Guide to Glycols

Propylene Glycols from Dow

The Versitile Performers

- Antifreeze/Coolant Formulations
- Heat Transfer Fluids
- Solvents
- Food
- Flavors and Fragrances
- Cosmetics and Personal Care Products
- Pharmaceuticals
- Chemical Intermediates
- Hydraulic Fluids
- Plasticizers
- Resin Formulations
- Gas Dehydration Operations

Propylene glycols (glycols) play a significant role in industry due to their wide range of practical applications. Glycols are found in such diverse products and applications as thermoset plastics, clothing, latex paints, glass and enamel surface cleaners, automotive antifreeze/coolants, heat transfer fluids, aircraft deicing fluids, natural gas treatment, chemical process fluids, hydraulic fluids, paper and packaging, adhesives, plasticizers, pesticides, printing inks, cosmetics, pharmaceuticals, foods and electronics. All of these applications utilize propylene glycols, either as an integral part of the product or as a facilitator in their production.

Dow's expertise, conscientious regulatory compliance, quality control in production, extensive distribution network, and dedicated customer service makes Dow's glycols the preferred glycol products of industry.

Dow offers the following quality products in its PROPYLENE GLYCOL group:

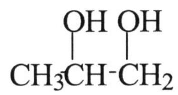
Propylene Glycol USP/EP (PG USP/EP)
Propylene Glycol Industrial (PGI)
Dipropylene Glycol (DPG)
Dipropylene Glycol LO+ (DPG LO+)
Tripropylene Glycol (TPG)
Tripropylene Glycol Acrylate Grade (TPG Ac)

Please visit www.dowpg.com to obtain more information about Dow's glycols product offering, such as Technical Datasheets (TDS), Material Safety Datasheets (MSDS or SDS) and sales specifications.

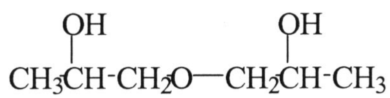
Chemistry of Glycols

The structural formulas of the propylene glycols commercially produced by Dow are:

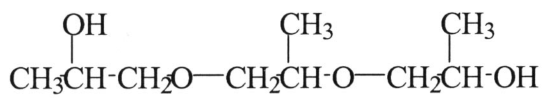
Propylene Glycol



Dipropylene Glycol[1]



Tripropylene Glycol[1]

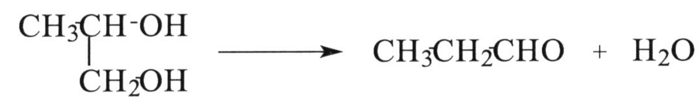


Propylene glycols (glycols) chemistry centers on the two hydroxyl (OH) groups that characterize them as glycols. They, therefore, have intermediate properties between alcohols, with a single hydroxyl group and glycerine with its three hydroxyl groups. Likewise, the solubility characteristics of glycols tend to be between those of the simple alcohols and glycerine.

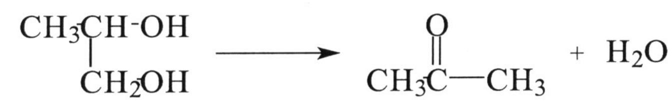
Glycols are normally quite stable under normal storage conditions, but can oxidize in the presence of air, particularly when heated. This gives rise to oxidation products such as carbonyl compounds and acids. The effects of such degradation can be controlled by the use of stabilizers, to the extent that these glycols can be used as heat transfer media at relatively high temperatures.

Under suitable dehydrating conditions, glycols can split out water in the following ways:

1. One molecule of water from one molecule of glycol to form aldehydes or ketones.

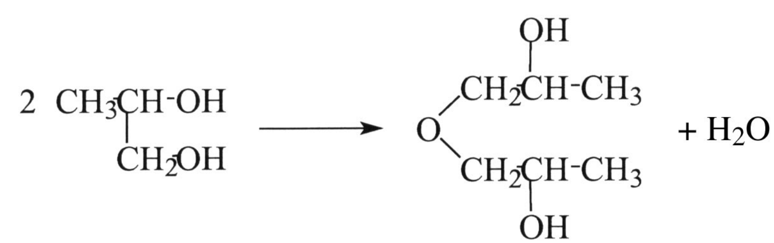


Propylene Glycol → Propionaldehyde + Water



Propylene Glycol → Acetone + Water

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

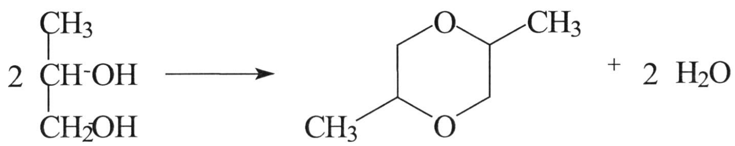


Propylene Glycol → Dipropylene Glycol + Water

Several isomers of dipropylene glycol are possible

[1]And other isomers

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



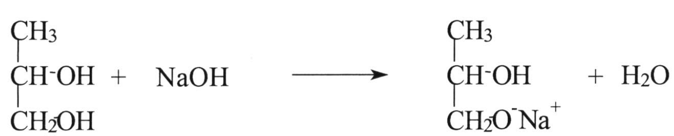
Propylene Glycol → Dimethyldioxane + Water

Several isomers of dimethyldioxane are possible

This can be a stepwise reaction with dipropylene glycol (DPG) as the intermediate.

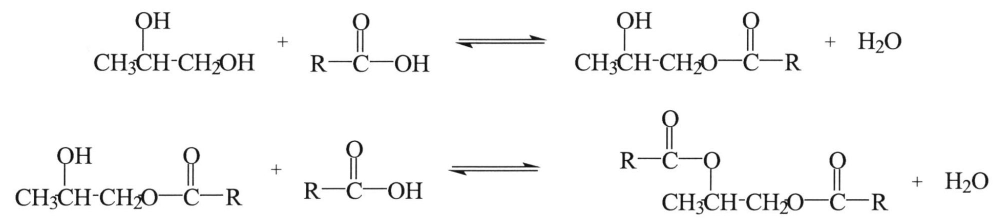
4. The hydrogens in either or both of the hydroxyl groups can be replaced by an alkali metal, either by direct reaction or by splitting out water from the corresponding alkali metal and hydroxide.

Propylene Glycol + Sodium metal → Propylene Glycol Monosodium alkoxide + Hydrogen



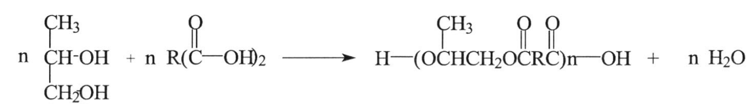
Propylene Glycol + Sodium Hydroxide → Propylene Glycol Monosodium alkoxide + Water

5. Glycols readily form mono- and diesters by reaction with acids, acid halides or acid anhydrides. Below, this reaction is illustrated using an acid.

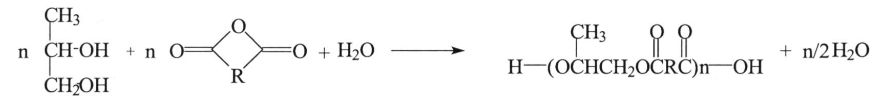


6. Unsaturated polyester resins (UPR) are synthesized by the stepwise stoichiometric polycondensation reactions between various ratios of saturated and unsaturated dicarboxylic acids or their anhydrides with glycols or polyols. Propylene glycol is used extensively in these systems.

The unsaturated dicarboxylic acid is typically maleic or fumeric acid and the saturated dicarboxylic acid is phthalic or isophthalic acid. Other glycols are also used but monopropylene glycol is the most typically used.



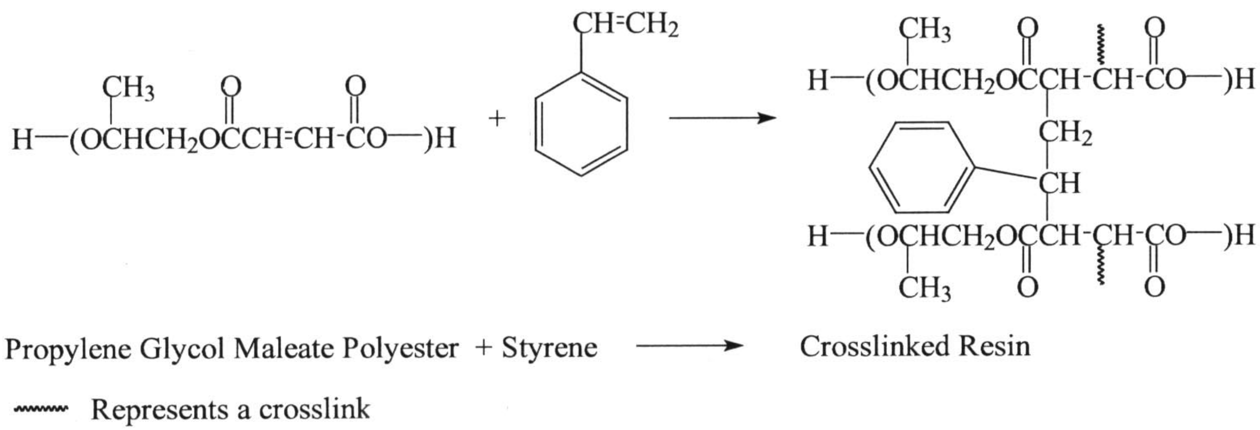
Propylene Glycol + Dicarboxylic Acid → Polyester + Water



Propylene Glycol + Dicarboxylic Acid Anhydride → Polyester + Water

larger view

7. After synthesis of the unsaturated polyester, the unsaturated acid functionality is used to react with an unsaturated monomer, such as styrene, to crosslink and cure the resin using vinyl copolymerization.



Physical Properties Summary

Propylene glycols (glycols) are liquids with high boiling and low freezing points, which permit volume storage in a wide range of climates, usually without special insulation or heating requirements. Vent losses are minimal since their vapor pressures are relatively low, and glycols are easily pumped and metered in industrial processes.

Glycols are aliphatic organic compounds having two hydroxyl groups per molecule. Glycols resemble water in that they are essentially clear, colorless liquids with practically no odor. Glycols 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 chemistry and properties of Dow's glycols are so wide-ranging, you may need assistance in determining how a particular glycol can be used and under what conditions it should be applied. Dow can help you by supplying the necessary information for their proper application. This product application support is part of the service Dow provides for its family of glycols.

Dow produces a series of propylene glycols as well as a series of polypropylene glycols (PPGs). We welcome inquiries on these or any other propylene oxide derivatives in which you may have interest, though this publication is focused on mono, di and tripropylene glycols. For more information, please visit The Dow Chemical Company or the Propylene Oxide web sites

Physical Properties of Glycols*

Physical Properties	Units	Propylene Glycol	Dipropylene Glycol	Tripropylene Glycol
Chemical Name		1,2-propanediol	oxybispropanol	[(1-methyl-1,2-ethanediyl)bis(oxy)] bispropanol
Formula		$C_3H_8O_2$	$C_6H_{14}O_3$	$C_9H_{20}O_4$
CAS Number[1]		57-55-6	25265-71-8	24800-44-0
EINECS Number		200-338-0	246-770-3	246-466-0
Molecular Weight		76.1	134.2	192.3
Boiling Point	760 mm Hg, °F	369.3	450.0	509.2
	760 mm Hg, °C	187.4	232.2	265.1
Vapor Pressure	mm Hg, 77°F (25°C)	0.13	0.016	0.002
Evaporation Rate	(n-Butyl Acetate = 1)	1.57E-02	1.55E-03	2.14E-04

*Note: These properties are laboratory results on pure compounds or are typical of the product. Typical properties should not be confused with, or regarded as, specifications.
**Electrical conductivity values are measured on pure materials. Contamination by other ionic species from storage, handling or use, may significantly affect electrical conductivity.
[1] Chemical Abstract Service Number

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Physical Properties	Units	Propylene Glycol	Dipropylene Glycol	Tripropylene Glycol
Density	g/cm^3, 77°F(25°C)	1.032	1.022	1.019
	g/cm^3, 140°F (60°C)	1.006	0.998	0.991
	lb/gal, 77°F (25°C)	8.62	8.53	8.51
Freezing Point	°F (°C)	Supercools	Supercools	Supercools
Pour Point	°F	<-71	-38	-42
	°C	<-57	-39	-41
Viscosity	Centipoise (mPas), 77°F (25°C)	48.6	75.0	57.2
	Centipoise (mPas), 140°F (60°C)	8.42	10.9	9.7
Surface Tension	dynes/cm (mN/m), 77°F (25°C)	36	35	34
Refractive Index at 77°F (25°C)		1.431	1.439	1.442
Specific Heat	Btu/lb/°F, 77°F	0.60	0.52	0.47
	J/g/K , 25°C	2.51	2.18	1.97
Flash Point	°F (°C)	220.2 (104)	255.2 (124)	290.2 (143)
Dipole Moment	Debyes	3.60	1.72	2.27
Coefficient of Expansion (0-60°C)		$7.3x10^{-4}$	$7.0x10^{-4}$	$8.1x10^{-4}$
Thermal Conductivity	Btu hr-1 ft-1 °F-1, 77°F (25°C)	0.1191	0.0966	0.0914
	W/m*K, 25°C	0.206	0.167	0.158
Heat of Formation	Kcal/g-mol	-101	-150	-199
	KJ/mol	-422	-628	-831
Heat of Vaporization	Btu/lb, 77°F (25°C)	379	257	200
	KJ/mol, 25°C	67	45.4	35.4
Hydroxyl Value		1470	836	584
Electrical Conductivity	mhos/cm (S/cm), 25°C**	$0.1x10^{-6}$	$<0.6x10^{-7}$	

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

**Electrical conductivity values are measured on pure materials. Contamination by other ionic species from storage, handling or use, may significantly affect electrical conductivity.
[1] Chemical Abstract Service Number

Specific Physical Properties

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 super-cooling. Glycols do not have sharp freezing points. Under normal conditions, propylene glycol and its homologs 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 1.

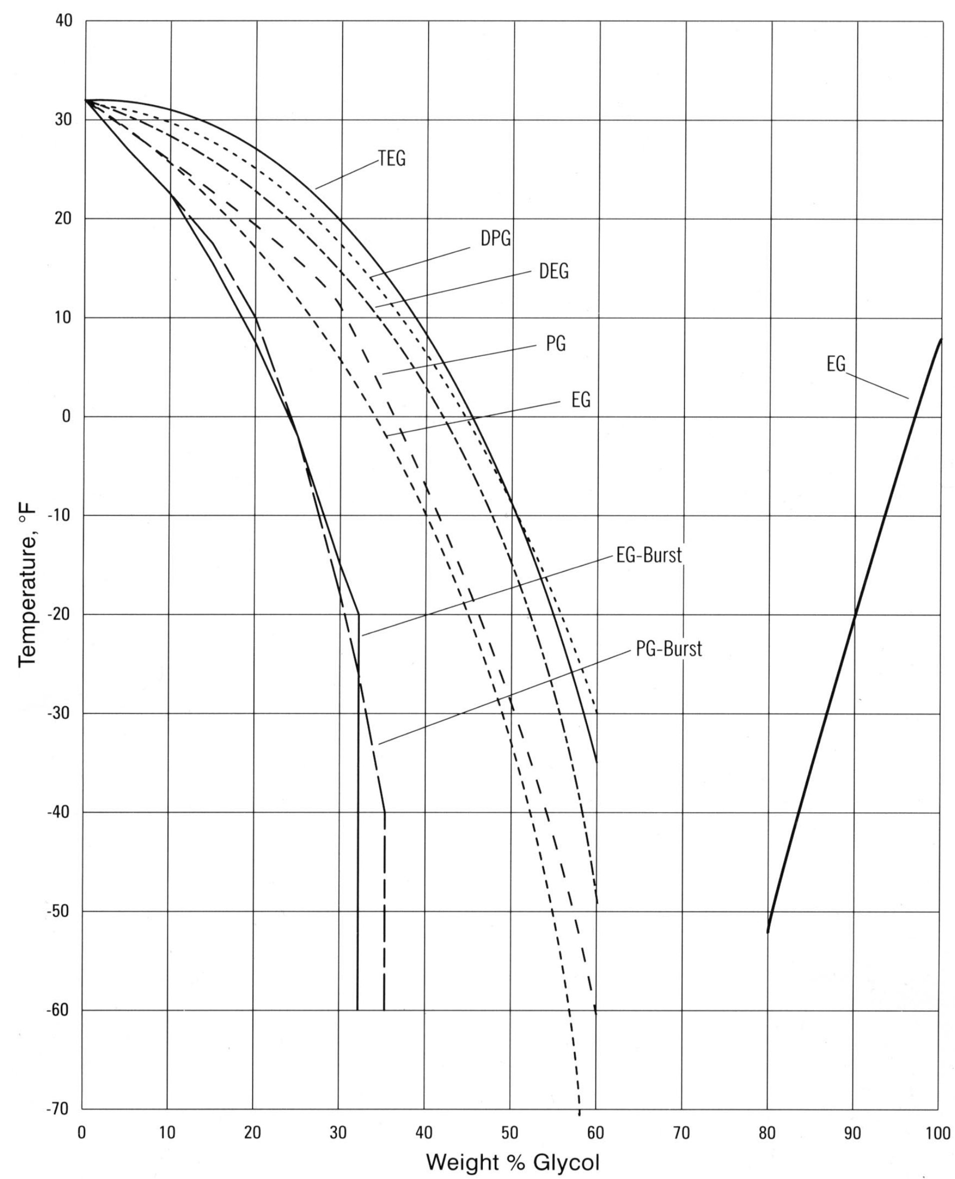
Burst Protection

Many liquids expand in volume upon cooling. This volume expansion may cause pipes and other enclosed systems containing a liquid to rupture or burst when exposed to low temperature conditions. Burst protection is needed to protect piping and other enclosed systems when they are inactive as they could rupture due to the expansion of an ice or slush mixture during low temperature conditions such as cold weather.

Glycol-based fluids provide such burst protection in water solutions due to their low freezing points. As a glycol-based fluid cools below the solution's freezing point, ice crystals begin to form, and the remaining solution becomes more concentrated in glycol. This ice/water/glycol mixture results in a flowable slush, and remains fluid, even as the temperature continues to cool.

The fluid volume increases as this slush forms and the temperature cools, flowing into available expansion volume in the system. If the concentration of glycol is sufficient, no damage to the system from fluid expansion should occur within the temperature range indicated in Figure 1.

Figure 1- Freeze Points and Burst Points of Aqueous Glycol Solutions



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Glycol-based solutions can give excellent burst protection across a wide range of cold temperatures as indicated in Figure 1. Consideration should be given to having appropriate expansion space for the solution and to the need for an inhibited glycol-based product such as DOWFROST*, DOWFROST* HP, DOWCAL* N, or DOWCAL* 20 Heat Transfer Fluid products or Industrial Coolants such as AMBITROL* NTC, AMBITROL* NTF 50, AMBITROL* NTF 40 or AMBITROL* 30[1].

Solubility

Glycols, like all low-molecular-weight alcohols, are 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 glycols.

As a general rule, propylene glycol is a better solvent for oils and organic chemicals than ethylene glycol. DPG and TPG show greater solvency than MPG. Tripropylene glycol, for example, has the most extensive solvent properties of the entire glycol group.

This relationship is well demonstrated by Figure 2, 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. Ester or acid type oils and gums are soluble to some extent in all glycols but are most soluble in tripropylene glycol.

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

Ethyl cellulose and cellulose acetate are completely insoluble in all glycols. Cellulose nitrate swells in ethylene glycol and propylene glycol and shows distinct solubility in the polyglycols. Small amounts of 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 (DPG) are compatible in all three cellulose films. Cellulose acetate shows compatibility for substantial quantities of all glycols.

[1] http://www.dow.com/heattrans/index.htm

Figure 2- Solubility of Various Compounds in Glycols

Weight % in Glycols at 25°C

S = Completely Soluble < = Less Than
I = Insoluble > = Greater Than

	Propylene Glycol	Dipropylene Glycol	Tripropylene Glycol
Benzene	19.2	S	S
Carbon Tetrachloride	23.4	S	S
Dibutyl Phthalate	8.1	S	S
Dichloroethyl Ether	37.1	S	S
Ethanolamine[1]	S	S	S
DOWANOL* PM Glycol Ether[1]	S	S	S
DOWANOL DPM Glycol Ether[1]	S	S	S
Ethyl Alcohol	S	S	S
Ethyl Ether	S	S	S
Methyl Alcohol	S	S	S
Methyl Isobutyl Carbinol	S	S	S
Methyl Isobutyl Ketone	S	S	S
Monochlorobenzene	22.5	S	S
Monoethanolamine[1]	S	S	S
ortho-Dichlorobenzene	19.4	S	S
Perchloroethylene[1]	14.5	S	S
Phenol[1]	S	S	S
Styrene[1]	15	S	S
Toluene	12.3	S	S
Urea	29	12	10
Castor Oil	0.8	S	S

[1] Product of The Dow Chemical Company
[2] Forms stable emulsion from this concentration to 100%
[3] Becomes too viscous to stir beyond 16%
*Trademark of The Dow Chemical Company

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	Propylene Glycol	Dipropylene Glycol	Tripropylene Glycol
Coconut Oil	1	1	3
Cottonseed Oil	1	1	<1
Hydrous Wool Fat	<0.5	<0.5	<1
Lard Oil	1	1	<1
Linseed Oil	1	1.4	2.5
Oiticica Oil	<1	<1	<1
Olive Oil	1	0.7	1.5
Pine Oil	S	S	S
Soya Bean Oil	1	1	<1
Sperm Oil	1	1	<1
Tall Oil	<1	S	S
Tung Oil	1	1	<1
Turkey Red Oil	<1[2]	3[2]	4[2]
Paraffin Oil	1	1	<1
SAE No. 10 Oil	1	1	<1
VMP Naphtha	1	10	14
Animal Glue (Dry)	<0.5	<0.5	<1
Dextrin	<1	<1	<1
Gum Damar	<0.5	<0.5	<1
Kauri Gum	<5	<5	>16[3]
Sudan III	<0.5	<0.5	<1
Shellac	<0.5	<0.5	<1

[1] Product of The Dow Chemical Company
[2] Forms stable emulsion from this concentration to 100%
[3] Becomes too viscous to stir beyond 16%
*Trademark of The Dow Chemical Company

Hygroscopicity

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. The addition of water modifies the properties of glycol. The properties of both anhydrous glycols and glycol-water solutions are presented in this publication.

The relative humectant value of 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 3, which may be used to determine the amount of glycol needed to condition a given quantity of a product requiring a humectant.

Figure 3- Relative Humectant Values [1]

Temperature of Air °F	Glycol	Relative Humidities								
		10%	20%	30%	40%	50%	60%	70%	80%	90%
20 (-6.7°C)	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 (4.4°C)	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 (15.6°C)	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 (26.7°C)	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 (37.8°C)	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 (48.9°C)	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

[1] Note: Values are given as the percent by weight of glycol in water solution required to maintain equilibrium in contact with air of various temperatures and humidities.

Humectancy Example

If six pounds of water are required to condition 100 pounds of product, and propylene glycol (PG) is chosen as the humectant, the following calculation can be made from Figure 3. With a 60% relative humidity and at 80°F, (26.7°C) a 75% PG solution in water is indicated in the table. Since six pounds of water are required, 6 divided by 0.25 equals 24 pounds of solution needed. Subtracting the 6 pounds of water, the total amount of PG required is 18 pounds.

It should be noted that a product will normally contain a certain amount of moisture, with 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 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.

Glycols For Dehydration of Gases

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 equilibrium with glycol-water solutions are given in Figure 4 for propylene glycol and Figure 5 for DPG. The graphs extend over the range of temperatures most commonly encountered, from 20°F to 320°F (-6.7°C to 160°C) and may be used to calculate dew point depressions of gases at equilibrium with the glycol solution at atmospheric pressure.

Dehydration Example

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 might plug the lines. The natural gas is introduced into the contractor in which the glycol solution is contained. The solution temperature is 80°F (26.7°C). It is desirable to depress the dew point of the gas to 50°F (10°C). Assume that propylene glycol is being used as the dehydrating medium. Turn to Figure 4 and locate 80°F (26.7°C) on the horizontal scale entitled “Solution Temperature, Degrees Fahrenheit.” Follow this line vertically up the scale until it intersects the 50°F (10°C) line of the vertical scale entitled “Water Vapor Dew Point, Degrees Fahrenheit.” The point thus found falls between the 85% by weight solution line and the 90% by weight solution line, but is nearer the 90% line. By estimation, approximately 88% propylene glycol solution would be required. Substituting another glycol in the same example, 93.5% dipropylene glycol (DPG) solution would be needed (Figure 5).

Figure 4- Water Vapor Dew Points Over Aqueous Propylene Glycol Solutions

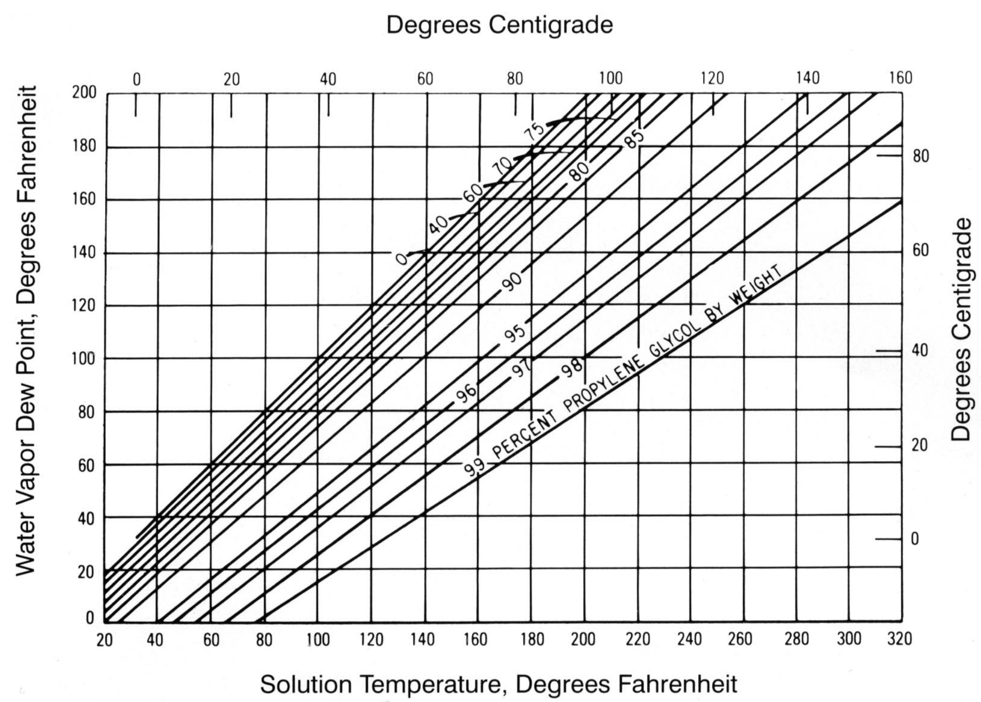

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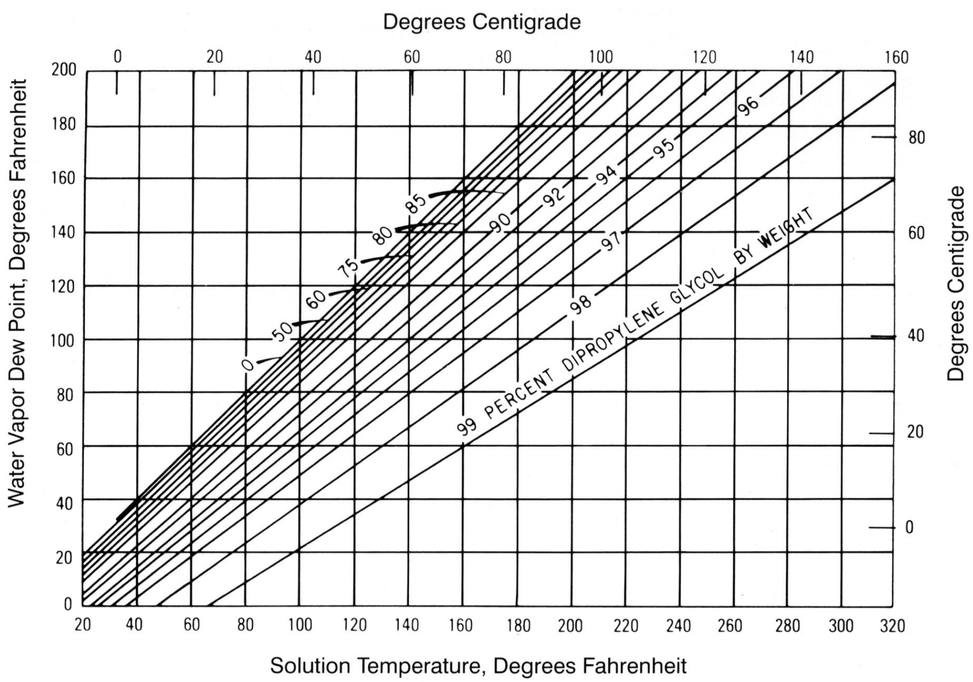
Figure 5- Water Vapor Dew Points Over Aqueous Dipropylene Glycol Solutions



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Vapor Pressure And Boiling Point

All liquids form vapors which exert pressure 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 6 and 7. 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. The normal boiling point is defined as the temperature at which a liquid boils at 760 mm Hg. (In Figures 6 and 7, bold 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 lines.

Glycols have lower vapor pressures than water and their boiling points are above the boiling point of water. If the external pressure is reduced, glycols will boil at lower temperatures, as shown in the following Figures, where the vapor pressures of glycols are equal to the reduced external pressure. The following table lists the boiling points of water and glycols when the external pressure is reduced to 50 mm Hg.

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 (20°C) 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 glycols lessens their tendency to evaporate and has led to their use as plasticizers, “permanent” antifreeze agents, solvent vehicles, hygroscopic agents, and ingredients of brake fluids.

Boiling Points at 50mm Hg		
Water	100.6°F	38.1°C
Propylene Glycol	240.6°F	115.9°C
Dipropylene Glycol	306.5°F	152.5°C
Tripropylene Glycol	358.9°F	181.6°C

Figure 6- Total Pressure Over Aqueous Propylene Glycol Solutions Versus Temperature

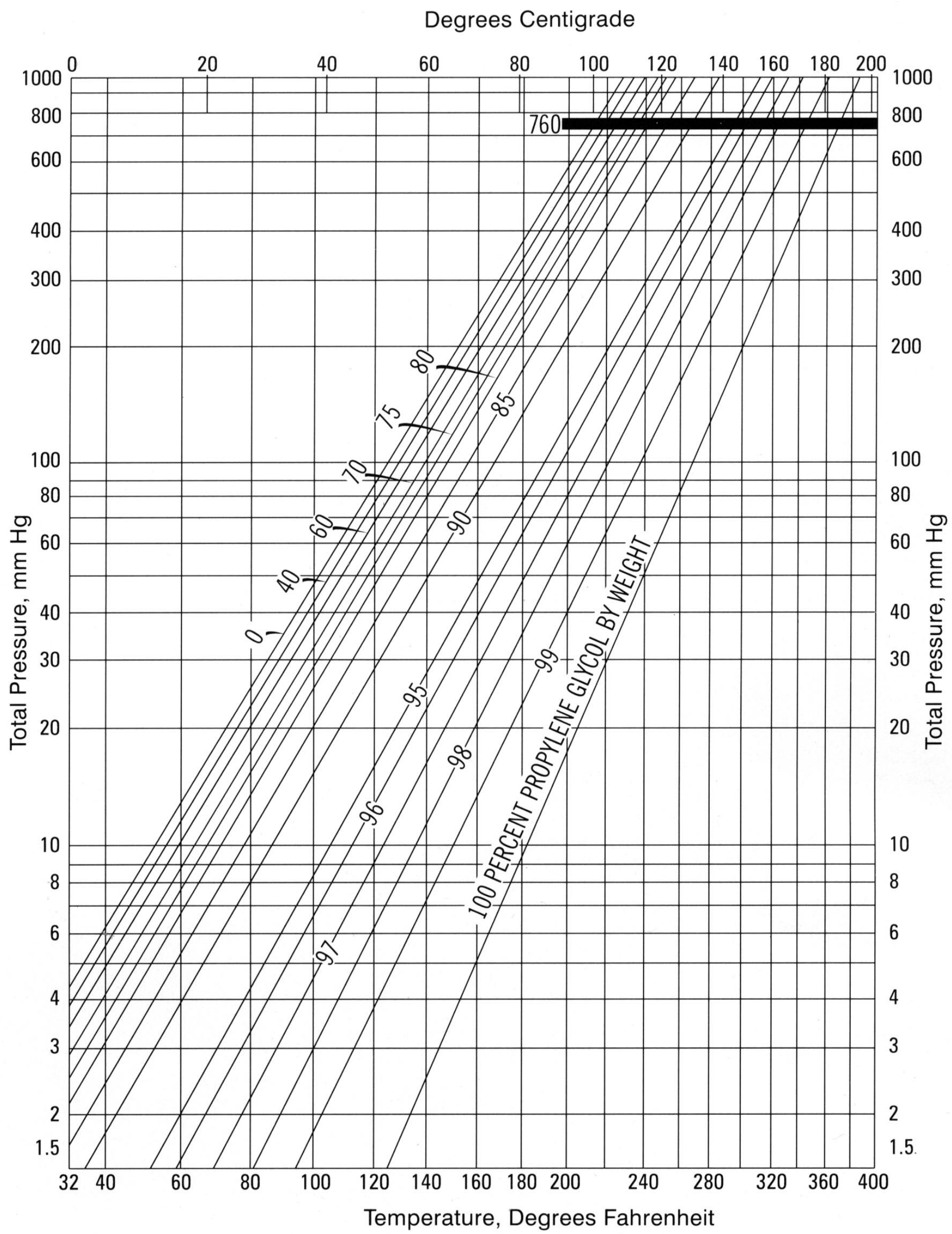

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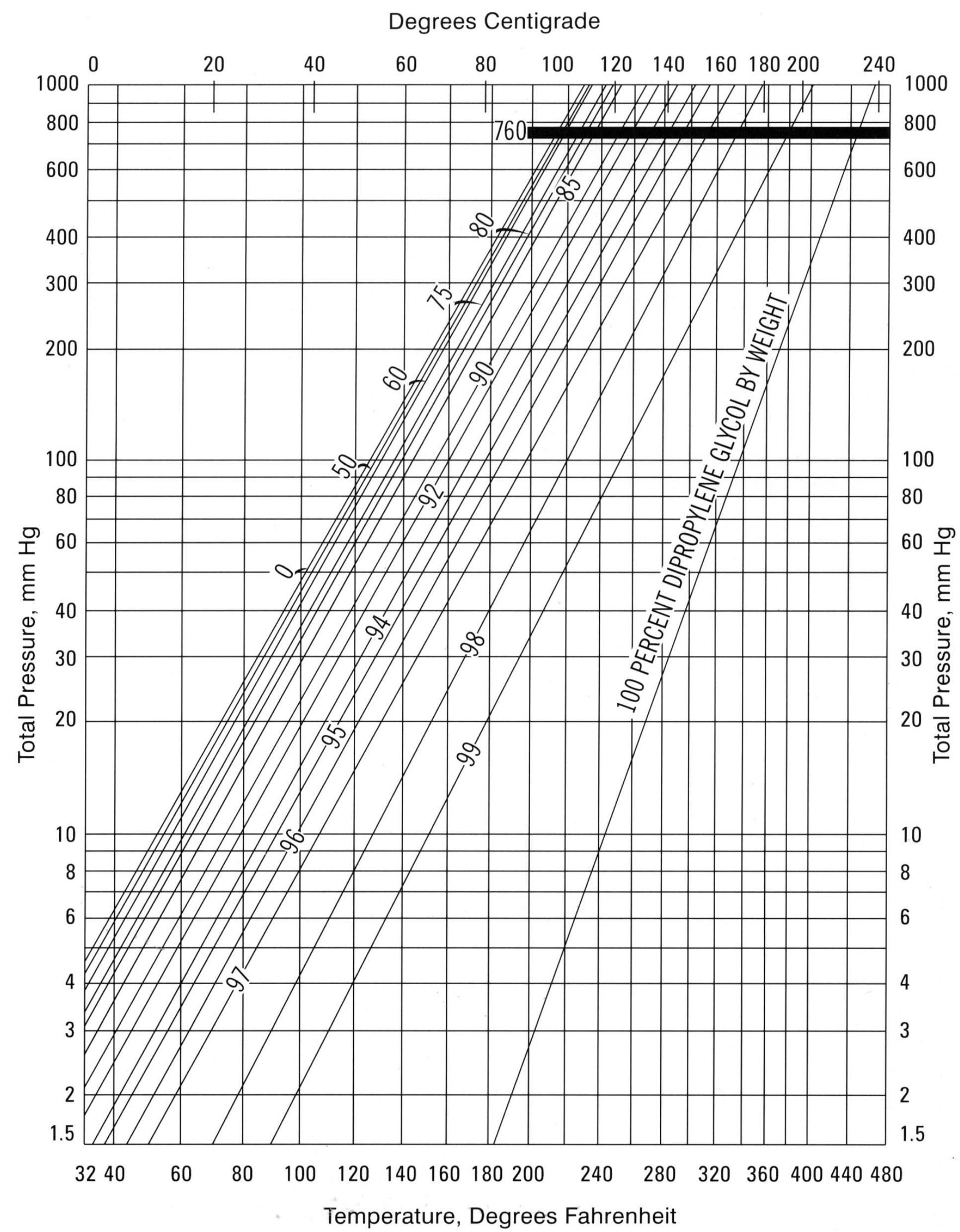
Figure 7- Total Pressure Over Aqueous Dipropylene Glycol Solutions Versus Temperature



[larger view]

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. PG-water solution boiling points at pressures of 100, 300, and 600 mm Hg are shown in Figure 8. The boiling points of aqueous solutions of dipropylene glycol are shown in Figure 9. To determine the boiling point of an 0.8 mole fraction propylene glycol-water solution at 600 mm Hg for example, turn to Figure 8 and, on the horizontal scale titled "Mole Fraction Propylene Glycol", locate the 0.8 mole fraction. Follow the 0.8 mole fraction 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 275°F (135°C). It is often desirable to determine the composition of the vapors in equilibrium with any given solution. This information may also be obtained from Figures 8 and 9.

In the example quoted, for an 0.8 molar PG solution, the vapor composition is found by reading across the chart on the 275°F (135°C) line to its point of intersection with the vapor curve – a point which turns out to be directly above (0.76 mole fraction PG) 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. The vapor-liquid composition curves included in this publication are useful in engineering such a reaction.

The vapor-liquid equilibrium diagrams provided are plotted as mole fraction vs. temperature. It is often desirable or necessary to express these values in weight percent or volume percent. Figures A1-A3 in the Appendix can be used for making conversions between mole fraction, weight percent, and volume percent.

Figure 8- Vapor-Liquid Composition Curves for Aqueous Propylene Glycol Solutions

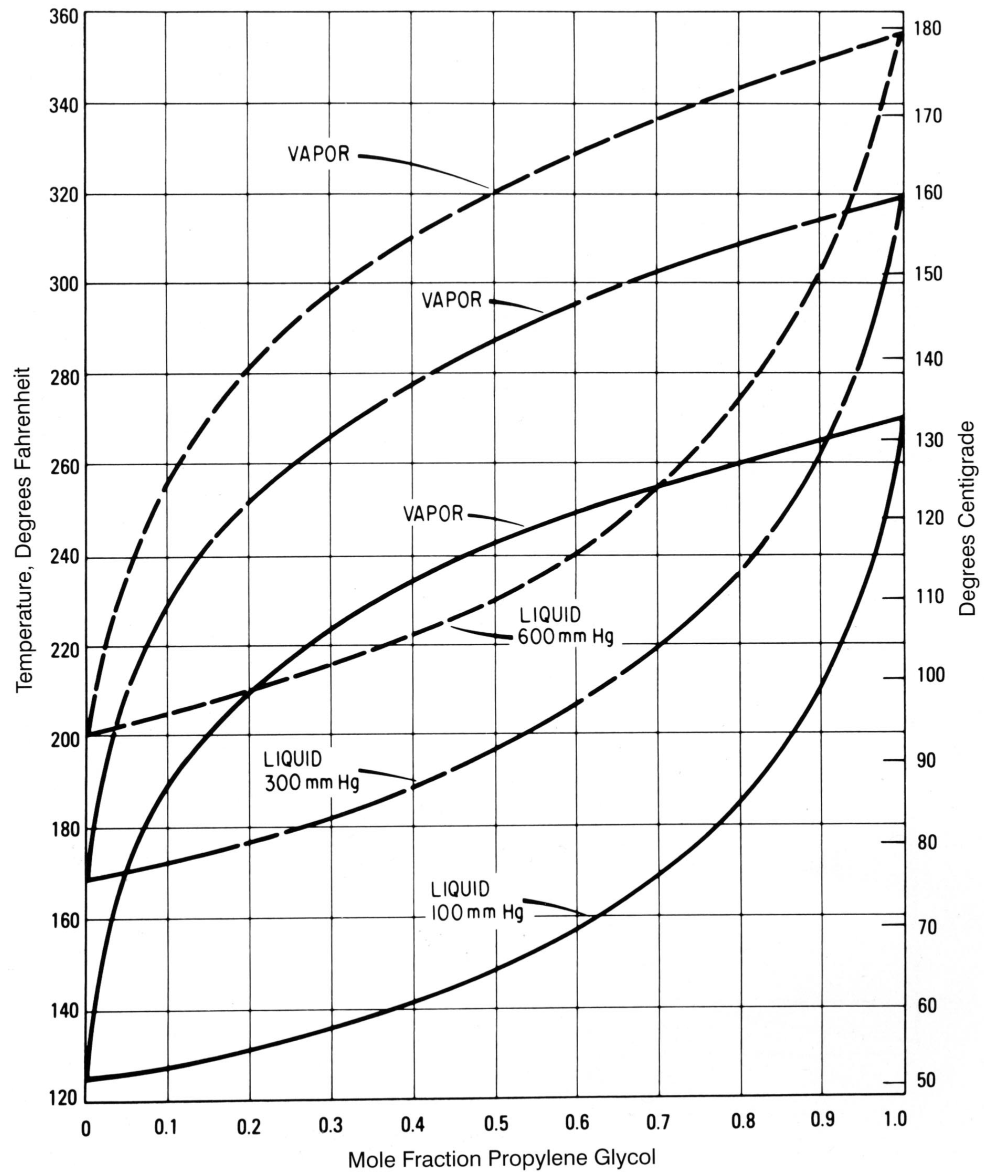
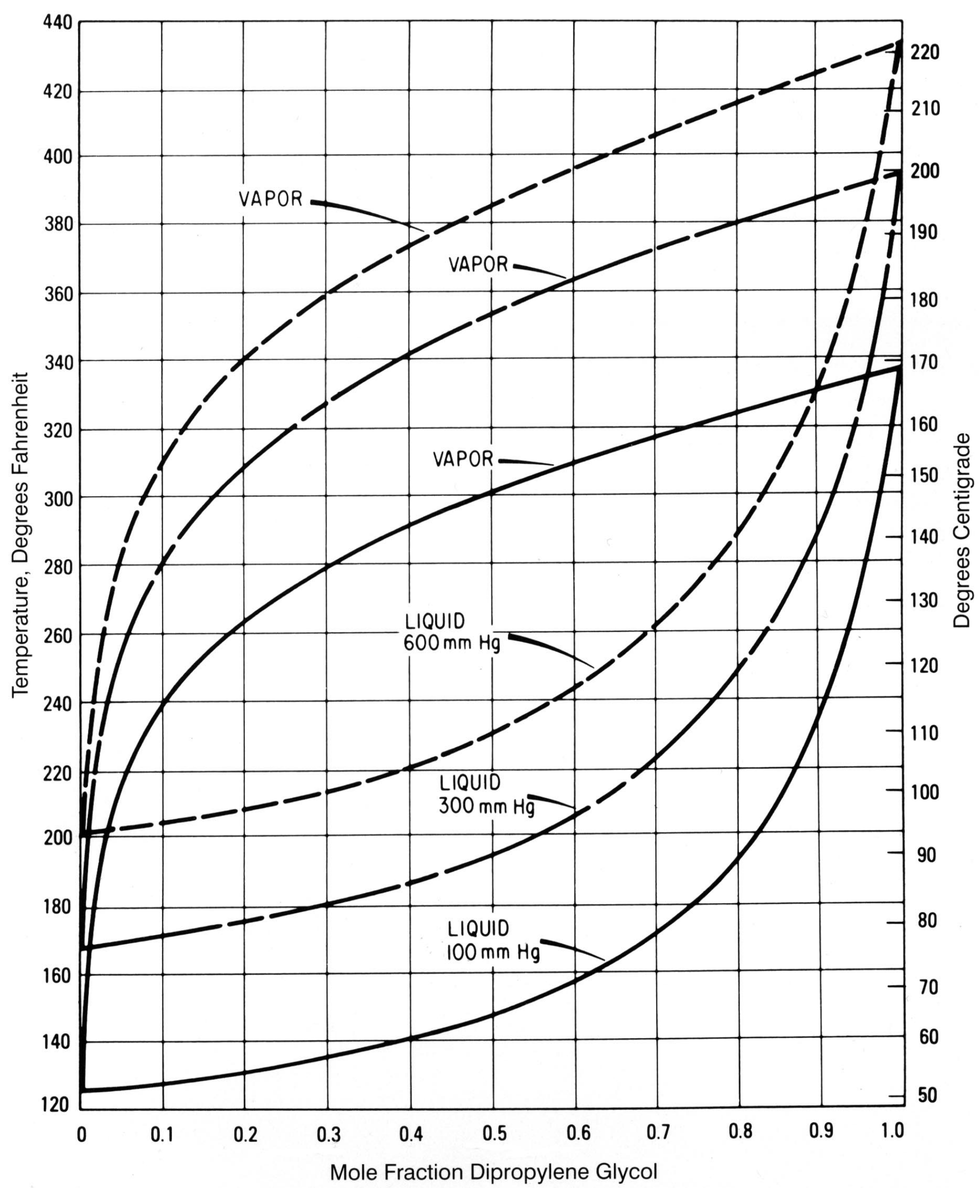


Figure 9- Vapor-Liquid Composition Curves for Aqueous Dipropylene Glycol Solutions



Viscosity

Viscosity is a measure of the internal friction of a liquid. As viscosity increases, the tendency to flow decreases. Viscosities of 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 glycols are listed below.

The viscosities of anhydrous glycols are shown by Figure 10, and those of aqueous glycol solutions by Figures 11-13.

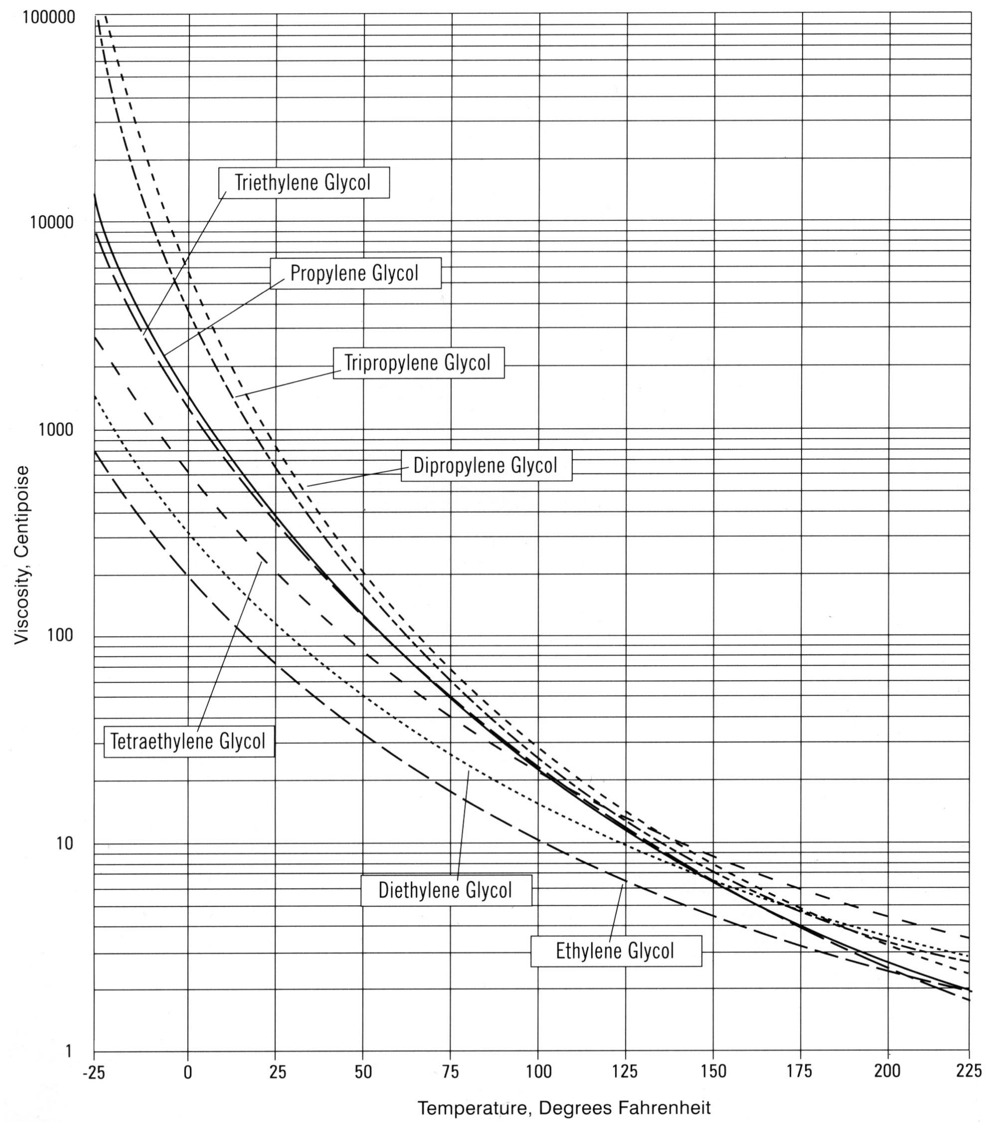
Glycol	Pour Point	
Propylene Glycol	<-71°F	-57°C
Dipropylene Glycol	-38°F	-39°C
Tripropylene Glycol	-42°F	-41°C

Viscosity information is required for pumping, filtering and piping calculations.

Although the viscosities of glycols are shown in centipoises (mPa*s) (dynamic viscosities), the values can easily be converted to centistokes (cS)(kinematic viscosity) 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 16-18.

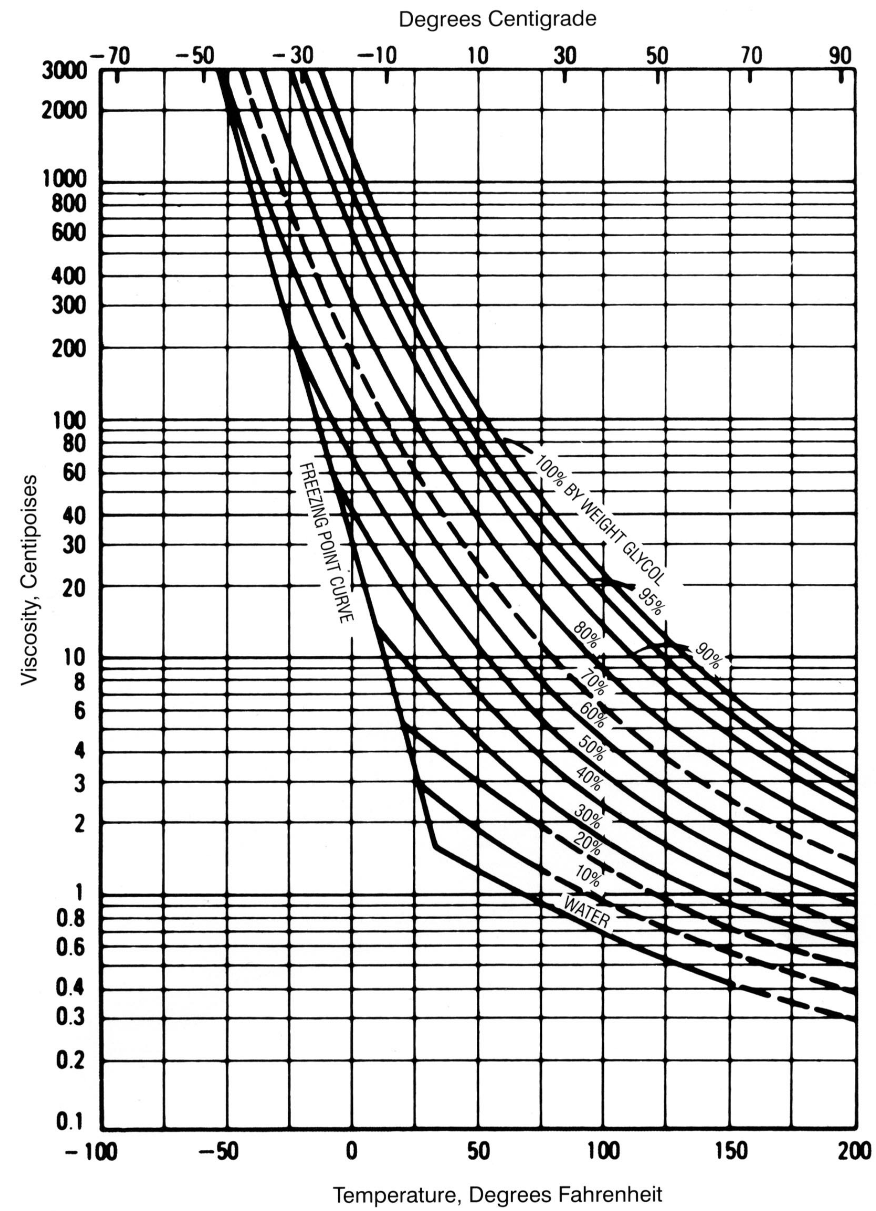
Glycols are more fluid than many high boiling solvents and plasticizers. For this reason they are often employed, either alone or in combination with other fluids, to reduce the viscosities of compositions with too much body.

Figure 10- Viscosities of Anhydrous Glycols



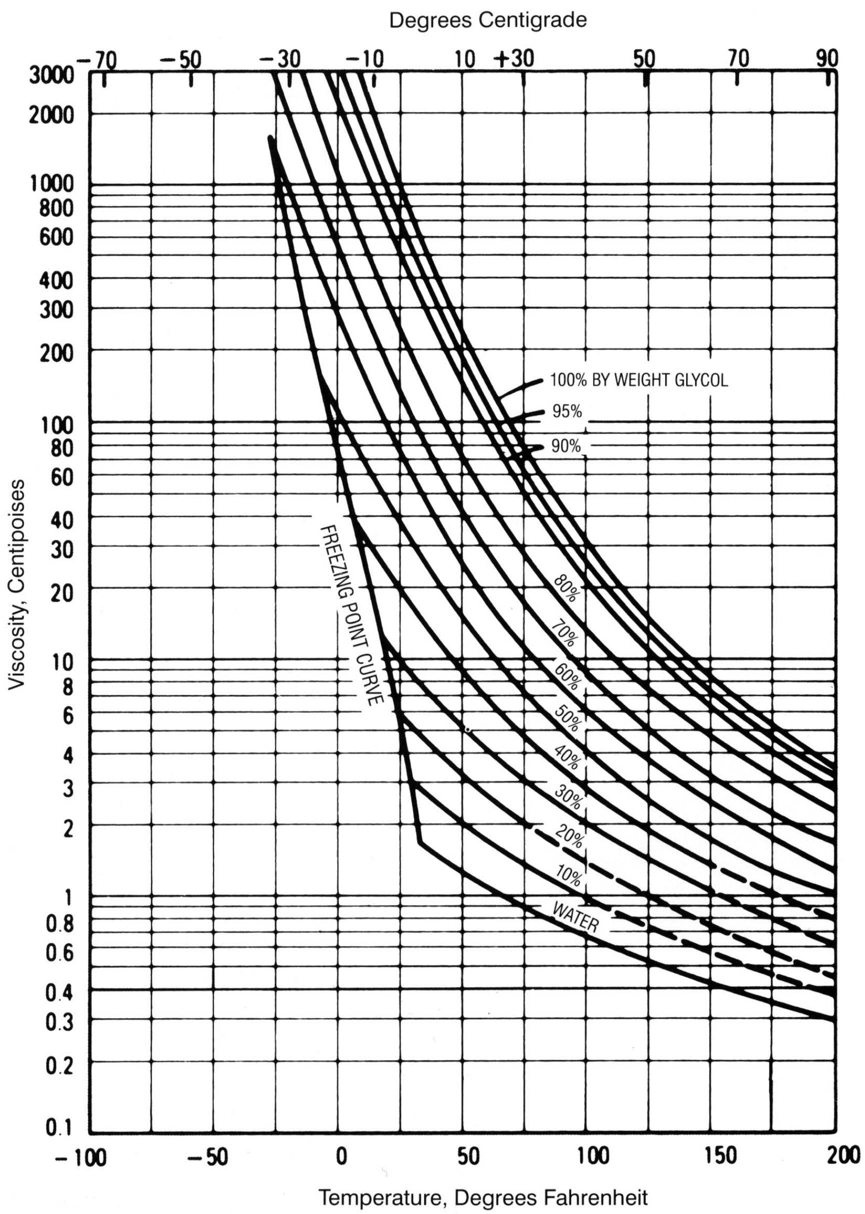
[larger view]

Figure 11- Viscosities of Aqueous Propylene Glycol Solutions



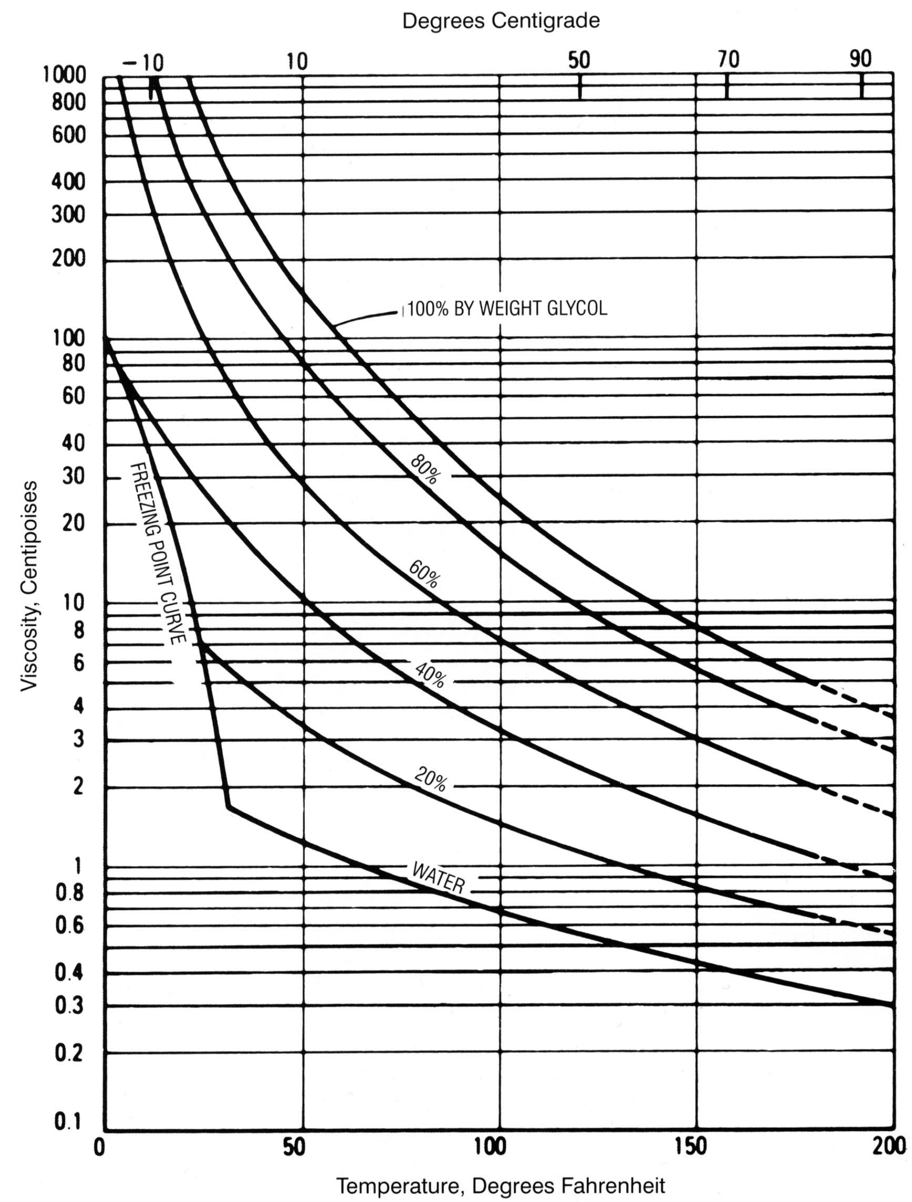
[larger view]

Figure 12- Viscosities of Aqueous Dipropylene Glycol Solutions



larger view

Figure 13- Viscosities of Aqueous Tripropylene Glycol Solutions



larger view

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.

The specific heat of water is approximately 1 at ordinary temperatures. Specific heat varies with temperature, and the specific heats of the glycols shown are found in Figure 14 for temperatures from 0°F to 240°F (-18°C to 115°C).

Specific heats of glycol-water solutions are shown in Figure 15. 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.

Figure 14- Specific Heat of Anhydrous Glycols

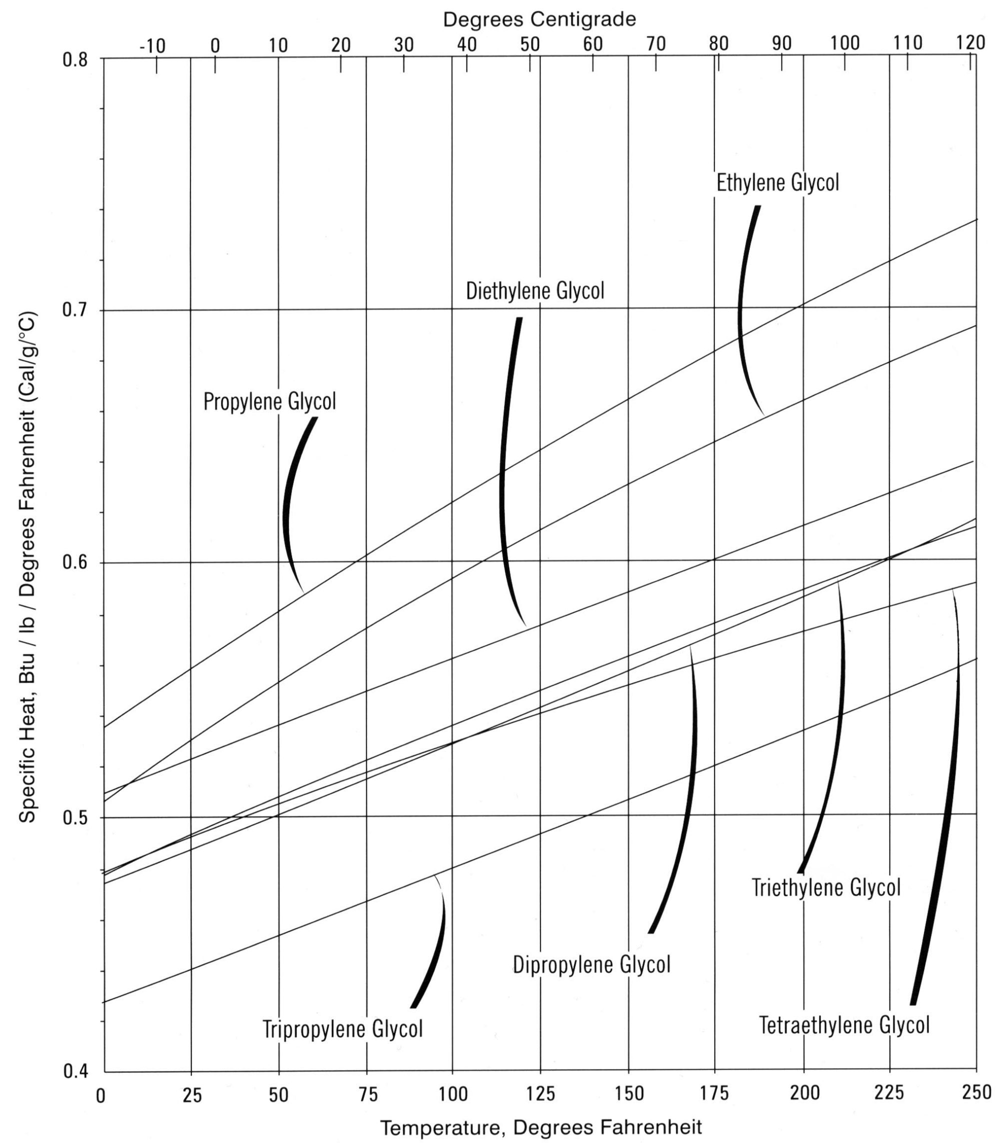


Figure 15- Specific Heats of Aqueous Glycol Solutions

	Glycol % by Weight						
Temp. °F	100	80	60	40	20	10	Temp. °C
Propylene Glycol							
60	0.587	0.687	0.795	0.900	0.970	0.985	15.6
80	0.603	0.702	0.808	0.907	0.972	0.986	26.7
100	0.619	0.717	0.821	0.913	0.975	0.988	37.8
120	0.635	0.733	0.833	0.919	0.977	0.990	48.9
140	0.651	0.748	0.846	0.925	0.980	0.991	60.0
160	0.667	0.763	0.857	0.930	0.983	0.992	71.1
180	0.683	0.778	0.871	0.936	0.984	0.994	82.2
200	0.699	0.794	0.882	0.944	0.987	0.955	93.3
220	0.715	0.809	0.895	0.949	0.990	0.996	104.4
240	0.731	0.824	0.907	0.954	0.993	0.998	115.5

	Glycol % by Weight						
Temp. °F	100	80	60	40	20	10	Temp. °C
Dipropylene Glycol							
60	0.570	0.687	0.801	0.900	0.967	0.985	15.6
80	0.582	0.698	0.810	0.905	0.970	0.986	26.7
100	0.594	0.708	0.819	0.910	0.972	0.988	37.8
120	0.606	0.718	0.828	0.915	0.974	0.990	48.9
140	0.618	0.728	0.836	0.920	0.976	0.991	60.0
160	0.631	0.739	0.845	0.924	0.978	0.993	71.1
180	0.644	0.749	0.854	0.929	0.980	0.995	82.2
200	0.656	0.760	0.863	0.934	0.983	0.997	93.3
220	0.668	0.770	0.872	0.939	0.985	0.998	104.4
240	0.680	0.781	0.881	0.944	0.988	0.999	115.5

Density

Density is the weight per unit volume of a mass. Density varies with temperature and the graphs on page 23 show the densities of Dow's glycols and glycol-water solutions over a range of temperatures. Figures 16 and 17 show that the densities of PG-water solutions and DPG-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 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. The specific gravity of PG, the density of which is 1.037 at 77°F (25°C), when compared to water, which has density of 0.997 at 77°F (25°C), could be calculated as follows:

Specific Gravity of PG at 77°F (25°C) = 1.037/0.997 = 1.040

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

Specific gravity of PG at ("x"°F)/("y"°F1)= (density of PG at "x"°F) /(density of water At "y"°F)

1 "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:

Density in g/ml at t°C x 8.345 = lb/gal at t°C

Pounds per gallon 77°F (25°C)

Propylene Glycol....................8.62
Dipropylene Glycol 8.53
Tripropylene Glycol...............8.51

Volume changes resulting from heating or cooling glycol-water solutions may be readily calculated from the data presented in Figures 16-18. For example, in heating 10,000 lb of PG from 77°F to 140°F (25°C to 60°C), the increase in volume will be:

[(10000lb) / ((1.006g/ml)(8.345lb/gal/g/ml))] – [(10000lb) / ((1.032g/ml)(8.345lb/gal/g/ml)] = 1191gal – 1161gal = 30 gal

Density of Water at Various Temperatures

Temperature, °C	Density, g/ml	Temperature, °C	Density, g/ml
-20	0.993490	15	0.999129
-10	0.998137	20	0.998234
0	0.999868	25	0.997075
1	0.999927	30	0.995678
2	0.999968	35	0.994063
3	0.999992	40	0.992247
4	1.000000	50	0.988066
5	0.999992	60	0.983226
6	0.999968	70	0.977793
7	0.999930	80	0.971819
8	0.999877	90	0.965340
9	0.999809	95	0.961920
10	0.999728	100	0.958384

Figure 16- Densities of Aqueous Propylene Glycol Solutions

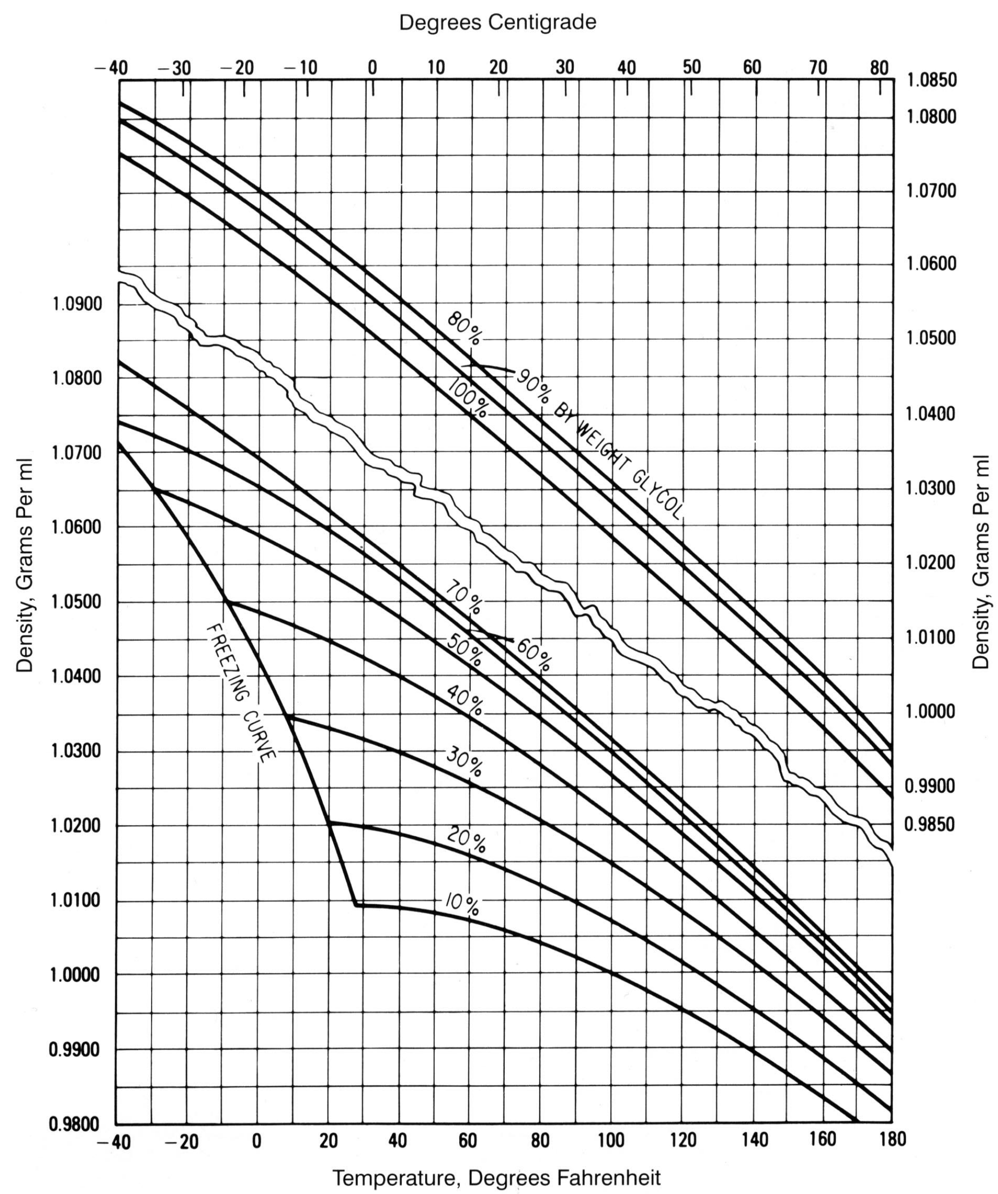
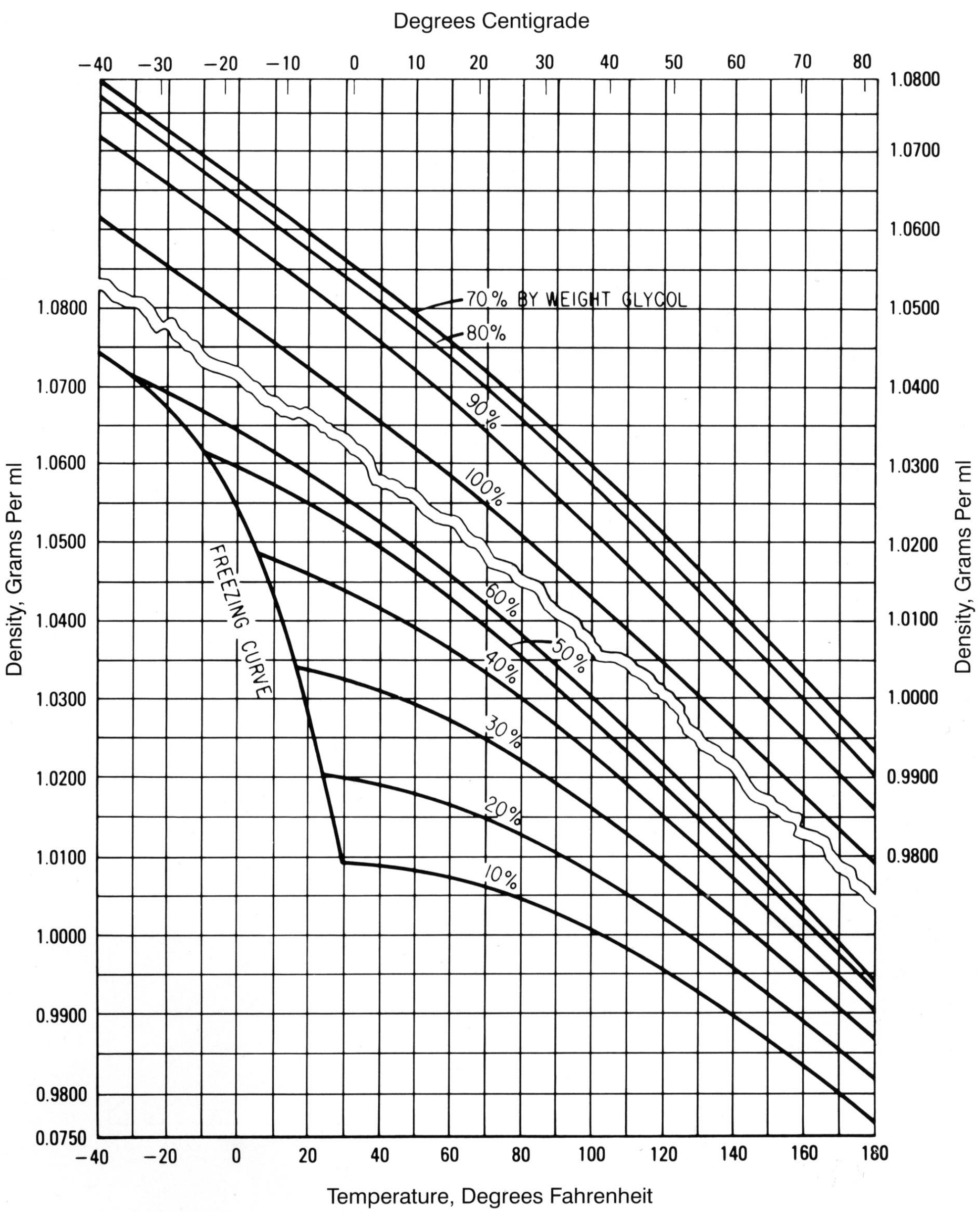
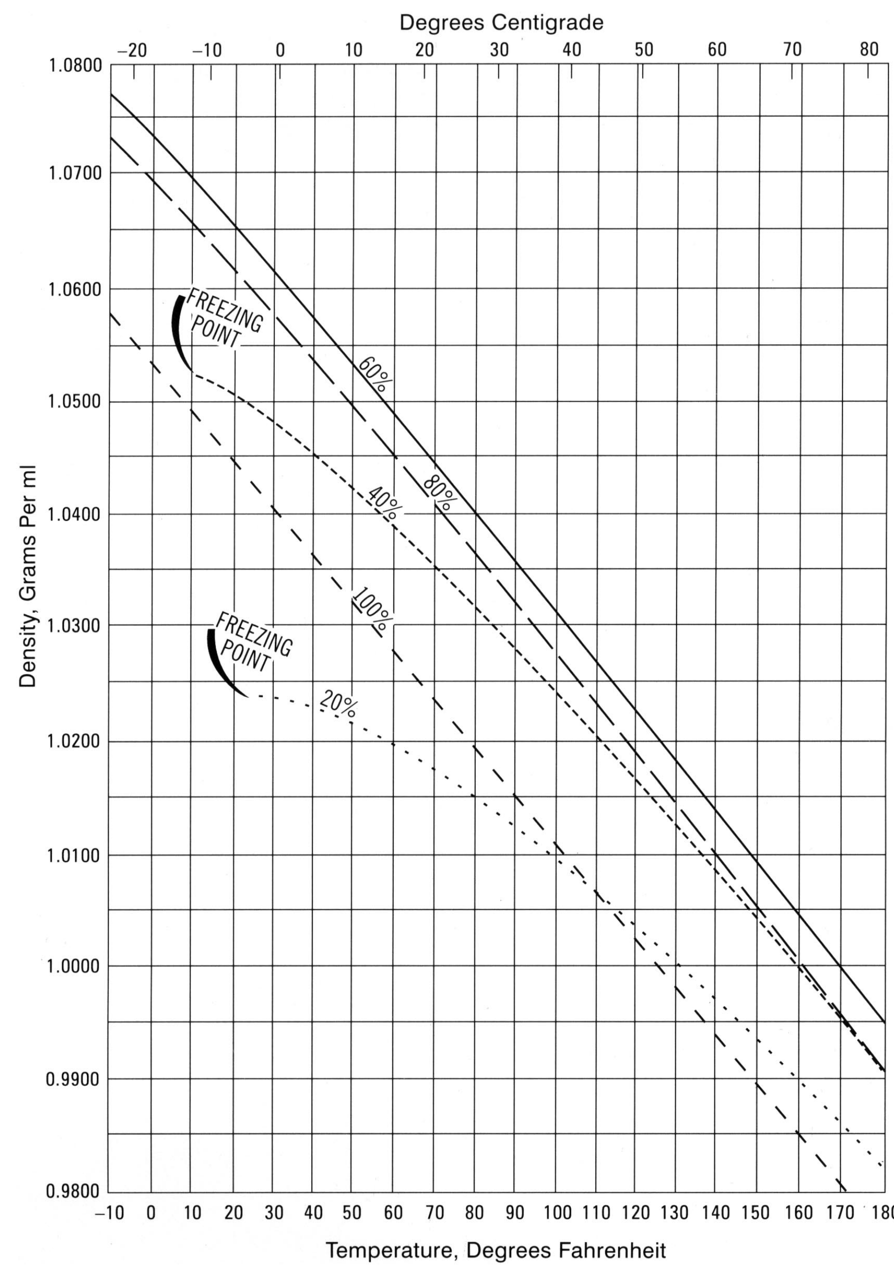


Figure 17- Densities of Aqueous Dipropylene Glycol Solutions



larger view

Figure 18- Densities of Aqueous Tripropylene Glycol Solutions



larger view

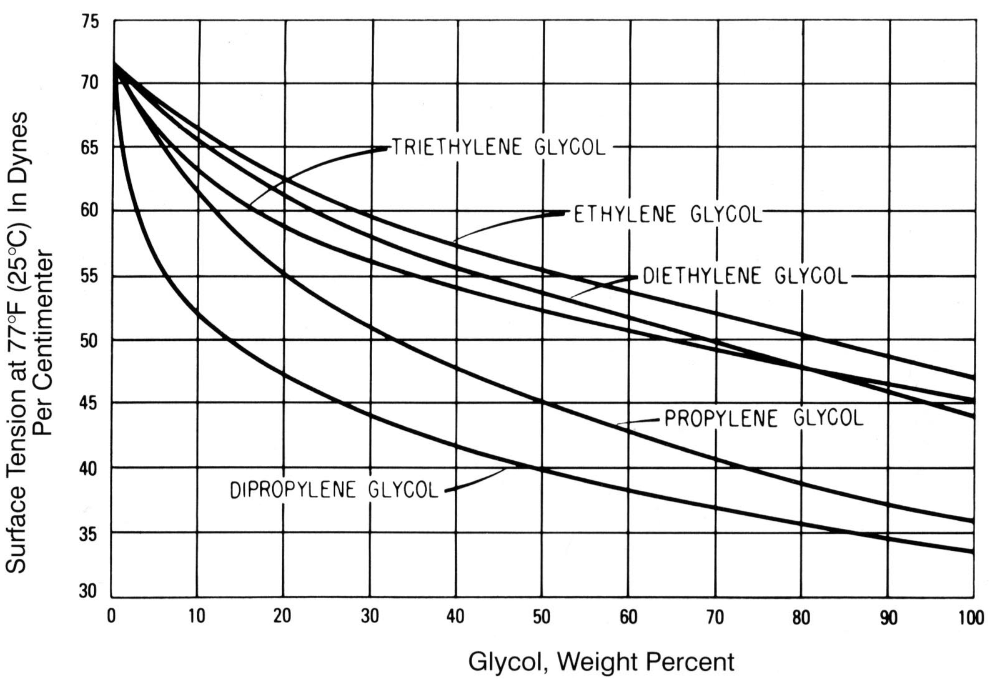
Surface Tension

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

Surface tensions of glycols are lower than that of water. Solutions of glycol and water have varying surface tensions, depending on the concentration of glycol in the solution. This is illustrated by Figure 19.

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.

Figure 19- Surface Tensions of Aqueous Solutions of Glycols at 77°F (25°C)



Stability of Propylene Glycols and Shelf Life

Prolonged contact of glycols with air should be avoided to decrease the possibility of oxidative degradation reactions and water absorption (glycols are hygroscopic). Dow recommends that propylene glycols be stored under nitrogen, ideally, but the use of dry air is also effective. Glycols should be stored under recommended warehouse conditions below 104°F (40°C) in closed containers.

Propylene glycols will degrade slowly in the presence of oxygen. Metal contamination, acidic or basic contaminants and higher temperatures all accelerate the degradation reactions. Typical oxidation products are aldehydes, ketones, acids and dioxolanes. A strong odor, higher acidity, higher ultra-violet (UV)-absorption or high color are indicators that a propylene glycol has been not been stored properly and has started to degrade.

Propylene glycols are sensitive to UV light, which can act as a radical initiator and initiate oxidation reactions. For this reason, it is recommended that glycols be stored in opaque containers and avoid frequent or prolonged exposure to sunlight.

Continuous stability testing programs show the following shelf lives, from the manufacturing date, for propylene glycols products, when stored under the recommended storage conditions.

Glycol	Shelf Life (Months)	Conditions
PG USP/EP	24	Bulk Storage, Drums, Plastic Containers
PGI	12	Bulk Storage in lined or stainless steel tanks; Drums
PGI	6	Bulk Storage in carbon steel tanks
DPG	12	Bulk Storage in lined or stainless steel tanks; Drums
DPG	6	Bulk Storage in carbon steel tanks
DPG LO+	12	Bulk Storage in lined or stainless steel tanks; Drums
TPG	6	Bulk Storage in lined or stainless steel tanks; Drums
TPG	3	Bulk Storage in carbon steel tanks
TPG AC	6	Bulk Storage in lined or stainless steel tanks; Drums
TPG AC	3	Bulk Storage in carbon steel tanks

Flammability

Because the flash and fire points of propylene glycols are above the boiling point of water, glycols present little fire hazard in storage or handling. Flash points were determined by Setaflash or by Pensky-Martins Closed Cup Methods (PMCC).

Fire Hazard Information

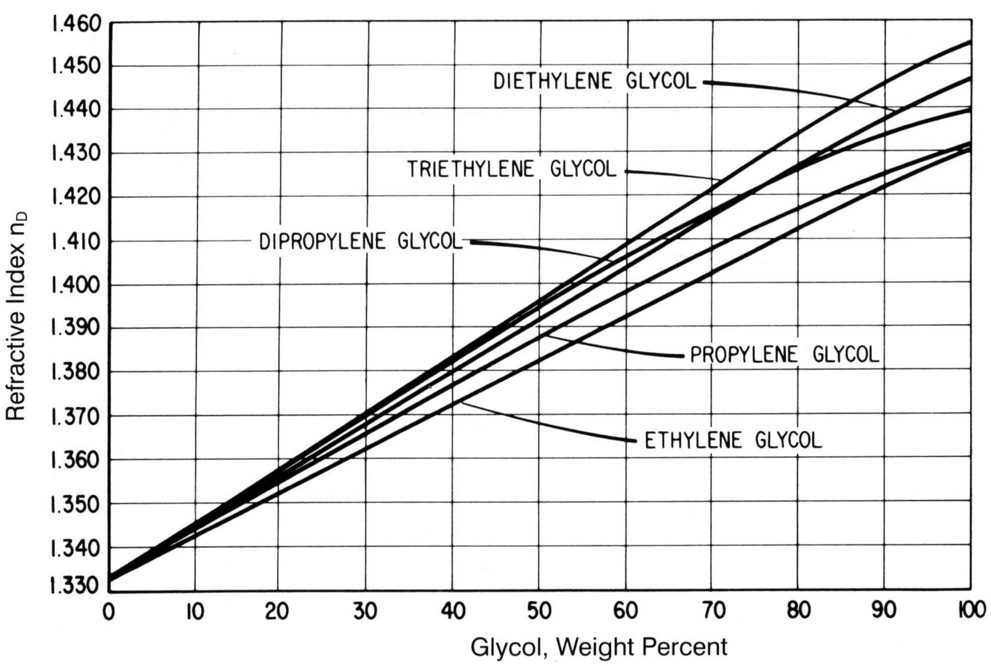
	Flammable Limits		Auto-Ignition Temp[1]	NFPA[2] Hazard Identification			Flash Point	
Glycol	Lower	Upper	°F (°C)	Health	Flammability	Reactivity	°F	°C
Propylene Glycol	2.6	12.5	700 (371)	0	1	0	220.2	104
Dipropylene Glycol	-	-	628 (331)	0	1	0	255.2	124
Tripropylene Glycol	-	-	511 (266)	0	1	0	290.2	143

[1]In presence of air
[2]NFPA—National Fire Protection Association

Refractive Index

Refractive index is an optical measurement of a materials ability to bend a beam of light. The refractive index may be used to determine the purity of the material. Figure 20 below, shows the refractive indices of glycols and their aqueous solutions at 77°F (25°C).

Figure 20- Refractive Indices of Aqueous Solutions of Glycols at 77°F (25°C)



larger view

Applications and Uses

Propylene Glycol (Monopropylene Glycol)

Propylene glycol (PG), also called Monopropylene Glycol (MPG) is unique among glycols in that its very low toxicity permits it to be ingested[3]. For applications such as foods, animal feed, pharmaceuticals, cosmetics and others involving possible ingestion or absorption through the skin, Dow offers its Propylene Glycol USP/EP (PG USP/EP)[4], which is produced and handled according to current Good Manufacturing Practices (cGMP). For other industrial and technical uses, Dow offers its Propylene Glycol Industrial (PGI)[5].

In common with the other glycols, PG is odorless and colorless, and has a wide range of solvency for organic materials, plus it is completely soluble in water. PG has inherent anti-microbial properties and can be part of an effective food preservative system.[6]

Dow's Propylene Glycol USP/EP is an important solvent 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. Dow's PG USP/EP finds additional use as a solvent in elixirs and pharmaceutical preparations containing 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 popular as emulsifiers in cosmetic and pharmaceutical creams.

Dow's PG USP/EP is an effective humectant, preservative and stabilizer, and may be used where allowed by local regulations, in such diverse applications as bakery goods, food flavorings, salad dressings, shave creams, and semi-moist pet food (with the notable exception of cat food where propylene glycol use is not approved).[7] Humectancy values and example calculations are presented in another section of this brochure.

For indirect food contact applications, such as brewing and dairy industries as well as refrigerated display cases, and fluids, Dow recommends its PG USP/EP.

Dow's Propylene Glycol Industrial (PGI) is the preferred glycol for use in high-performance unsaturated polyester resins when manufacturing reinforced plastic laminates for marine construction, gel coats, sheet molding compounds (SMC) and synthetic marble castings. It is an important inter-mediate in the production of alkyd resins for paints and varnishes. Aqueous solutions of Dow's PGI display excellent antifreeze properties and are therefore valuable as low temperature heat-transfer and aircraft and runway deicing fluids. Dow's PGI also functions well as a solvent in printing inks, a solvent and enzyme stabilizer in liquid laundry detergents, and a stabilizer in hydraulic fluids.

Dipropylene Glycol

Dipropylene glycol (DPG) is produced as a co-product in the manufacture of propylene glycol by the hydrolysis of propylene oxide. DPG is used as a solvent, humectant, coupling agent and chemical intermediate.

Dow's Dipropylene Glycol Regular Grade[8] is most often used as a chemical intermediate in several diverse application areas. DPG dibenzoate is a high-volume plasticizer made by the esterification of dipropylene glycol with benzoic acid. As a reactant in unsaturated polyester resins, dipropylene glycol adds flexibility and hydrolytic stability to the finished resin and reduces the viscosity of the uncured resin. In dicyclopentadiene (DCPD)-modified unsaturated polyester resins (UPRs), DPG helps to add flexibility to the cured resin making it less brittle.

[3] by humans and animals, with the exception of cats
[4] Propylene Glycol USP/EP Sales Specification, www.dowpg.com
[5] Propylene Glycol Industrial Sales Specification, www.dowpg.com
[6] Martin Burr and Linwood Tice, *"A Study of the Inhibitory Concentration of Glycerine – Sorbitol and Propylene Glycol – Sorbitol Combinations on the Growth of Microorganisms,"* JAP Association, Vol. XLV1, No. 4, p.217.
[7] 21CFR500.50
[8] For more information, including sales specifications for Dow's Dipropylene Glycol Regular Grade, visit www.dowpg.com.

In urethane production, DPG acts as an initiator for urethane polyol synthesis using epoxides, and as the polyol itself in rigid polyurethane foam systems.

Diacrylate esters of DPG are used as reactive diluents in radiation-cured resin formulations. Reactive diluents are integral parts of these formulations, reducing the viscosity of the uncured resin and enabling easier, more efficient application of the formulation to the substrate. Radiation-cured resins are fast-reacting and cured by exposure to ultraviolet or electron beam radiation. The reactive diluent actually becomes part of the final matrix, eliminating the need for a non-reactive solvent and thereby providing a non-volatile organic compound (VOC) emitting coating.

DPG is similar to other glycols in general properties. However, its greater solvency for certain materials, low evaporation rate, low toxicity and higher viscosity makes it better-suited for applications where other glycols are less effective. Some applications that take advantage of DPG's unique properties are brake fluid formulations, cutting-oils, textile lubricants, printing inks, coatings, industrial soaps, as well as solvents for agricultural and insecticidal formulations. DPG's excellent solvency for castor oil makes it extremely useful as a component of hydraulic brake-fluid formulations, while its affinity for other oils has led to its use in cutting oils, textile lubricants and industrial soaps.

Dow's Dipropylene Glycol LO+[9] (DPG LO+) is the solvent of choice for many fragrance and cosmetic applications. Excellent co-solvency for water, oils, and hydrocarbons, combined with low odor, low skin irritation potential, low toxicity, consistent isomer distribution and excellent quality, make it an important raw material in this industry. To provide the purity and consistency demanded by producers of cosmetics and fragrances, Dow provides DPG LO+ in accordance with Cosmetics Good Manufacturing Practices (Cosmetics GMP). Since consistency of product is an important attribute in these applications and DPG comprises a mixture of structural isomers, Dow includes isomer distribution limits in its DPG LO+ sales specification. The isomer composition is set by the manufacturing process and comprises:

1. 1,1'-oxybis-2-propanol (CAS 110-98-5, EINECS 203-821-4)
2. 2,2'-oxybis-1-propanol (CAS 108-61-2)
3. 2-(2-hydroxypropoxy)-1-propanol (CAS 106-62-7)

Dow's DPG LO+ is used as a coupling agent and humectant in a variety of cosmetic applications. The Cosmetic Ingredients Review issued a report in 1985 on the use of dipropylene glycol in cosmetic products.[10] The conclusion of this report was that dipropylene glycol is safe as presently used in cosmetic formulations.

In perfumes, the use level of Dow's DPG LO+ is greater than fifty percent in some formulations, while in others it is typically less than 10 weight percent. Some specific applications of DPG are wave sets, skin cleansing preparations (cold creams, lotions, liquids, and pads), deodorants, face, body, and hand skin care preparations, moisturizing skin care preparations and lipsticks.

Dow's DPG LO+ complies with the European cosmetic directive 76/768/EEC[11] and subsequent amendments and adaptations. DPG is included in the INCI list (International Nomenclature Cosmetic Ingredients) with the INCI name dipropylene glycol.

9 Dipropylene Glycol LO+ Sales Specifications and other information is available at www.dowpg.com.

10 Final Report on the Safety Assessment of Butylene Glycol, Hexylene Glycol, Ethoxydiglycol, and Dipropylene Glycol, Mary Anne Liebert, Inc., publishers, Journal of the American College of Toxicology, Volume 4, Number 5, 223, 1985.

11 Council Directive 76/768/EEC of 27 July 1976 on the approximation of the laws of the Member States relating to cosmetic products, OJ No L 262, 27.9.1976, p.169

Tripropylene Glycol

Tripropylene glycol (TPG) is also a co-product in the manufacture of propylene glycol (PG), from the hydrolysis of propylene oxide (PO) with excess water. TPG is a colorless, water soluble, medium viscosity, hygroscopic liquid with a low vapor pressure, low toxicity and a faint glycol-specific odor. TPG is a mixture of structural isomers (CAS number 24800-44-0), comprising:

- 1,1′-[(1-methyl-1,2-ethanediyl)bis(oxy)]bis-2-propanol, CAS 1638-16-0.
- 2,2′-[(1-methyl-1,2-ethanediyl)bis(oxy)]bis-1-propanol.
- 2-[1-(2-hydroxypropoxy)-2-propoxy]-1-propanol.
- 2-[2-(2-hydroxypropoxy)-propoxy]-1-propanol, CAS 45096-22-8.

Dow's Tripropylene Glycol Regular Grade[12] is an excellent solvent in many applications where other glycols are not as effective. Its ability to solubilize resins commonly used in printing-ink is especially effective; and in fact, it is often used in creams designed to remove ink stains from skin. The combination of water solubility and good solvent power for many organic compounds plus low volatility and high boiling point has led to its use by formulators of textile soaps and lubricants, cutting-oil concentrates and many similar products. Tripropylene glycol is used as an initiator for reaction with oxides in polyether synthesis for polyglycol and urethane polyols.

Dow's Tripropylene Glycol Acrylate Grade[13] is specifically used as a raw material for radiation-curable formulations. It is esterified with acrylic acid to make tripropylene glycol diacrylate, an important ingredient in the fast-growing radiation cure industry. Tripropylene glycol diacrylate functions as a reactive diluent, which lowers the viscosity of formulations prior to application. Radiation cured systems are used in printing inks, varnishes, paints and coating applications and offer several advantages including no post curing, low volatile organic compound emissions (VOC), energy efficiency, fast processing rates, compact plant size and excellent finish quality.

Dow's Tripropylene Glycol Acrylate Grade is specifically monitored for acidity, aldehydes and peroxides that can cause color and operational problems in the synthesis of the diacrylates. Typically values for these impurities in Dow's Tripropylene Glycol Acrylate Grade product are in the low ppm range.

[12] Tripropylene Glycol Regular Sales Specification , as well as other useful TPG information can be found at www.dowpg.com

[13] Tripropylene Glycol Acrylate Sales Specification, as well as other useful TPG information can be found at www.dowpg.com

Food Additive and Pharmaceutical Status

Note To Customers Concerning Food Additive Status

The information given here is for use as a general guideline. All applicable national and local regulations must be consulted for complete details. The final responsibility for proper use of glycols in direct or indirect food applications is that of the user or formulator.

Propylene Glycol

U.S. Regulations

Propylene glycol (PG), when manufactured according to current Cosmetics Good Manufacturing Practices (cGMP) per United States Food and Drug Administration guidelines, is cleared for various uses under Food Additive Regulations (Title 21, U.S. Code of Federal Regulations-21CFR) promulgated in accordance with the U.S. Food, Drug and Cosmetic Act as amended. Since PG functions as an excipient (a non-active ingredient in pharmaceutical formulations) Dow follows excipient cGMP guidelines issued by the International Pharmaceutical Excipients Council[14] when manufacturing its PG USP/EP grade product. PG is listed as generally recognized as safe (GRAS) in 21CFR184.1666 and meets the specifications of the Food Chemicals Codex, 3d ED. (1981), p. 255. Dow recommends that only USP/EP-grade PG be used for all direct and indirect food applications.

Direct Food Applications

PG is listed in the monographs of the Food Chemicals Codex and can, therefore, be used for direct and indirect food additive applications. Also, PG is considered to be generally recognized as safe (GRAS) as a multiple-purpose food substance under 21CFR184.6666.

PG may be used to give foods the following physical or technical attributes as defined in the following sections of 21CFR170.3(o):

- (1)anticaking agent
- (3)antioxidant
- (6)dough strengthener
- (8)emulsifier
- (12)flavor agent
- (14)formulation aid
- (16)humectant
- (24)processing aid
- (27)solvent and vehicle
- (28)stabilizer and thickener
- (29)surface active agent
- (32)texturizer

Maximum use levels for propylene glycol are defined in accordance with cGMP in accordance with 21CFR184.1(b)(1). Maximum use levels as defined in 21CFR170.3(n):

- (2) – 5 percent for alcoholic beverages
- (9) – 24 percent for confections and frostings
- (20) – 2.5 percent in frozen dairy products
- (26) – 97 percent in seasonings and flavorings
- (32) – 5 percent in nuts and nut products
- In all other foods categories the maximum level is 2 percent

[14] "The IPEC Good Manufacturing Practice Guide for Bulk Pharmaceutical Excipients" Copyright " The International Pharmaceutical Excipients Council (IPEC), 2001.

A number of standardized foods allow for the use of optional ingredients which are "safe and suitable." PG qualifies as an optional ingredient where the use is suitable. These standardized foods are described in the following 21CFR sections:

- 133.128 (cottage cheese)
- 133.131 (low fat cottage cheese)
- 135.110 (ice cream and frozen custard)
- 135.120 (ice milk)
- 135.130 (mellorine)
- 135.140 (sherbets)
- 135.160 (water ices)
- 169.175 (vanilla extract)
- 169.176 (concentrated vanilla extract)
- 169.177 (vanilla flavoring)

When employed as a direct food additive, the nutritional information of PG is of importance for end-users. The caloric value of PG is defined as 4 calories per gram, according to the general definition for a carbohydrate given in the 21CFR101.9(c)(1)(I)(B).

Dow recommends that only PG USP/EP grade product be used for direct food applications.

PG is also generally recognized as safe (GRAS) in animal feeds as a general purpose food additive (21CFR582.1666) and as an emulsifying agent (21CFR582.4666). However, PG is not generally recognized as safe (GRAS) for use in cat food (21CFR500.50, 21CFR589.1001) and should not be used in this application area.

Dow recommends that only PG USP/EP grade product be used for animal feed applications and does not support the use of PG in cat food.

Unreacted Indirect Food Applications

PG is cleared for used in the unreacted form under 21CFR sections:

- 175.105 (adhesives)
- 175.300 (resinous and polymeric coatings)
- 175.380 (xylene-formaldehyde resins condensed with 4-4'-isopropylidenediphenol-epichlorohydrin epoxy resins)
- 175.390 (zinc-silicon dioxide matrix coatings)
- 176.170 (components of paper and paperboard in contact with aqueous and fatty foods)
- 176.180 (components of paper and paperboard in contact with dry food)
- 177.1210 (closures with sealing gaskets for food containers)
- 177.2600 (rubber articles intended for repeated use)
- 178.3300 (corrosion inhibitors used for steel or tinplate)
- 182.99 (adjuvants for pesticide chemicals are exempt from tolerance requirements when used in accordance with 40CFR180.1001)

Reactive Component Indirect Food Applications

PG is cleared for use only as a reactive component under 21CFR sections:

- 175.320 (resinous and polymeric coatings for polyolefin films)
- 176.210 (defoaming agents used in the manufacture of paper and paperboard)
- 177.1680 (polyurethane resins)
- 177.2420 (polyester resins, cross-linked)

European Regulations

Direct Food Applications

Propylene glycol (PG) is classified as E1520 in an amendment to European Union Directive 95/2/EC, which regulates human food additives, other than colors and sweeteners. It allows the use of PG as a carrier or carrier solvent for colors, emulsifiers, antioxidants and enzymes, up to a maximum of 1 gram per kilogram of final foodstuff.

However, PG is not approved as a general-purpose direct-food additive in countries of the European Union.

Indirect Food Applications

PG is cleared for indirect food contact applications by EU Directive 90/128/EEC, and subsequent amendments, relating to plastic materials and articles intended to come into contact with foodstuffs. Of suitable quality, PG is authorized as a monomer and starting substance (1,2-propandiol, PM/Ref No 23740) for the manufacture of plastic materials and articles, without restriction or specific migration limits. 1,2-propandiol (PM/Ref No 81840) is also recognized as an additive for the same purpose.

Dow recommends that only Propylene Glycol USP/EP (PG USP/EP) grade product be used for direct food applications.

Dipropylene Glycol

U.S. Regulations

Dipropylene glycol (DPG) is cleared for various indirect uses under Food Additive Regulations (Title 21, Code of Federal Regulations) promulgated in accordance with the U.S. Food, Drug and Cosmetic Act as amended. Dow recommends that its DPG LO+ grade material be used in these application areas.

Unreacted Indirect Food Applications

It is cleared for use in the unreacted form under 21 CFR sections:

- 175.105 (adhesives)
- 176.170 (components of paper and paperboard in contact with aqueous and fatty foods)
- 176.180 (components of paper and paperboard in contact with dry food)
- 176.200 (defoaming agents used in coatings)
- 177.1200 (cellophane)
- 178.3910 (surface lubricants used in the manufacture of metallic articles)
- 182.99 (adjuvants for pesticide chemicals exempt from tolerance requirements when used in accordance with 40CFR180.1001)

Reactive Component Indirect Applications

DPG is cleared for use only as a reactive component under sections 175.320 (resinous and polymeric coatings for polyolefin films), and 177.2420 (polyester resins, cross-linked).

European Regulations

In countries of the European Union DPG is cleared for indirect food contact applications as a monomer and other starting substance in the manufacture of plastic materials for food contact in the EU Commission Directive 90/128 EEC (PM/REF No 16660) and subsequent amendments.

For product handling and safety information, please refer to the Material Safety Data Sheet (MSDS/SDS) for DPG LO+. These documents can be obtained at www.dowpg.com.

The applicable regulations for food contact are country-specific and must be consulted for details prior to using DPG.

Tripropylene Glycol

U.S. Regulations

Tripropylene glycol (CAS number 24800-44-0) is not specifically listed by name in 21CFR the U.S. food additive regulations. TPG, molecular weight (192.3) is part of a general class of compounds, polypropylene glycol (PPG) with CAS number of 25322-69-4 and a chemical formula of $(C_3H_6O)nH_2O$ where n equals 3. PPGs may be used in some food applications but with molecular weight or use limitations in some cases.

Unreacted PPG (TPG) may be used as a component of an adhesive for food packaging as defined in 21CFR175.105. All other allowed applications for TPG as a PPG are as a reactant. In 21CFR175.300 polypropylene glycol (TPG) is an esterification agent for certain listed drying oils. The esters, in turn, are allowed under 175.380 in xylene-formaldehyde resins condensed with 4,4’-isopropylidenediphenol-epichlorohydrin epoxy resins, 175,390 in zinc-silicon dioxide matrix coatings, and 175.1210 in closures with sealing gaskets for food containers by cross-reference to 175.300. In 21CFR177.1680 PPG (TPG) is allowed as a reactant with listed isocyanates to make polyurethane resins for use in food contact articles.

European Regulations

In countries of the European Union, TPG is cleared for indirect food contact applications as a monomer in the manufacture of plastic materials for food contact in the EU Commission Directive 90/128 EEC (PM/REF No 25910) and subsequent amendments.

Toxicological and Environmental Considerations

Note to Customers Concerning Toxicological and Environmental Considerations

The information given here is for use as a general guideline. Material Safety Datasheets (MSDS or SDS) must be referenced and depended upon for completeness and currency of information. The final responsibility for proper use of glycols in all applications is that of the user or formulator.

Toxicological Considerations

Acute Oral Toxicity

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

LD50 Values for Various Glycols

Single Doses to Rats	
Glycol	LD_{50} gm/kg bw
Propylene	33.7
Dipropylene	14.8
Tripropylene	>3.0†

† Largest dose survived by all rats tested: 10.0 gm/kg-bw resulted in the death of all the rats tested.

Chronic Oral Toxicity

Glycols vary considerably in chronic oral toxicity. Propylene glycol (PG) toxicity is especially low in this respect; studies in which rats were provided with drinking water containing as much as 10% propylene glycol over a period of 140 days showed no apparent ill effects. Other investigations have revealed that rats can tolerate up to 4.9% PG 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, PG is generally considered safe (GRAS Ref 21CFR) 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 it is listed in the United States Pharmacopoeia. It is widely used and accepted as an ingredient of dental preparations and is considered GRAS Ref 21CFR for use in foods if used in accordance with good manufacturing practices.

Rats showed no adverse effects from 5.0 % dipropylene glycol (DPG) in their drinking water for 77 days, but a dose of 10.0 % in the drinking water resulted in kidney and liver injury and some deaths. Longer-term (2 years) administration resulted in similar kidney and liver injury in rats but no such effects were noted for mice. Chronic, lifetime administration of DPG did not cause cancer in rats or mice.

There are not enough data to evaluate tripropylene glycol (TPG) to permit conclusions to be drawn regarding its suitability for uses involving ingestion, although both DPG and TPG are permitted in various indirect food additive uses under the Food Additive Regulations under the Federal Food, Drug and Cosmetic Act. As this permission may vary by region, all applicable national and local regulations must be consulted for complete details. The final responsibility for proper use of glycols in direct or indirect food applications is that of the user or formulator.

Eye And Skin Contact

Data from animals has shown that glycols produce a negligible degree of irritation upon eye or skin contact. Some studies conducted with dermatology patients indicate at most a minimal response to PG in a small fraction of the population.

Vapor Inhalation and Eye Exposure[15]

Inhalation of the vapors of propylene glycol (PG) appears to present no significant hazard in ordinary applications. However, limited human experience indicates that breathing of mists of propylene glycols may be irritating to some individuals. Prolonged inhalation of saturated vapors of PG have produced only minor effects in animals (irritation). However, such concentrations may be irritating[17] to the upper respiratory tract and eyes of humans.

Therefore breathing spray mists of these materials should be avoided. In general, Dow does not support or recommend the use of Dow's glycols in applications where breathing or human eye contact with the spray mists of these materials is likely, such as fogs for theatrical productions or antifreeze solutions for emergency eye wash stations.

Environmental Considerations

Biodegradation

PGs are believed to be "readily biodegradable" and thus will not remain in the environment. The data in the chart below and numerous scientific studies indicate that biodegradation is expected to be moderate to high under both aerobic and anaerobic conditions for all glycols. If additional information is needed, contact your local Dow sales representative or call the Dow Customer Information Center (1-800-258-2436).

Biodegradation			
Glycol	ThOD[a]	BOD[b] - 20 Day	% Biodegradation in 10-day window
Propylene Glycol	1.68P/p[c]	1.45	91.1
Dipropylene Glycol	1.91	0.71	58.7
Tripropylene Glycol	1.38	—	55.3

[a] ThOD: Theoretical oxygen demand.
[b] BOD: Biological oxygen demand.
[c] p/p: Part per part – units of oxygen needed per unit of material for biodegradation.

Aquatic Toxicity

PG is considered to be practically non-toxic to fish on an acute basis (LC50>100mg/L) and practically non-toxic to aquatic invertebrates on an acute basis (LC50>100mg/L). Dipropylene and tripropylene glycol, are also considered to be practically non-toxic to fish on an acute basis (LC50>100mg/L). If additional information is needed, contact your local Dow sales representative or call the Dow Customer Information Center (1-800-258-2436).

General Conclusion

The glycols discussed in this pamphlet have a relatively low degree of toxicity and present no serious hazard for normal industrial handling and use.

Most of the toxicological information on these glycols has been reviewed and summarized in Patty's Industrial Hygiene, fifth edition, edited by Robert Harris published March 31, 2000, by John Wiley and Sons, New York.

[15] Threshold Limit Values for Chemical Substances and Physical Agents in the Workroom Environment with intended changes for 1981. American Conference of Governmental Industrial Hygienists. 6500 Glenway Ave., Building D-5, Cincinnati, Ohio 45211.

[16] **Experimental exposure to propylene glycol mist in aviation emergency training: acute ocular and respiratory effects.** Wieslander G; Norback D; Lindgren T Department of Medical Sciences/Occupational and Environmental Medicine, Uppsala University, University Hospital, S-751 85, Uppsala, Sweden. gunilla.wieslander@medsci.uu.se OCCUPATIONAL AND ENVIRONMENTAL MEDICINE (2001 Oct), 58(10), 649-55. Wieslander et al (2001)

Quality And Product Specifications

Glycol Quality

Dow's glycols are made to exacting specifications in modern production facilities with advanced process and analytical instrumentation. Dow's propylene glycol (PG) production plants routinely use quality techniques such as statistical quality control and statistical process control to produce glycol products which meet or exceed our customers' requirements.

Dow's Propylene Glycol USP/EP (PG USP/EP) is manufactured in compliance with current Good Manufacturing Practices (cGMP) requirements for an excipient utilizing the GMP guidelines set up by International Pharmaceutical Excipients Council (IPEC).,[17]

Dow's Dipropylene Glycol LO+ (DPG LO+) is manufactured following Cosmetics Good Manufacturing Practices (Cosmetics GMP).[18, 19]

More information regarding Dow's commitment to cGMP and cosmetics GMP are available at www.dowpg.com.[20]

Specifications

PGs are commonly available in bulk quantities directly from Dow, sourced from one of our strategically located distribution terminals or from one of our national or regional distributors. For copies of specifications, contact your Dow representative or visit the Dow Internet site at www.dowpg.com.

Analytical Methods

Each product has analytical methods associated with each of the specifications which have been developed and validated by Dow or by recognized standards organizations such as the American National Standards Testing Institute which publishes the well known ASTM Standards. Information on these is available to our customers either from Dow or from the ASTM, or compendial organizations. If additional information is needed, contact your local Dow sales representative or call the Dow Customer Information Center (1-800-258-2436).

[17] "The IPEC Good Manufacturing Practice Guide for Bulk Pharmaceutical Excipients" Copyright " The International Pharmaceutical Excipients Council.

[18] Cosmetic Handbook , U. S. Food and Drug Administration; Center for Food Safety and Applied Nutrition; FDA/IAS* Booklet: 1992[, available at www.cfsan.fda.gov/~dms/cos-hdb1.html.

[19] The European Cosmetic Toiletry and Perfumery association (COLIPA): Cosmetics GMP - Guidelines for the Manufacturer of Cosmetic Products, July 1994.

[20] www.dow.com

Storage of Glycols

The storage of glycols presents no unusual problems. A tank truck or tank car can be off-loaded into a storage tank and kept with little difficulty since glycols do not freeze nor degrade readily. They are easy to handle since they have low vapor pressures and relatively low degrees of toxicity.

Refer to American Petroleum Institute (API) Standards 620 – Design and Construction of Large Welded low-pressure Tanks, and 650 – Welded Steel Tanks for Oil Storage, and ASME Code Section VIII Div 1 for the design and construction of storage tanks.

There are several acceptable types of bases for storage tanks, depending on local soil conditions.

Base construction is perhaps the most important facet of tank installation and should be based on good civil engineering practice and soil conditions.

An all stainless steel system is recommended for USP/EP grade of propylene glycol (PG). Carbon steel systems may be utilized for other grades of glycols if slight coloration of the glycol can be tolerated.

Epoxy and phenolic resins provide an excellent liner for carbon steel storage tanks. A number of the liner systems have been approved by the FDA for food contact and are suitable for PG USP/EP. The following table provides a list of some of the coating systems, which are approved under cGMP.

Manufacturer	Product Name or Number	Generic Type Material	FDA Approved
Bisonite	Phenaflex 957	High Baked Epoxy Phenolic	Yes
Heresite-Sakaphen	EB 6917	Low Baked Epoxy Phenolic	Yes
	P-403	High Baked Phenolic	Yes
Lithcote	LC-19	High Baked Phenolic	Yes
	LC-24	High Baked Phenolic	Yes
Wisconsin Protective Coatings	Plasite 3066	High Baked Phenolic	Yes
	Plasite 9570	Low Baked Epoxy Phenolic	Yes

Coatings require special tank preparations and application procedures. Consult with the coating suppliers for guidelines and recommendations.

Above-ground installations are preferred over underground tanks. Installation is cheaper and above-ground tanks have a lower long-term cost of ownership. The gauging of and pumping from underground vessels is more difficult. In addition, leakage from an underground vessel is more difficult to detect and more expensive to correct.

Glycols become viscous at low temperatures (See Figure 19). Propylene, dipropylene and tripropylene glycols at temperatures below 35°F (2°C) become quite viscous and difficult to transfer due to an increase in viscosity. Insulation and heating may be required in cold climates to prevent pumping problems. If storage temperatures only occasionally drop slightly below these prescribed limits, low-pressure steam heating coils or external electric heating pads will prevent freezing or excessive viscosity of glycols. However, if the low temperatures are sustained, the tank needs to be insulated and heated for satisfactory usage of the facility. A 1-1/2 inch thick layer of polyisocyanurate type insulation will provide adequate insulation, in most situations. Heating coils should be constructed from stainless steel. Consideration should be given to the design of the heating system to avoid high surface temperatures or prolonged exposure to high temperatures, which can lead to accelerated product degradation.

To prevent external corrosion under insulation, attention must be paid to detailed design of weather shield rings at the top of vertical tanks, insulation support rings, paint system under the insulation and sealing of joints in the insulation covering.

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

Pressure and vacuum relief devices, such as Protectoseal Series 8540D, are required to protect the vessel. See API Standard 2000 for design details.

Since glycols are hygroscopic, open atmospheric vents are not recommended unless increased water concentration in the glycol can be tolerated.

Nitrogen blanketing is the preferred means of keeping glycols dry. A padded control system is typically utilized to control the pressure in the tank. To facilitate the operation of this type of system, it is recommended that the tank be designed for at least one pound of pressure (gage) in the vapor space.

If a nitrogen pad is not feasible, dried air can be utilized. A calcium chloride desiccator is an efficient and inexpensive means for drying the air used for padding. The desiccator dryer is a high maintenance item. The calcium chloride will become saturated, necessitating periodic cleaning and recharging. If not maintained, the dryer system will become inoperative and the tank will breathe through the vacuum relief device.

Pumps And Piping

Centrifugal pumps are commonly used in glycol service. If extremely high heads are required, reciprocating pumps may be necessary.

Fabrication, assembly, and erection of the piping system should comply with the minimum requirements of American National Standards Institute (ANSI) Piping Code. ANSI Schedule 40 piping is normally utilized in low-pressure services.

Glycols are likely to leak past defective fittings or packing. Consequently, the installation of all fittings, packing and gaskets should be done with the utmost care.

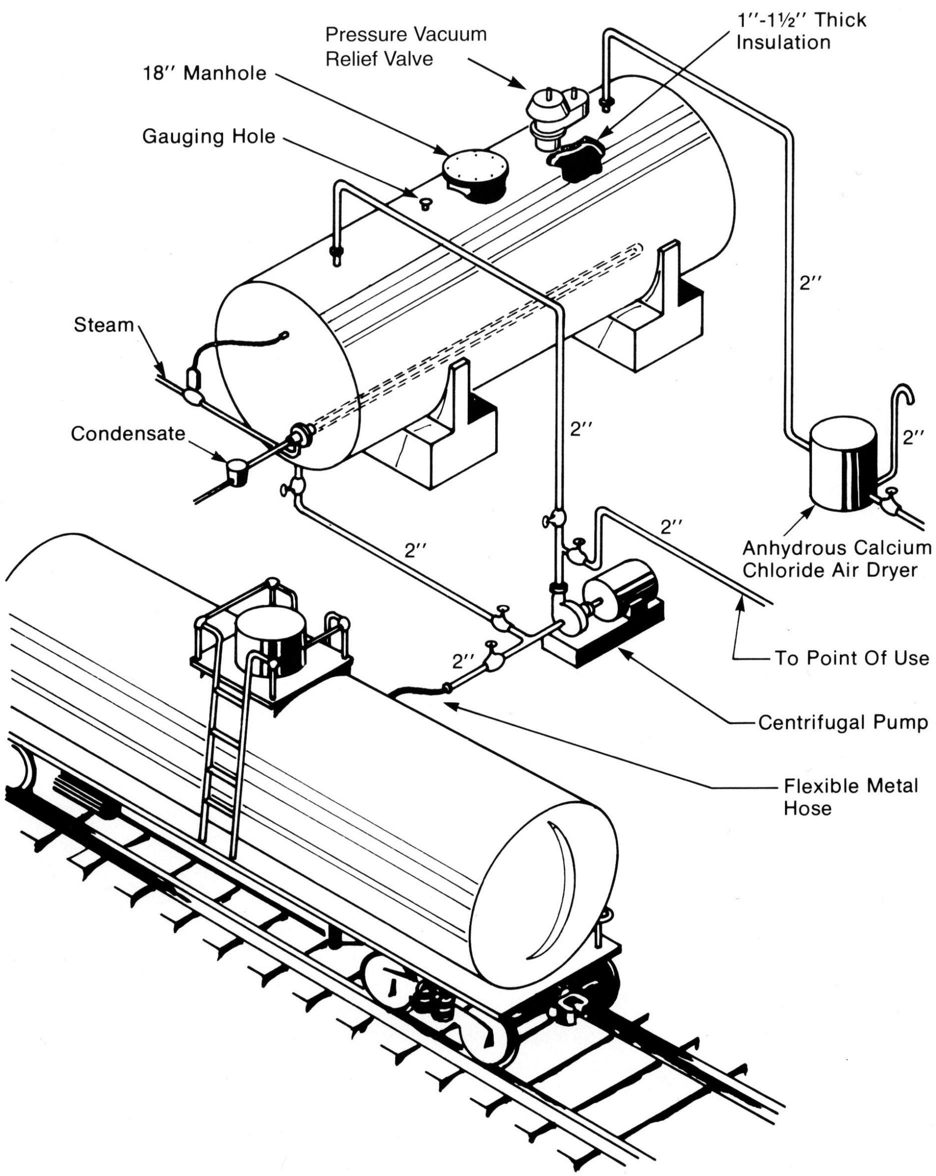
PTFE (polytetrafluoroethylene) tape or joint compounds, such as John Crane Thread-Gard or Felpro C-102, are recommended to seal threaded connections.

Gaskets and packing made from PTFE or graphite are recommended. PTFE or graphite filled spiral wound gaskets, such as Flexitallic CG with a centeringring, are typically utilized in piping systems.

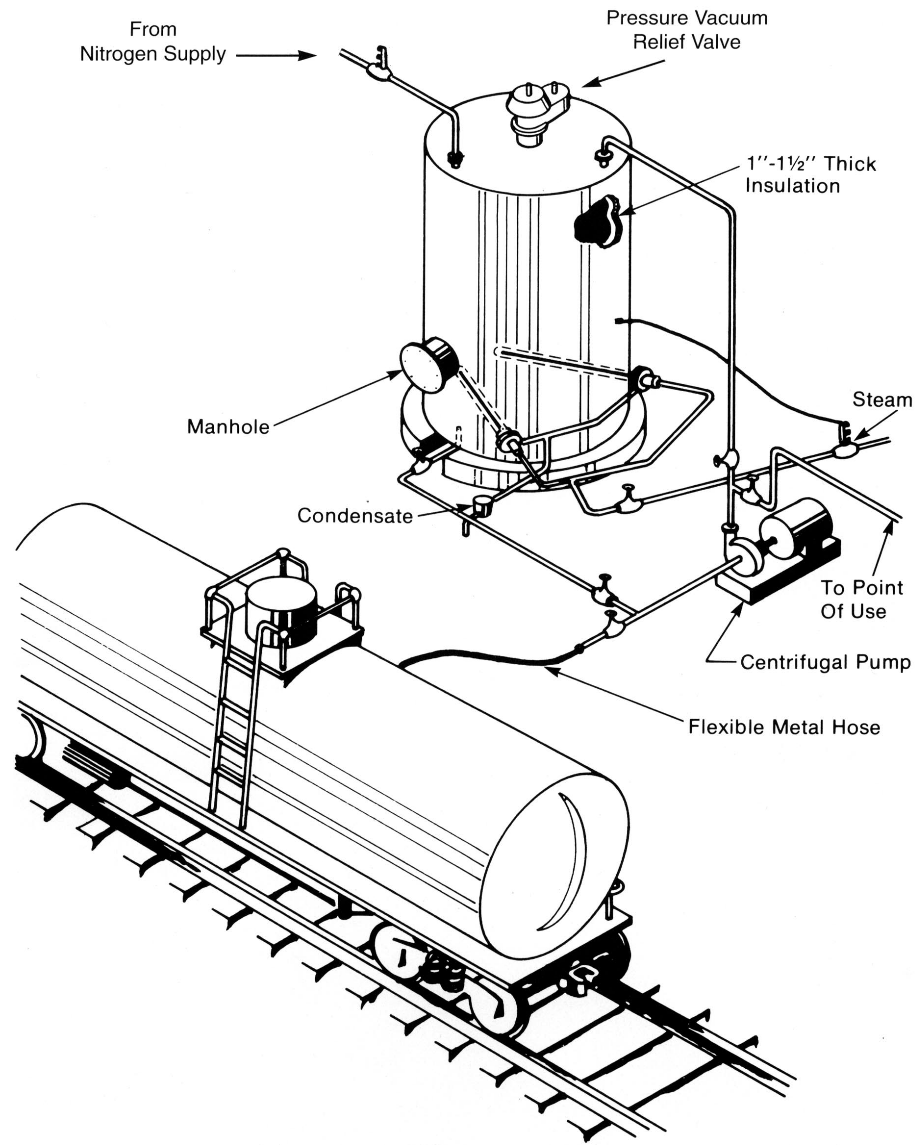
Mechanical seals with a satellite seal ring and #5 carbon insert, such as DuraSeal ROTT ES5NFO, are recommended for centrifugal pumps.

Buna N, EPDM, Viton and PTFE elastomers are all compatible with glycols.

Horizonal Storage Tank for Glycols



Vertical Storage Tank for Glycols



Material Compatibility

Selection of the proper materials of construction including gaskets and elastomers is important to maintaining product quality and preventing spills to the environment. The best source of material compatibility information is often the supplier of the material in question. Material compatibility information, appearing in the following table, was obtained from the published literature and equipment suppliers. Conditions of exposure and the presence of other chemicals and trace impurities should always be considered when choosing a construction material. Glycols are likely to leak past improperly assembled or defective fittings, seals and block valves.

Specific recommendations for storage and handling of Dow's glycols can be found in this brochure in the "Storage of Glycols" section. The information in Figure 21 provides additional general guidance for corrosion resistance of various metals and plastics in glycol service.

Figure 21- Glycol Material Compatibility

	Propylene Glycol	
Material	Temp°F	Rating
Aluminum	60-170	2
Brass	60-90	3
Bronze	60-210	3
Carbon Steel	60-210	2
Copper	60-90	3
Hastelloy B	60-90	2
Inconel	60-90	3
Monel	60-90	3
Nickel	60-90	3
304 SS	60-90	2
316 SS	60-210	2
Titanium	60-90	1
ABS	80	
CPVC	50	
Epoxy	200	
Fluorocarbons FEP	400	
Fluorocarbons TFE	470	
Furfuryl Alcohol	250	
Chlorinated Polyesters	100	
Polyethylene	140	
Polypropylene	140	
PVC	50	
Vinyl Ester	210	
Viton A	90	
Neoprene GR-M (CR)	80	
Nitrile Buna N (NBR)	80	

Rating Code
Metals: 1 = <2 mils/year 2 = <20 mils/year 3 = <20 mils/year not recommended for glycol service
Plastics & Elastomers: Temperature indicates upper limit

Appendix

Conversion Charts for Weight to Volume

Figure A1- Conversion Chart for Aqueous Propylene Glycol Solutions

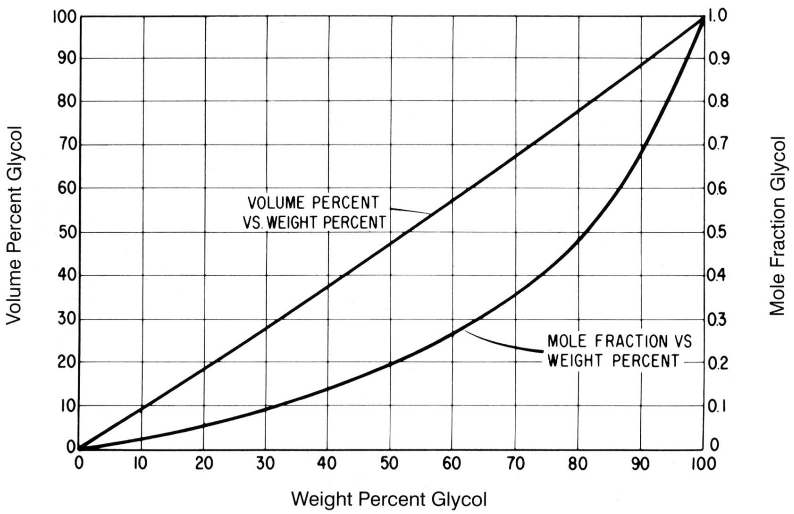
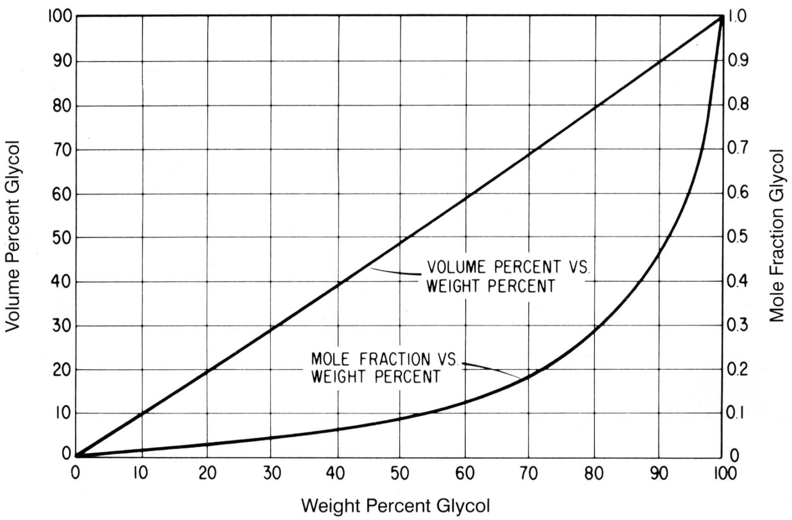
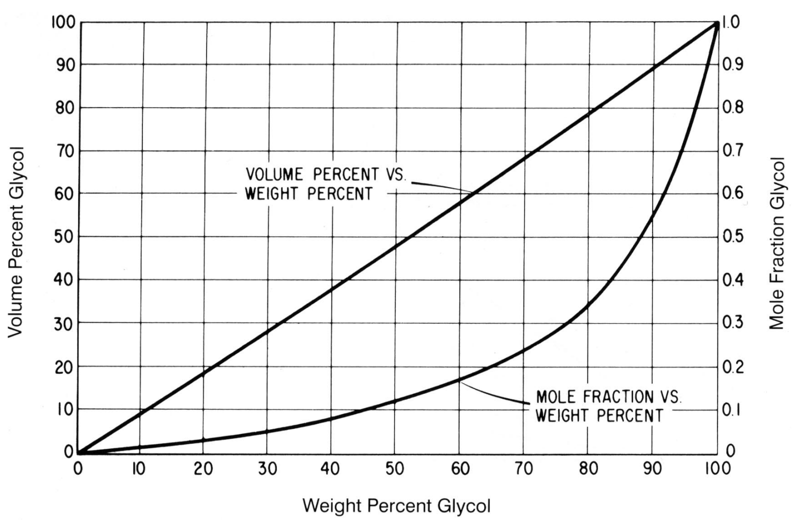


Figure A3- Conversion Chart for Aqueous Tripropylene Glycol Solutions



(Figure A2- Conversion Chart for Aqueous Dipropylene Glycol Solutions)



Temperature Conversion Charts

NOTE: If the reading to be converted is in centigrade, locate that reading in the middle column and read the corresponding Fahrenheit temperature in the left column. If the reading is in Fahrenheit, locate the reading in the center column and read the corresponding centigrade temperature in the right column.

°F	°F or °C to be converted	°C
–94.0	–70	–56.67
–76.0	–60	–51.11
–58.0	–50	–45.56
–40.0	–40	–40.00
-22.0	-30	-34.44
– 4.0	–20	–28.89
– 2.2	–19	–28.34
– 0.4	–18	–27.78
+ 1.4	–17	–27.23
+ 3.2	-16	-26.67
+ 5.0	–15	–26.12
+ 6.8	–14	–25.56
+ 8.6	–13	–25.00
+10.4	–12	–24.44
+12.2	–11	–23.89
+14.0	–10	–23.33
+15.8	– 9	–22.78
+17.6	– 8	–22.22
+19.4	– 7	–21.67
+21.2	– 6	–21.11
+23.0	– 5	–20.56
+24.8	– 4	–20.00
+26.6	– 3	–19.44
+28.4	– 2	–18.89
+30.2	– 1	–18.33
+32.0	0	–17.78
+33.8	+ 1	–17.22
+35.6	+ 2	–16.67
+37.4	+ 3	–16.11
+39.2	+ 4	–15.56
+41.0	+ 5	–15.00
+42.8	+ 6	–14.44
+44.6	+ 7	–13.89
+46.4	+ 8	–13.33
+48.2	+ 9	–12.78
+50.0	+10	–12.22
+51.8	+11	–11.67
+53.6	+12	–11.11
+55.4	+13	–10.56
+57.2	+14	–10.00
+59.0	+15	– 9.44
+60.8	+16	– 8.89
+62.6	+17	– 8.33
+64.4	+18	– 7.78
+66.2	+19	– 7.22
+68.0	+20	– 6.67
+69.8	+21	– 6.11
+71.6	+22	– 5.56
+73.4	+23	– 5.00
+75.2	+24	– 4.44
+77.0	+25	– 3.89
+78.8	+26	– 3.33
+80.6	+27	– 2.78
+82.4	+28	– 2.22
+84.2	+29	– 1.67
+86.0	+30	– 1.11
+87.8	+31	– 0.56
+89.6	+32	+ 0.00
+91.4	+33	+ 0.56
+93.2	+34	+ 1.11
+95.0	+35	+ 1.67
+96.8	+36	+ 2.22
+98.6	+37	+ 2.78
+100.4	+38	+ 3.33
+102.2	+39	+ 3.89
+104.0	+40	+ 4.44

°F	Temp.	°C
+105.8	+41	+ 5.00
+107.6	+42	+ 5.56
+109.4	+43	+ 6.11
+111.2	+44	+ 6.67
+113.0	+45	+ 7.22
+114.8	+46	+ 7.78
+116.6	+47	+ 8.33
+118.4	+48	+ 8.89
+120.2	+49	+ 9.44
+122.0	+50	+10.00
+123.8	+51	+10.56
+125.6	+52	+11.11
+127.4	+53	+11.67
+129.2	+54	+12.22
+131.0	+55	+12.78
+132.8	+56	+13.33
+134.6	+57	+13.89
+136.4	+58	+14.44
+138.2	+59	+15.00
+140.0	+60	+15.56
+141.8	+61	+16.11
+143.6	+62	+16.67
+145.4	+63	+17.22
+147.2	+64	+17.78
+149.0	+65	+18.33
+150.8	+66	+18.89
+152.6	+67	+19.44
+154.4	+68	+20.00
+156.2	+69	+20.56
+158.0	+70	+21.11
+159.8	+71	+21.67
+161.6	+72	+22.22
+163.4	+73	+22.78
+165.2	+74	+23.33
+167.0	+75	+23.89
+168.8	+76	+24.44
+170.6	+77	+25.00
+172.4	+78	+25.56
+174.2	+79	+26.11
+176.0	+80	+26.67
+177.8	+81	+27.22
+179.6	+82	+27.78
+181.4	+83	+28.33
+183.2	+84	+28.89
+185.0	+85	+29.44
+186.8	+86	+30.00
+188.6	+87	+30.56
+190.4	+88	+31.11
+192.2	+89	+31.67
+194.0	+90	+32.22
+195.8	+91	+32.78
+197.6	+92	+33.33
+199.4	+93	+33.89
+201.2	+94	+34.44
+203.0	+95	+35.00
+204.8	+96	+35.56
+206.6	+97	+36.11
+208.4	+98	+36.67
+210.2	+99	+37.22
+212.0	+100	+37.78
+230.0	+110	+43.33
+248.0	+120	+48.89
+266.0	+130	+54.44
+284.0	+140	+60.00
+302.0	+150	+65.56
+320.0	+160	+71.11

°F	Temp.	°C
+338.0	+170	+76.67
+356.0	+180	+82.22
+374.0	+190	+87.78
+392.0	+200	+93.33
+410.0	+210	+98.89
+428.0	+220	+104.44
+446.0	+230	+110.00
+464.0	+240	+115.56
+482.0	+250	+121.11
+500.0	+260	+126.67
+518.0	+270	+132.22
+536.0	+280	+137.78
+554.0	+290	+143.33
+572.0	+300	+148.89
+590.0	+310	+154.44
+608.0	+320	+160.00
+626.0	+330	+165.56
+644.0	+340	+171.11
+662.0	+350	+176.67
+680.0	+360	+182.22
+698.0	+370	+187.78
+716.0	+380	+193.33
+734.0	+390	+198.89
+752.0	+400	+204.44
+770.0	+410	+210.00
+788.0	+420	+215.56
+806.0	+430	+221.11
+824.0	+440	+226.67
+842.0	+450	+232.22
+860.0	+460	+237.78
+878.0	+470	+243.33
+896.0	+480	+248.89
+914.0	+490	+254.44
+932.0	+500	+260.00
+950.0	+510	+265.56
+968.0	+520	+271.11
+986.0	+530	+276.67
+1040.0	+540	+282.22
+1022.0	+550	+287.78
+1040.0	+560	+293.33
+1058.0	+570	+298.89
+1076.0	+580	+304.44
+1094.0	+590	+310.00
+1112.0	+600	+315.56

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

$$°F = (1.8 \times °C) + 32$$

$$°C = \frac{(°F - 32)}{1.8}$$

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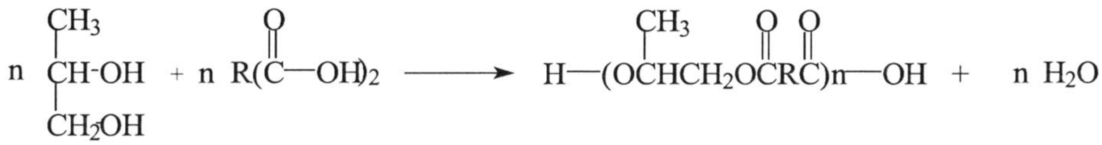
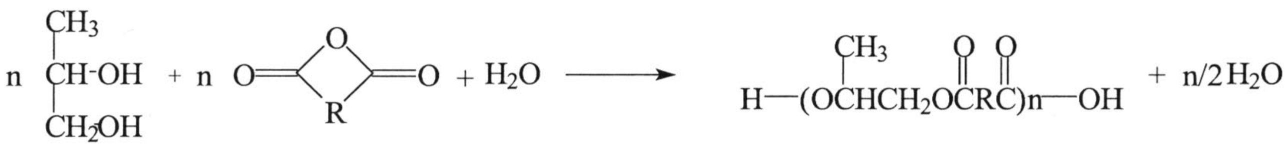


Propylene Glycol + Dicarboxylic Acid → Polyester + Water



Propylene Glycol + Dicarboxylic Acid Anhydride → Polyester + Water

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Figure 1- Freeze Points and Burst Points of Aqueous Glycol Solutions

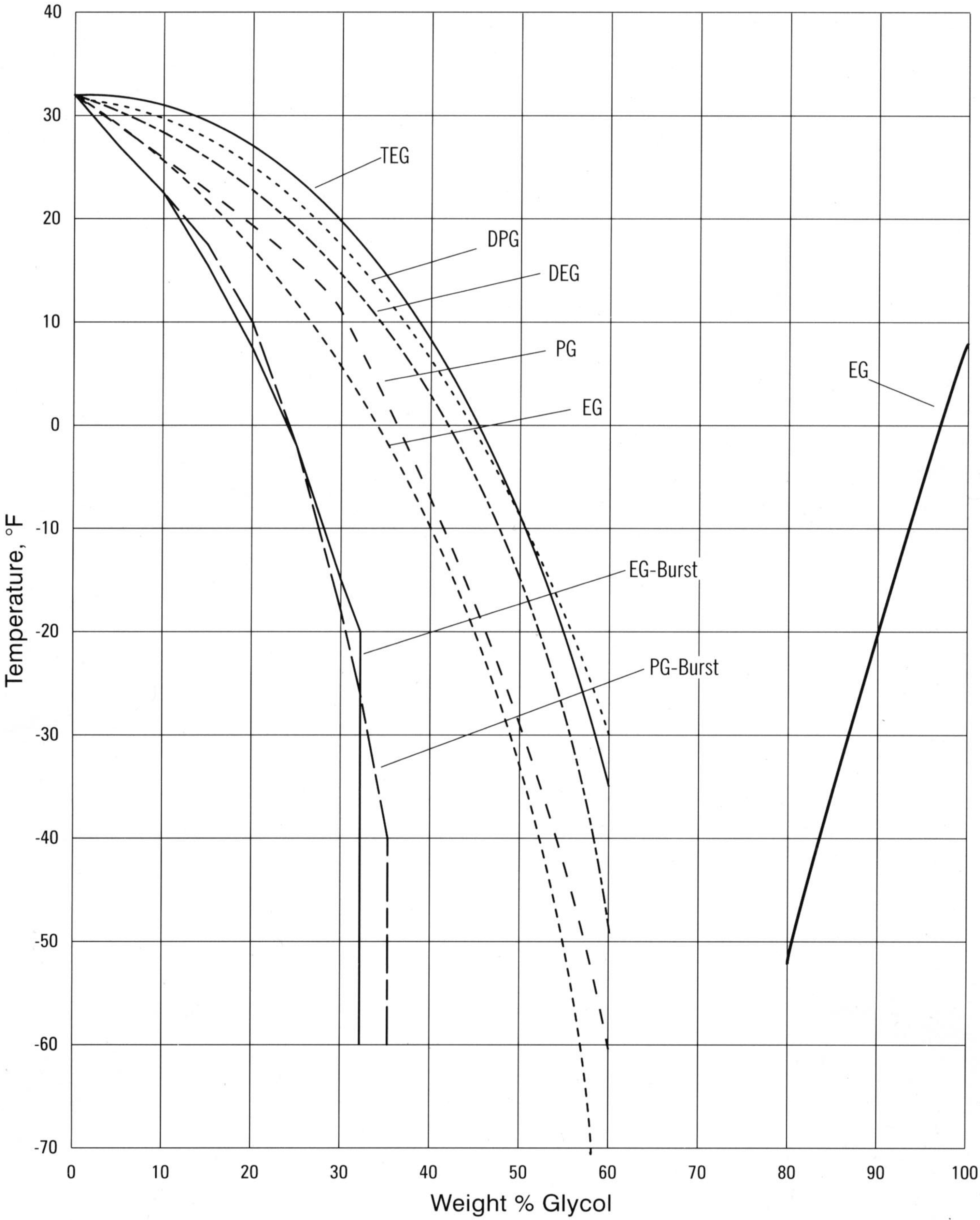

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Figure 4- Water Vapor Dew Points Over Aqueous Propylene Glycol Solutions

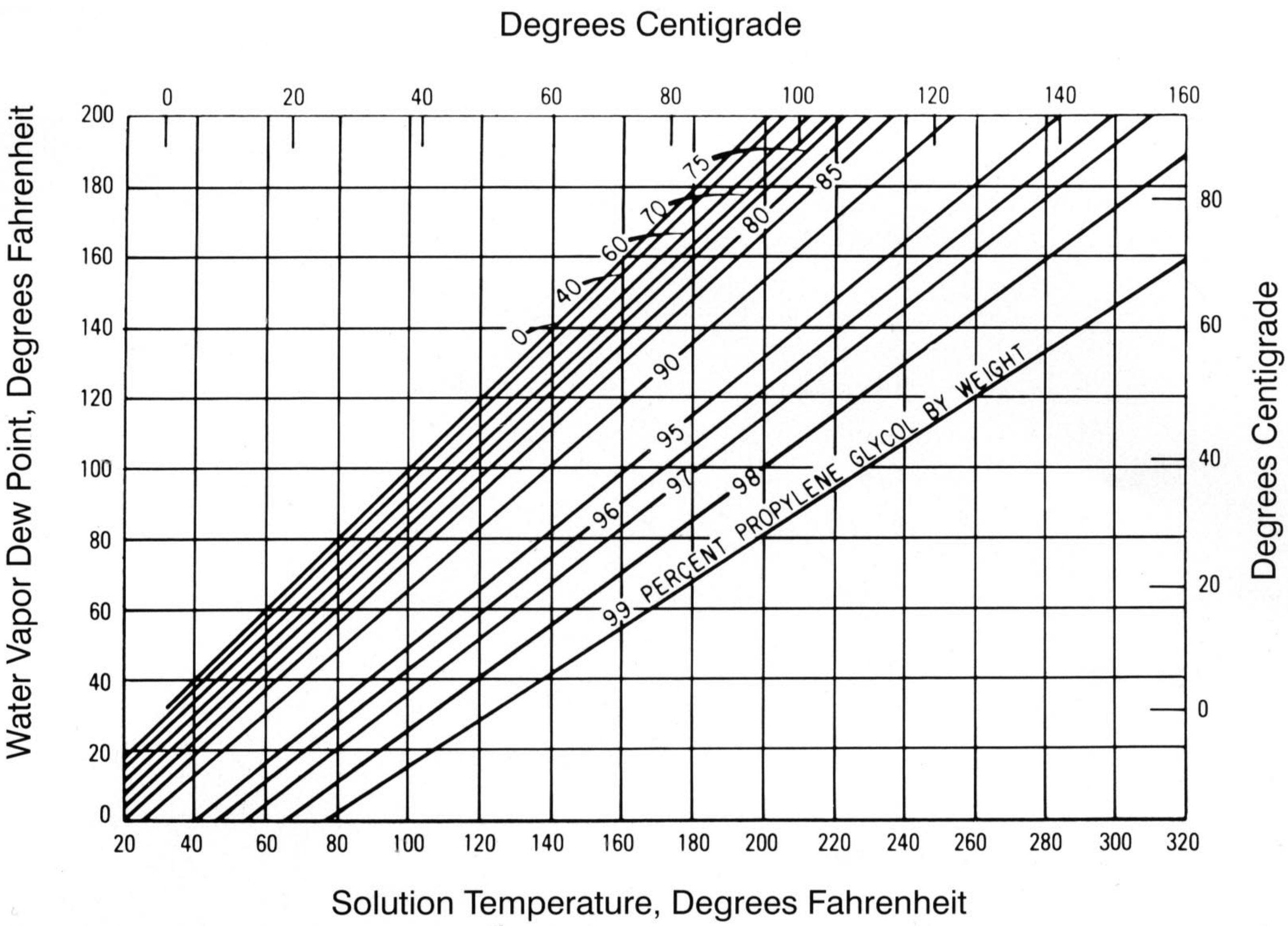

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Figure 5- Water Vapor Dew Points Over Aqueous Dipropylene Glycol Solutions

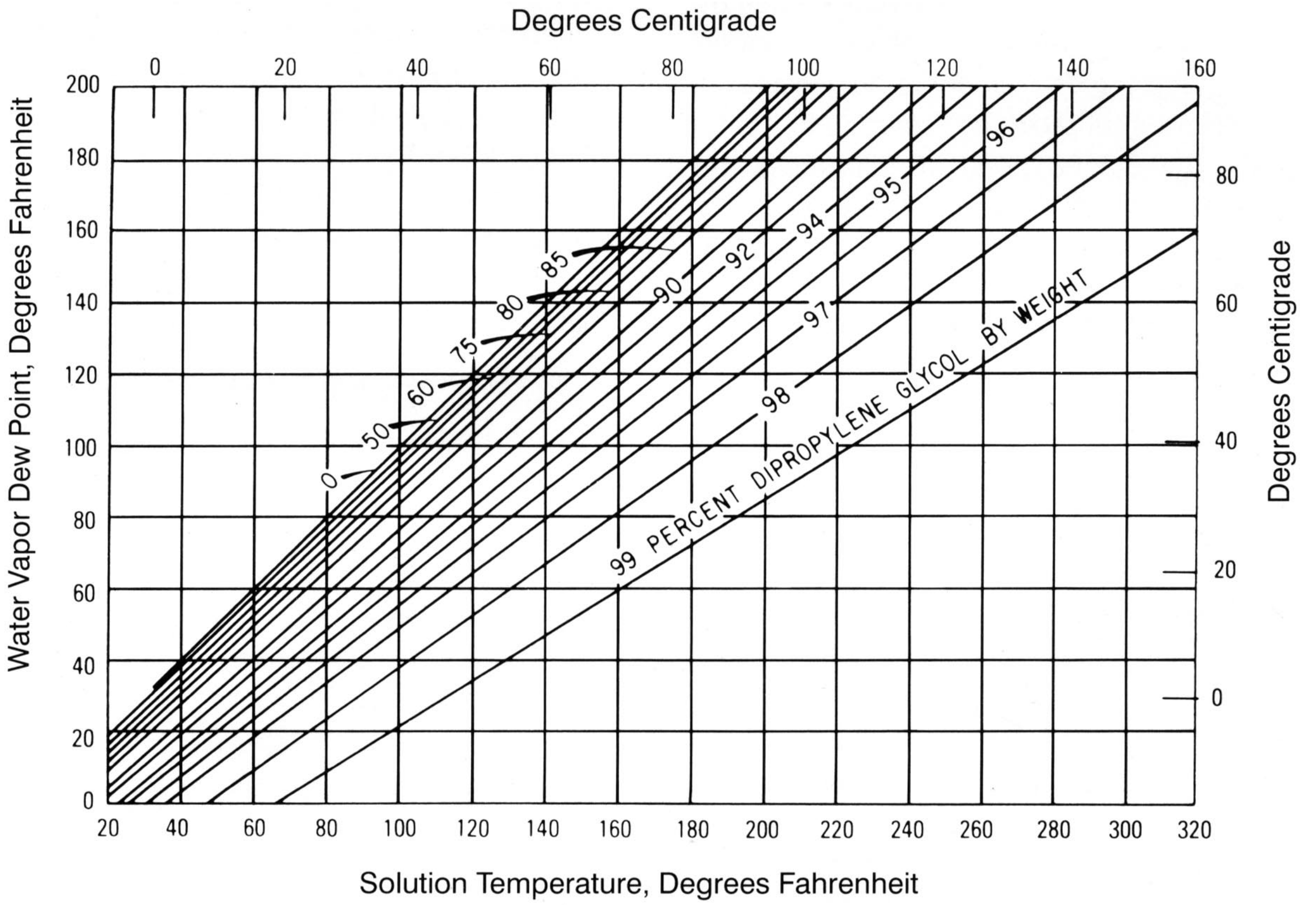

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Figure 6- Total Pressure Over Aqueous Propylene Glycol Solutions Versus Temperature

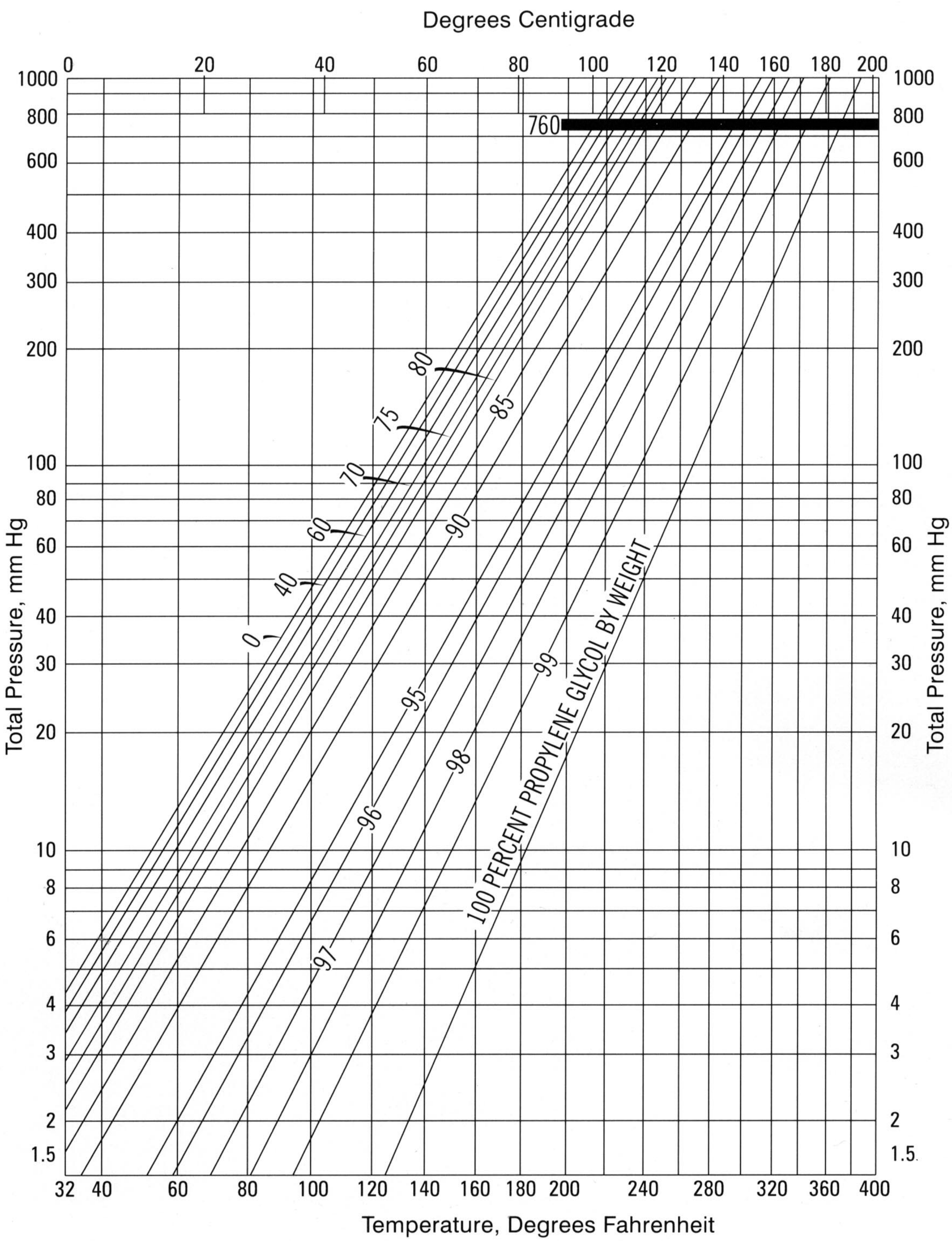

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Figure 7- Total Pressure Over Aqueous Dipropylene Glycol Solutions Versus Temperature

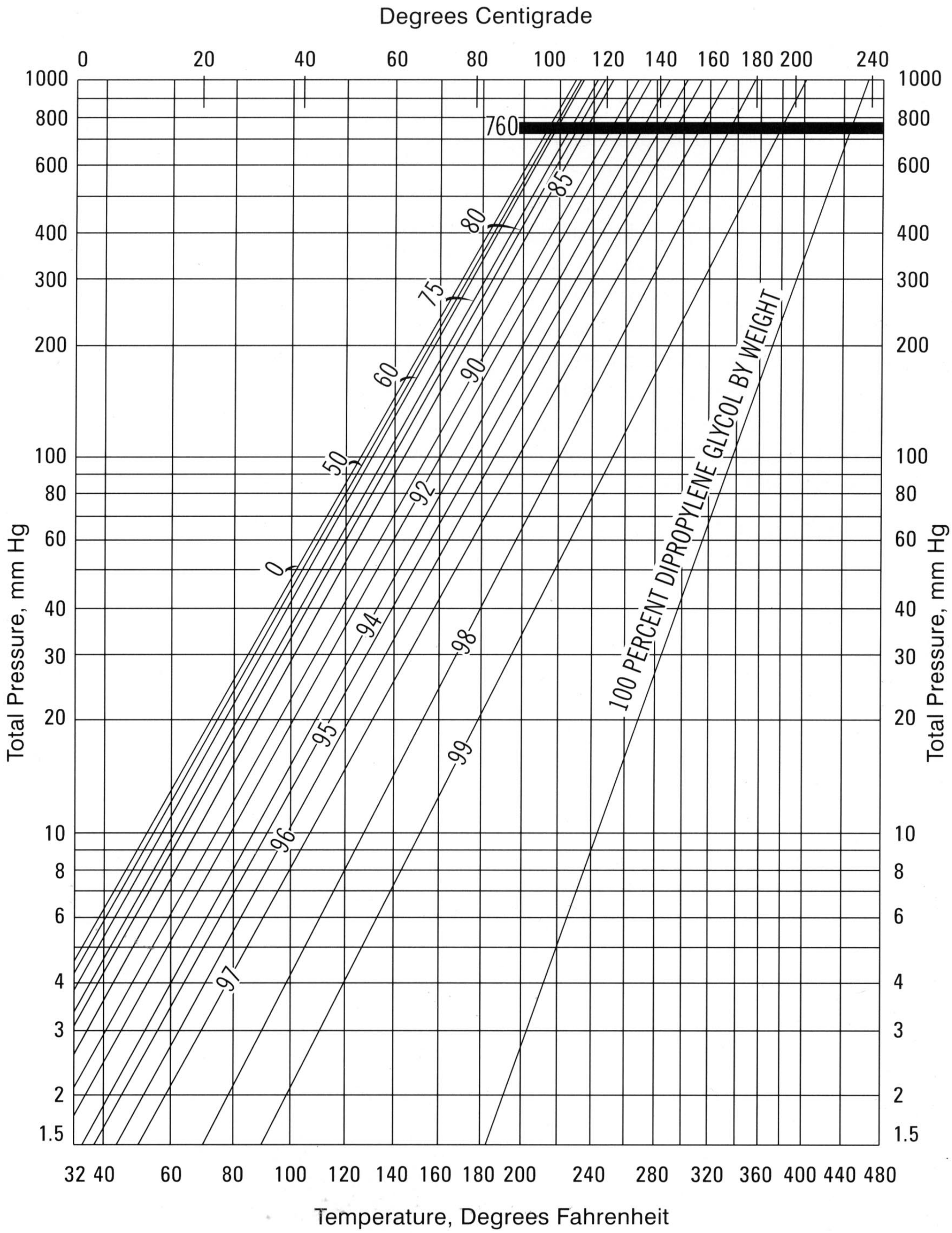

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Figure 10- Viscosities of Anhydrous Glycols

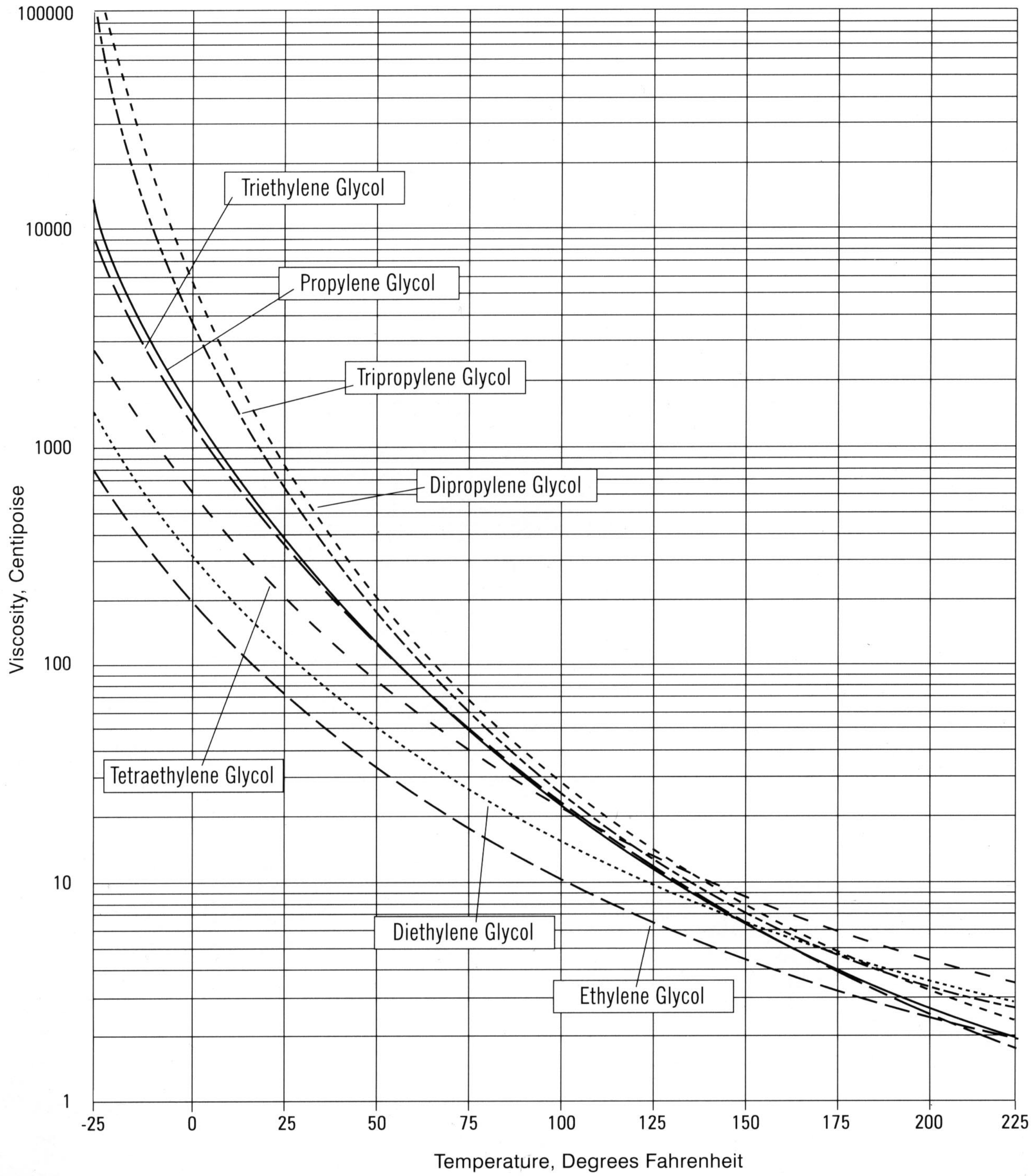

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Figure 11- Viscosities of Aqueous Propylene Glycol Solutions

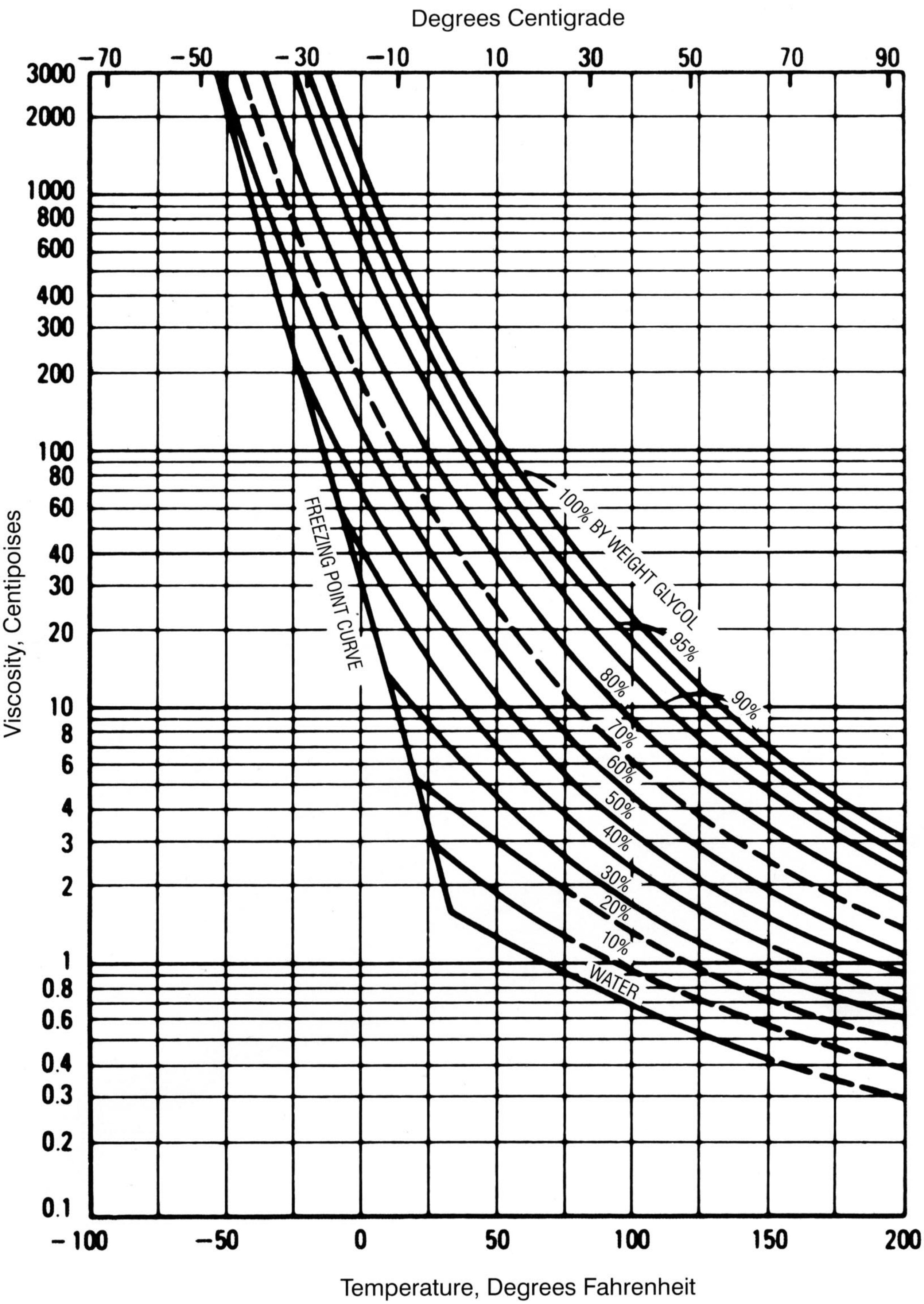

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Figure 12- Viscosities of Aqueous Dipropylene Glycol Solutions

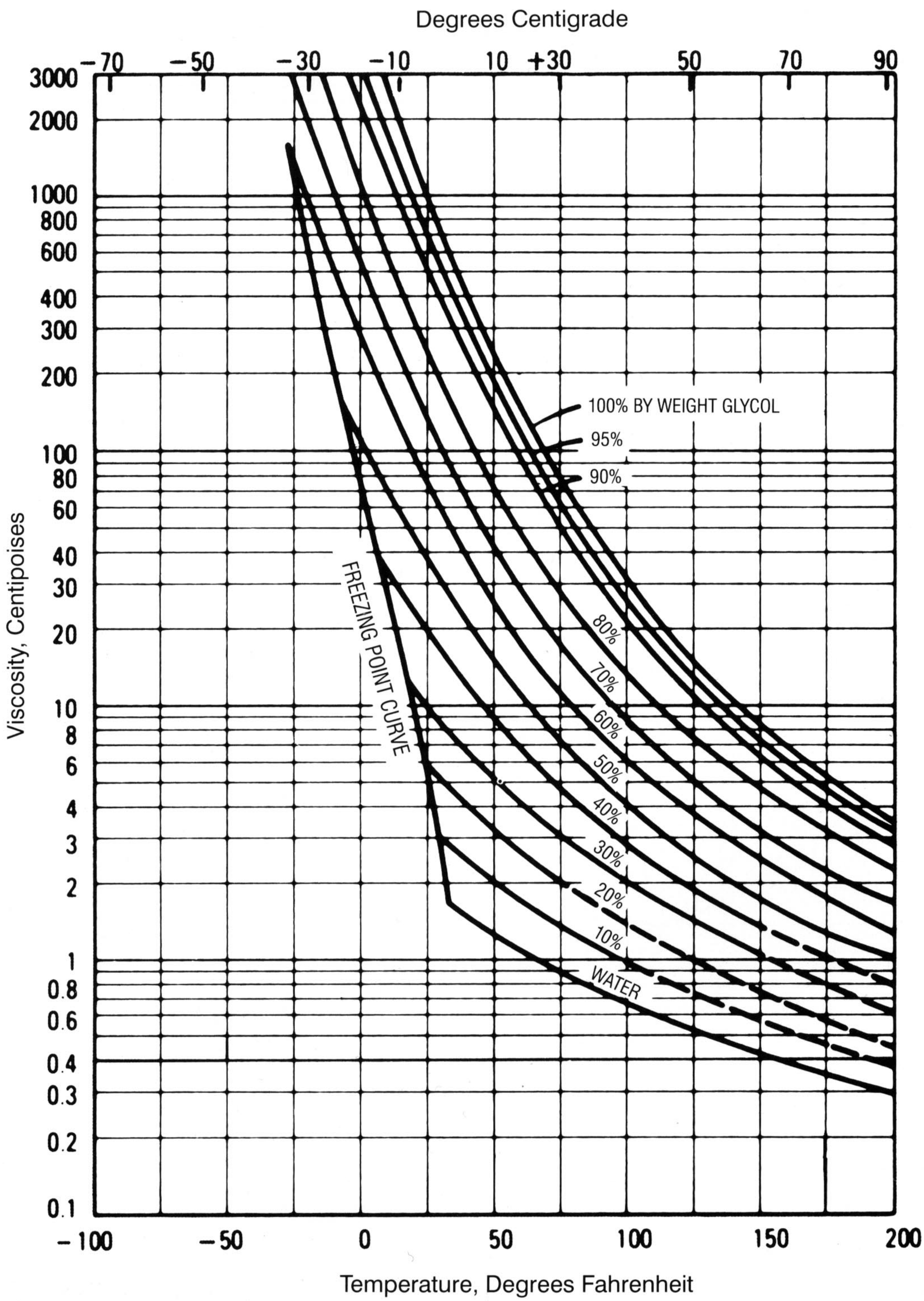

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Figure 13- Viscosities of Aqueous Tripropylene Glycol Solutions

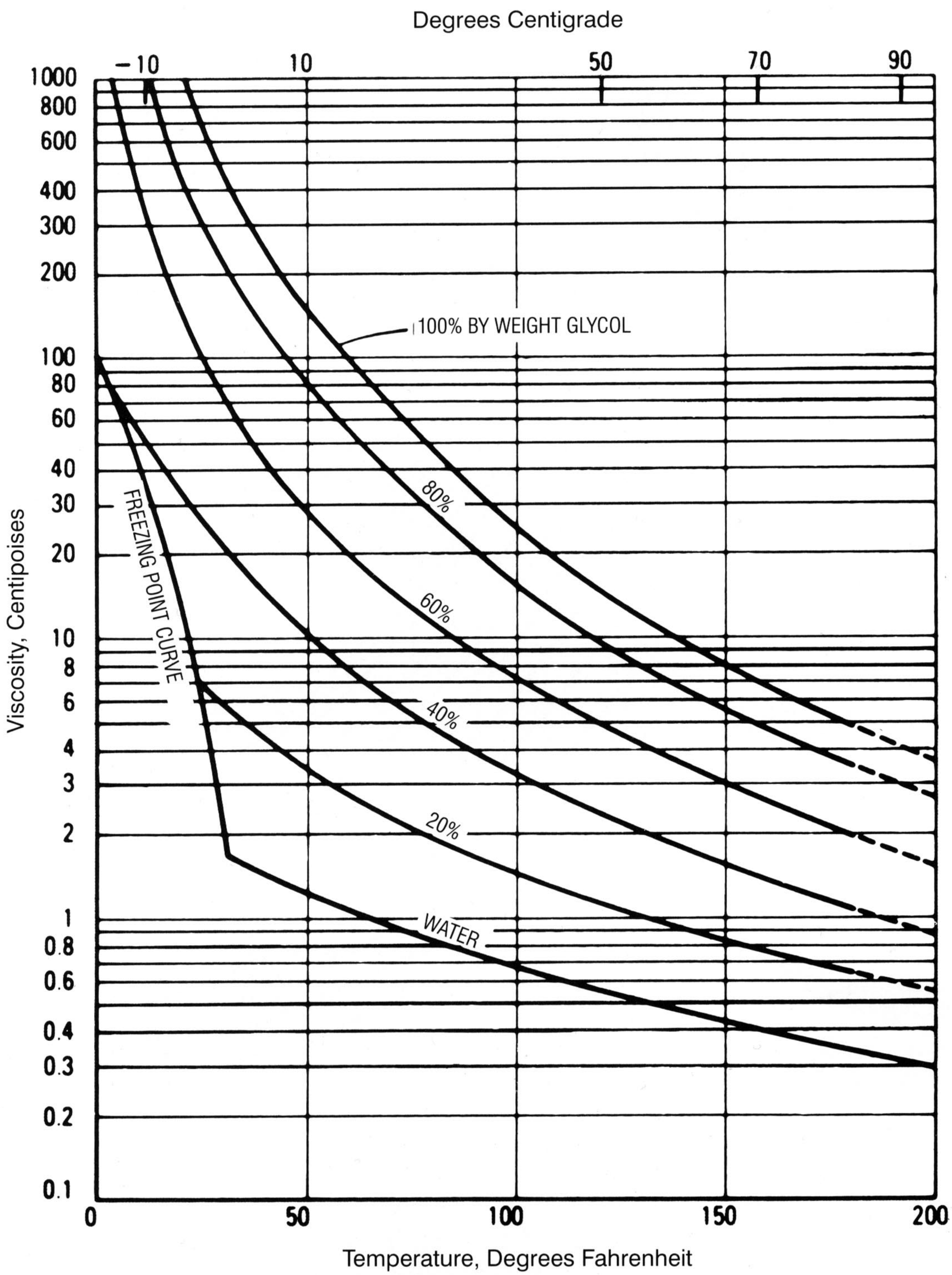

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Figure 17- Densities of Aqueous Dipropylene Glycol Solutions

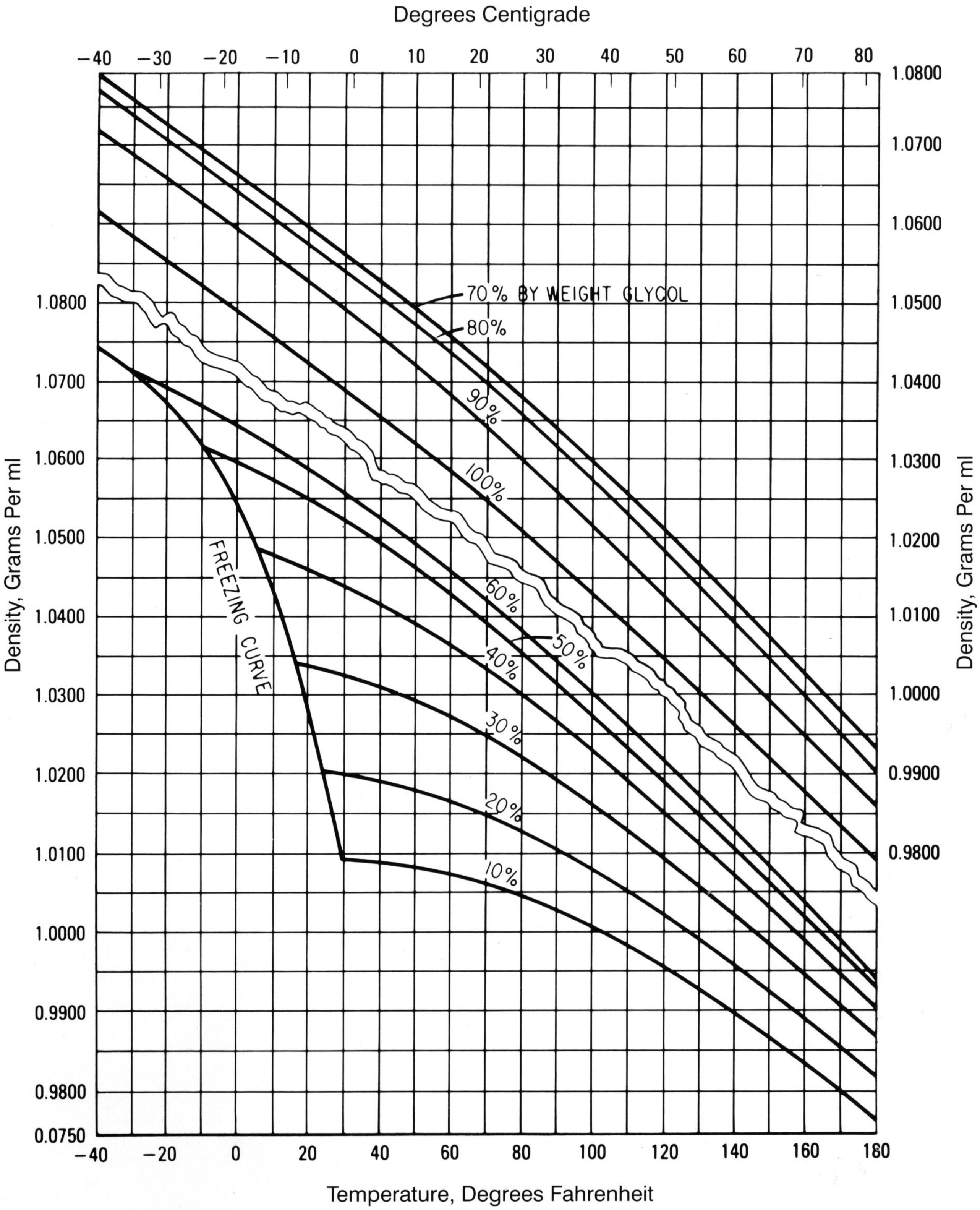

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Figure 18- Densities of Aqueous Tripropylene Glycol Solutions

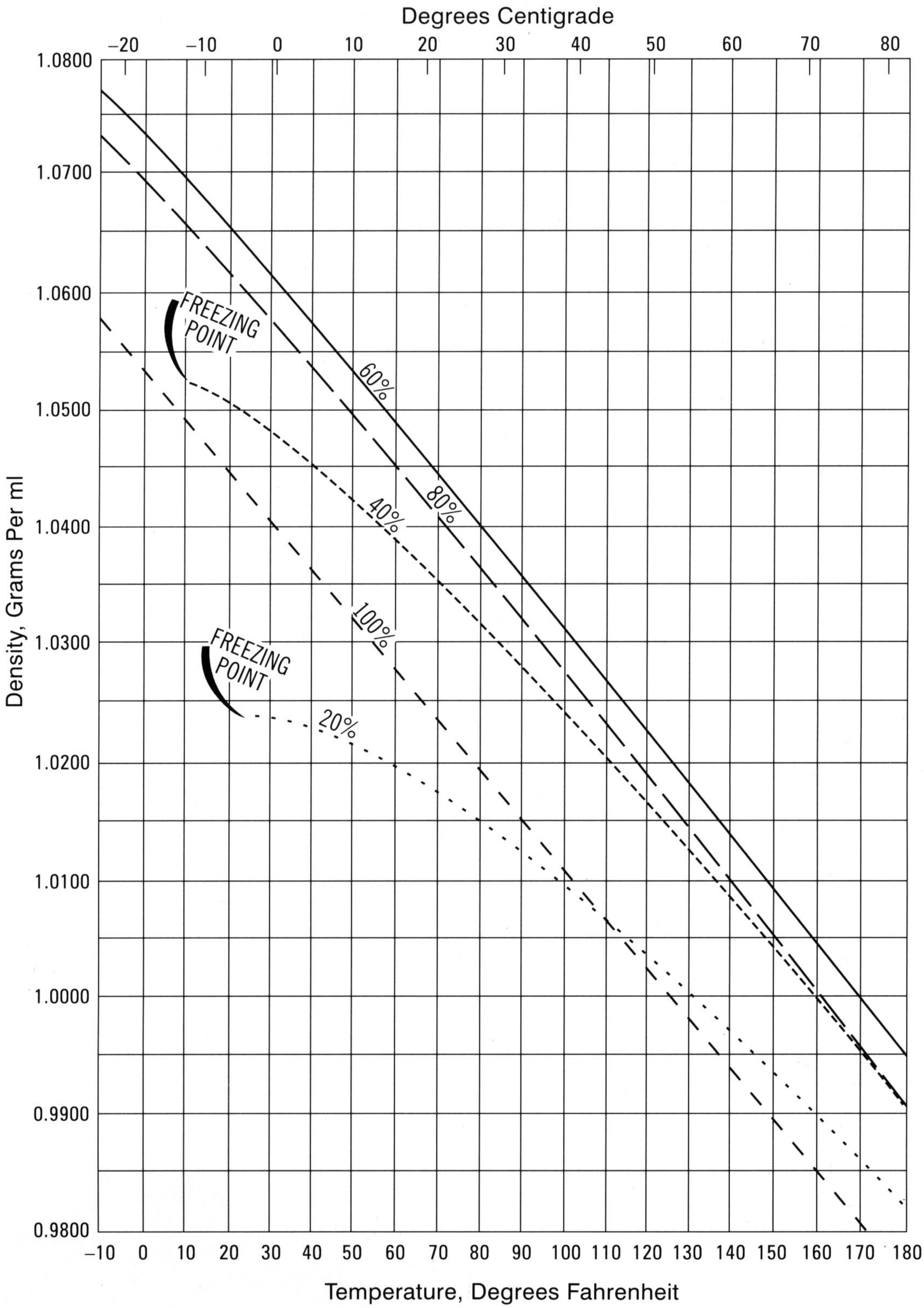

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Figure 20- Refractive Indices of Aqueous Solutions of Glycols at 77°F (25°C)