*Kirk-Othmer Encyclopedia of Chemical Technology.*

# GLYCOLS, PROPYLENE GLYCOLS

The propylene glycol family of chemical compounds consists of monopropylene glycol (PG), dipropylene glycol (DPG), and tripropylene glycol (TPG). The proper IUPAC chemical name for PG is 1,2-propanediol and it is listed on the U.S. EPA Toxic Substances Control Act (TSCA) inventory of chemical substances by its CAS Registry Number, [57-55-6]. The IUPAC name and TSCA listing for DPG is oxybispropanol [25265-71-8] and for TPG [(1-methyl-1,2-ethanediyl)bis(oxy)]bispropanol [24800-44-0]. These chemicals are manufactured as coproducts and are used commercially in a large variety of applications. They are available as highly purified products which meet well-defined manufacturing and sales specifications. All commercial production is via the hydrolysis of propylene oxide. A fourth propylene glycol product, trimethylene glycol or 1,3-dihydroxypropane [504-63-2], has been available in commercial quantities in the past, but is not an important product in the 1990s (1). It was obtained as a by-product in the production of glycerol by either saponification or fermentation of animal fats (see Glycerol).

The propylene glycols are clear, viscous, colorless liquids that have very little odor, a slightly bittersweet taste, and low vapor pressures. The most important member of the family is monopropylene glycol, also known as 1,2-propylene glycol, 1,2-dihydroxypropane, 1,2-propanediol, methylene glycol, and methyl glycol. The more common commercial names are Propylene Glycol Industrial (PGI) and Propylene Glycol USP (PG USP), which designates the grade for general industrial as opposed to the food and drug grade. All of the glycols are totally miscible with water.

Propylene glycol, when produced according to the U.S. Food and Drug Administration good manufacturing practice guidelines at a registered facility, meets the requirements of the U.S. Food, Drug, and Cosmetic Act as amended under Food Additive Regulation CFR Title 21, Parts 170–199. It is listed in the regulation as a direct additive for specified foods and is classified as generally recognized as safe (GRAS). In addition, it meets the requirements of the *Food Chemicals Codex* and the specifications of the *U.S. Pharmacopeia XXII*. Because of its low human toxicity and desirable formulation properties it has been an important ingredient for years in food, cosmetic, and pharmaceutical products.

## 1. Manufacturing

Wurtz (2) first prepared propylene glycol in 1859 by hydrolysis of propylene glycol diacetate, and it was commercialized in 1931 by Carbide and Carbon Chemicals Corp. (3). This first commercial production used the chlorohydrin process to make propylene oxide, which was subsequently hydrolyzed to the glycol. In the mid-1930s Du Pont Co. operated a high pressure coconut oil hydrogenation plant which yielded propylene glycol as a by-product. Propylene glycol was gaining acceptance as a substitute for glycerol in pharmaceuticals, and shortages during World War II led to new production facilities by Dow Chemical Co. in 1942 and Wyandotte Chemical Corp. in 1948.

All commercial production of propylene glycol is by high pressure, high temperature, noncatalytic hydrolysis of propylene oxide (qv). A large excess of water is used in the conversion of propylene oxide to a mixture of

**Table 1. U.S. Producers of Propylene Glycols**

| Producer | Location | Annual capacity, $10^3$ t |
|---|---|---|
| Arco[a] | Bayport, Tex. | 163 |
| Dow[a] | Freeport, Tex. | 113 |
| Dow[a] | Plaquemine, La. | 68 |
| Eastman[a] | S. Charleston, W.Va. | 36 |
| Olin[a] | Brandenburg, Ky. | 32 |
| Texaco[b,c] | Beaumont, Tex. | 68 |
| *Total* | | *480* |

[a] Ref. 4.
[b] Ref. 5.
[c] Projected 1994 startup.

**Table 2. Production and Sales of Propylene Glycols, 1990[a]**

| Glycol | Production, $10^3$ t | Sales, $10^3$ t | Average sales, \$/kg |
|---|---|---|---|
| propylene | 342.2 | 258.3 | 0.94 |
| dipropylene | 35.6 | 29.4 | 0.90 |
| tripropylene | 10.4 | [b] | [b] |

[a] Ref. 6.
[b] Not reported.

mono-, di-, and tri-propylene glycols. Typical product distribution is 90% PG and 10% coproducts. Hydration reactor conditions are 120–190°C at pressures up to 2170 kPa. After the hydration reaction is completed, excess water is removed in multieffect evaporators and drying towers, and the glycols are purified by high vacuum distillation.

Propylene oxide [75-56-9] is manufactured by either the chlorohydrin process or the peroxidation (coproduct) process. In the chlorohydrin process, chlorine, propylene, and water are combined to make propylene chlorohydrin, which then reacts with inorganic base to yield the oxide. The peroxidation process converts either isobutane or ethylbenzene directly to an alkyl hydroperoxide which then reacts with propylene to make propylene oxide, and *t*-butyl alcohol or methylbenzyl alcohol, respectively. Table 1 lists producers of propylene glycols in the United States.

Table 2 shows the production, sales, and value for the glycols in the United States in 1990. Production of monopropylene glycol peaked in 1988 at 404,000 t. Imports have been minimal except for the mid-1980s when 25,600 t were imported in 1984. In the period 1986–1989 U.S. exports averaged about 75,000 t per year.

## 2. Chemistry

Monopropylene glycol (1,2-propanediol) is a difunctional alcohol with both a primary and a secondary hydroxyl. Chemically, the presence of the secondary hydroxyl group differentiates propylene glycol from ethylene glycol, which has two primary hydroxyl groups. Coproducts dipropylene glycol and tripropylene glycol have several possible structural and stereochemical isomers. Examination of the mechanisms for addition of an alcohol to an oxirane ring under various reaction conditions explains the distribution of the various isomers in the product mix (7). In the high pressure, high temperature process for hydrolysis of propylene oxide to propylene glycol and the subsequent formation of dipropylene and tripropylene glycol, the neutral to slightly acidic conditions dictate a nonspecific opening of the oxirane ring. The nonspecific nature of the acid-catalyzed reaction is seen in the approximately 50:50 product distribution for the primary to secondary alcohol isomers in the dipropylene glycol produced in the process. In the base-catalyzed propoxylation of an alcohol, for example in poly(propylene glycol) manufacture, attack is at the less substituted position of the oxirane ring, leading to the preferential formation of the secondary alcohol.

The primary and secondary alcohol functionalities have different reactivities, as exemplified by the slower reaction rate for secondary hydroxyls in the formation of esters from acids and alcohols (8). 1,2-Propylene glycol undergoes most of the typical alcohol reactions, such as reaction with a free acid, acyl halide, or acid anhydride to form an ester; reaction with alkali metal hydroxide to form metal salts; and reaction with aldehydes or ketones to form acetals and ketals (9, 10). The most important commercial application of propylene glycol is in the manufacture of polyesters by reaction with a dibasic or polybasic acid.

$$CH_3CHOHCH_2OH + HOOCRCOOH \longrightarrow HO\!\left(\overset{CH_3}{\overset{|}{C}}HCH_2OOCRCOO\right)_{n}H + n\,H_2O$$

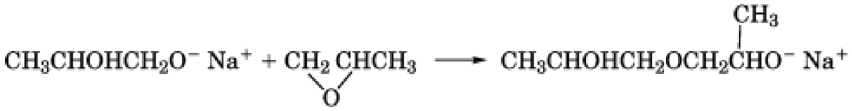
In the manufacture of unsaturated polyester resins the polyester is synthesized and then diluted with a vinyl reactive monomer such as styrene (see Polyesters, unsaturated). A portion of the dibasic acid of the polyester is maleic or some other vinyl reactive diacid that can be polymerized with the styrene to yield a highly cross-linked, high performance polymer system. Other esters made with propylene glycol, dipropylene glycol, and tripropylene glycol are used as emulsifiers in foods, as plasticizers in polymer systems, and as part of acrylate resin systems.

Polyethers are also products of commercial importance. Ethers can be formed by thermal dehydration, as shown for the formation of dipropylene glycol from propylene glycol. Cyclic ethers can form by elimination of water from di- or tripropylene glycol.

$$2\ CH_3CHOHCH_2OH \longrightarrow CH_3CHOHCH_2OCH_2CHOHCH_3 + H_2O$$

The principal product obtained when heating propylene glycol in the presence of aluminum silicate at 200 to 400°C is the cyclic ether 2,5-dimethyl-1,4-dioxane (11). The synthesis practiced in industry to make the important class of polyethers called polyols or polyglycols is the acid- or base-catalyzed addition of an epoxide such as propylene oxide to an active hydrogen compound such as a glycol. Any of the propylene glycols may be used for this purpose. Polyglycols can be tailored to meet rigorous application specifications for use in polyesters, polyurethanes, or other systems where active hydrogen compounds are needed.

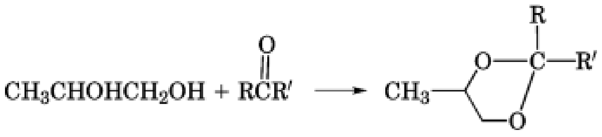
$$CH_3CHOHCH_2OH + NaOH \longrightarrow CH_3CHOHCH_2O^{-}Na^{+}$$



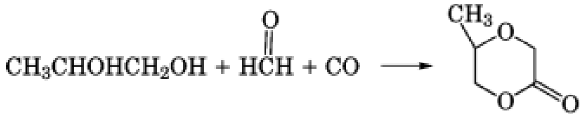
Oxidation of a glycol can lead to a variety of products. Periodic acid quantitatively cleaves 1,2-glycols to aldehydes and is used as an analysis method for glycols (12, 13). The oxidation of propylene glycol over Pd/C modified with Pb, Bi, or Te forms a mixture of lactic acid, hydroxyacetone, and pyruvic acid (14). Air oxidation of propylene glycol using an electrolytic crystalline silver catalyst yields pyruvic aldehyde.

Certain bacterial strains convert propylene glycol to pyruvic acid in the presence of thiamine (15); other strains do the conversion without thiamine (16). Propylene oxide is the principal product of the reaction of propylene glycol over a cesium impregnated silica gel at 360°C in the presence of methyl ethyl ketone and xylene (17).

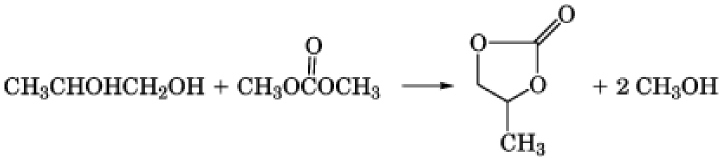
Aldehydes and ketones react with glycols to form acetals and ketals which are easily hydrolyzed, making this a convenient method for protecting aldehyde or ketone functionality in organic synthesis. Propylene glycol in the presence of an acid catalyst reacts with aldehydes and ketones with concurrent removal of water to give 4-methyl-1,3-dioxolanes (18). The reaction of chloroacetaldehyde with propylene glycol in the presence of an acid catalyst gives 2-(chloromethyl)-4-methyl-1,3-dioxolane ($R = CH_2Cl$; $R' = H$) (19).



Lactones are prepared from formaldehyde and carbon monoxide by cyclocondensation with propylene glycol in the presence of a strong acid and a Cu(I) or Ag carbonyl catalyst (20).



Cyclic carbonates are made by treating 1,2-diols with dialkyl carbonates using an alkyl ammonium and tertiary amine catalyst. The combination of propylene glycol and dimethyl carbonate has been reported to result in a 98% yield of propylene carbonate (21).



## 3. Stereochemical and Structural Isomers

Propylene glycol, dipropylene glycol, and tripropylene glycol all have several isomeric forms. Propylene glycol has one asymmetric carbon and thus there are two enantiomers: (*R*)-1,2-propanediol and (*S*)-1,2-propanediol. 1,3-Propanediol is a structural isomer. Dipropylene glycol exists in three structural forms and since each structural isomer has two asymmetric carbons there are four possible stereochemical isomers per structure or a total of twelve isomers. These twelve consist of four enantiomer pairs and two meso- compounds. Tripropylene glycol has four structural isomers and each structural isomer has three asymmetric carbons so each structural isomer has eight possible stereochemical isomers or a total of 32 isomers of tripropylene glycol. Table 3 gives a listing of the IUPAC names, unique structures, and CAS Registry Numbers for the various isomers of propylene glycol, dipropylene glycol, and tripropylene glycol that have been reported in the literature.

## 4. Physical and Chemical Properties

Table 4 lists various physical and chemical properties and constants for the propylene glycols. A comprehensive source for additional physical and chemical properties is Reference 25.

**Table 3. Propylene Glycol Isomers**

| IUPAC name | Formula | CAS Registry Number | Boiling point,[a] °C |
|---|---|---|---|
| | *Propylene glycol* | | |
| 1,2-propanediol | $CH_3CH(OH)CH_2OH$ | [57-55-6] | 189, 115.9[b,c] |
| (±)-1,2-propanediol | | [4254-16-4] | |
| (*R*)-1,2-propanediol | | [4254-14-2] | |
| (*S*)-1,2-propanediol | | [4254-15-3] | |
| | *Dipropylene glycol* | | |
| oxybispropanol | | [25265-71-8] | 152.5[b,d] |
| 1,1′-oxybis-2-propanol | $[CH_3CH(OH)CH_2]_2O$ | [110-98-5] | 222.2[c], 229–32[d] |
| (*R**,*R**)-(±)-1,1′-oxybis-2-propanol | | [55716-55-7] | |
| (*R**,*R**)-1,1′-oxybis-2-propanol | | [55716-54-6] | |
| [*S*-(*R**,*R**)]-1,1′-oxybis-2-propanol | | [61217-63-8] | |
| 2,2′-oxybis-1-propanol | $[HOCH_2CH(CH_3)]_2O$ | [108-61-2] | 225.7[c] |
| (*R**,*R**)-(±)-2,2′-oxybis-1-propanol | | [20753-87-1] | |
| (*R**,*S**)-2,2′-oxybis-1-propanol | | [20753-88-2] | |
| [*S*-(*R**,*R**)]-2,2′-oxybis-1-propanol | | [125948-51-8] | |
| 2-(2-hydroxypropoxy)-1-propanol | $HOCH_2CH(CH_3)OCH_2CH(CH_3)OH$ | [106-62-7] | 224.0[c] |
| (*R**,*R**)-(±)-2-(2-hydroxypropoxy)-1-propanol | | [62376-49-2] | |
| (*R**,*S**)-2-(2-hydroxypropoxy)-1-propanol | | [62376-50-5] | |
| [*S*-(*R**,*R**)]-2-(2-hydroxypropoxy)-1-propanol | | [110813-96-2] | |
| | *Tripropylene glycol* | | |
| [(1-methyl-1,2-ethanediyl)bis(oxy)]bispropanol | | [24800-44-0] | 181.6[b,d] |
| 1,1′-[(1-methyl-1,2-ethanediyl)bis(oxy)]bis-2-propanol | $HOCH(CH_3)CH_2OCH(CH_3)CH_2OCH_2CH(CH_3)OH$ | [1638-16-0] | |
| 2,2′-[(1-methyl-1,2-ethanediyl)bis(oxy)]bis-1-propanol | $HOCH_2CH(CH_3)OCH(CH_3)CH_2OCH(CH_3)CH_2OH$ | | |
| 2-[1-(2-hydroxypropoxy)-2-propoxy]-1-propanol | $HOCH_2CH(CH_3)OCH(CH_3)CH_2OCH_2CH(CH_3)OH$ | | |
| 2-[2-(2-hydroxypropoxy)propoxy]-1-propanol | $HOCH_2CH(CH_3)OCH_2CH(CH_3)OCH_2CH(CH_3)OH$ | [45096-22-8] | 268[e] |

[a] At 101.3 kPa = 1 atm, unless otherwise noted.
[b] At 6.7 kPa (50 mm Hg).
[c] Ref. 22.
[d] Ref. 23.
[e] Ref. 24.

## 5. Consumption and Use

Consumption of propylene glycol follows an erratic pattern in the United States which reflects domestic economic conditions. Table 5 gives a breakdown by percentage for the principal uses of propylene glycol in the United States.

### 5.1. Propylene Glycol

Propylene glycol is unique among the glycols in that it is safe for humans to take internally. Propylene glycol intended for human use is designated as USP grade and is commonly found in foods, pharmaceuticals, cosmetics,

**Table 4. Properties of Glycols**

| Physical properties | Propylene glycol | Dipropylene glycol | Tripropylene glycol |
|---|---|---|---|
| formula | $C_3H_8O_2$ | $C_6H_{14}O_3$ | $C_9H_{20}O_4$ |
| molecular weight | 76.1 | 134.2 | 192.3 |
| boiling point at 101.3 kPa,[a] °C | 187.4 | 232.2[b] | 265.1[b] |
| vapor pressure, kPa,[a] 25°C | 0.017 | 0.0021 | 0.0003 |
| density, g/mL | | | |
| 25°C | 1.032 | 1.022 | 1.019 |
| 60°C | 1.006 | 0.998 | 0.991 |
| freezing point, °C | supercools | supercools | supercools |
| pour point, °C | $< -57$ | −39 | −41 |
| viscosity, mPa·s( = cP) | | | |
| 25°C | 48.6 | 75.0 | 57.2 |
| 60°C | 8.42 | 10.9 | 9.7 |
| surface tension, mN/m( =dyn/cm), 25°C | 36 | 35 | 34 |
| refractive index at 25°C | 1.431 | 1.441 | 1.442 |
| specific heat at 25°C, J/(g·K)[c] | 2.51 | 2.18 | 1.97 |
| flash point, °C, PMCC[d] | 104 | 124 | 143 |
| coefficient of expansion × $10^4$, 0–60°C | 7.3 | 7.0 | 8.1 |
| thermal conductivity at 25°C, W/(m·K) | 0.2061 | 0.1672 | 0.1582 |
| heat of formation, kJ/mol[c] | −422 | −628 | −833 |
| heat of vaporization at 25°C, kJ/mol[c] | 67.0 | 45.4 | 35.4 |

[a] To convert kPa to mm Hg, multiply by 7.5.
[b] Varies with isomer distribution.
[c] To convert J to cal, divide by 4.184.
[d] PMCC = Penskey − Martens closed cup.

**Table 5. Uses of Propylene Glycols in the United States, 1992**

| Application | Consumed, % |
|---|---|
| unsaturated polyester resins | 37 |
| cosmetics, pharmaceuticals, foods | 17 |
| pet food | 3 |
| tobacco humectant | 4 |
| functional fluids | 16 |
| paints and coatings | 5 |
| liquid detergents | 11 |
| others | 7 |

and other applications involving possible ingestion or absorption through the skin. The U.S. Food and Drug Administration has approved the use of propylene glycol in various food categories, as shown in Table 6.

An industrial grade of propylene glycol is usually specified for other uses. In common with most other glycols, propylene glycol is odorless and colorless, and has a wide range of solvency for organic materials, besides being completely water soluble. Propylene glycol is also a known antimicrobial and is an effective food preservative (26).

Propylene glycol 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. PG also finds 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 sunscreen lotion, shampoos, shaving creams, and other similar products.

**Table 6. U.S. FDA-Approved Use of Propylene Glycol in Foods**

| Food category | Maximum content, wt % |
|---|---|
| alcoholic beverages | 5.0 |
| confections and frosting | 24.0 |
| frozen dairy products | 2.5 |
| seasonings and flavorings | 97.0 |
| nuts and nut products | 5.0 |
| all other foods | 2.0 |

Certain esters of propylene glycol such as propylene glycol monostearate [1323-39-3] are also popular as an emulsifier in cosmetic and pharmaceutical creams.

Aqueous solutions of propylene glycol display excellent antifreeze properties and are therefore valuable as low temperature heat-transfer fluids. For applications involving indirect food contact, heat-transfer fluids formulated with the USP grade product are preferred, since there could be inadvertent contact with a food product. These fluids are commonly used in the brewing and dairy industries as well as in refrigerated display cases in retail grocery stores.

Propylene glycol is also an effective humectant, preservative, and stabilizer and is found in such diverse applications as semimoist pet food, bakery goods, food flavorings, salad dressings, and shave creams. Humectancy, or the capability of retaining moisture in a product, is a result of the vapor–liquid equilibria of the glycol–water system and can be estimated from tables provided by suppliers (27).

The industrial grade of propylene glycol is an important intermediate in the production of alkyd resins for paints and varnishes. It is the preferred glycol for manufacturing high performance, unsaturated polyester resins for many uses, eg, reinforced plastic laminates for marine construction, gel coats, sheet molding compounds (SMC), and synthetic marble castings. It is also used as a solvent and plasticizer in printing inks, as a preservative in floral arrangements, and as a stabilizer in hydraulic fluids. Heat-transfer fluidsused in commercial and industrial building heating and cooling systems, chemical plants, stationary engines, and solar heat recovery can be formulated with the industrial grade of propylene glycol. More recently, propylene glycol-based coolants for automobiles and heavy-duty diesel engine trucks have been introduced which compete with traditional ethylene glycol-based products (28, 29). The newly published ASTM standard D5216 specifies aqueous propylene glycol-based engine coolants for automobile and light-duty truck service. All heat-transfer applications require corrosion inhibitor additives and are designed for specific operating temperature ranges and types of materials of construction. Operation at low temperature without freezing and at high temperature without excessive pressure are the principal features of these systems.

Due in large part to its lower toxicity and the concomitant lesser concern about its environmental impact, propylene glycol use in the air transportation industry as an airplane and runway deicing agent has grown substantially in recent years (see Antifreezes and deicing fluids). Other glycols, such as ethylene glycol, have historically been used in this industry.

### 5.2. 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 and higher viscosity make it of interest in certain applications for which the other glycols are not as well suited. The greater solvency of dipropylene glycol for castor oil indicates its usefulness as a component of hydraulic brake fluid formulations; its affinity for certain other oils has likewise led to its use in cutting oils, textile lubricants, and industrial soaps. It is also used as a reactive

**Table 7. Acute Oral Toxicity of Propylene Glycols**[a]

| Compound | Oral rat $LD_{50}$, g/kg |
|---|---|
| propylene glycol | 20.0 |
| dipropylene glycol | 14.9 |
| tripropylene glycol | 3.0 |
| sucrose | 29.7 |

[a] Ref. 30.

intermediate in manufacturing polyester resins, plasticizers, and urethanes. Fragrance or low odor grades of dipropylene glycol are established standard base formulating solvents in the fragrance industry and for some personal care products such as deodorants.

### 5.3. 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 a high boiling point also have led to its use by formulators of textile soaps and lubricants, cutting oil concentrates, and many similar products. Tripropylene glycol is also used as a reactant to produce acrylate resins which are useful in radiation-cured coatings, adhesives, and inks. Polyethers used in the manufacture of urethane rigid foam insulation are made by alkoxylation of tripropylene glycol.

## 6. Toxicology

All of the propylene glycols display a low acute oral toxicity in laboratory rats as shown in Table 7 (30). Information for sucrose is shown for comparison.

Studies in which rats were fed drinking water containing as much as 10% propylene glycol over a period of 140 days (31, 32) showed no apparent ill effects. Other investigations have revealed that rats can tolerate up to 4.9% propylene glycol in the diet for two years without significant effects on growth rate (33). However, minor liver damage was observed. In a more recent study (34), dogs were fed a diet containing 8% propylene glycol for two years and were unaffected, as judged by mortality, body weight changes, diet utilization, histopathology, organ weights, and blood, urine, and biochemical parameters. Because of its low chronic oral toxicity, propylene glycol is considered safe for use in foods and pharmaceuticals.

Rats showed no adverse effects from 5.0% dipropylene glycol in their drinking water for 77 days, but at a dose of 10.0% in the drinking water, kidney and liver injury and some deaths occurred (35). A sufficient number of studies have not been carried out on tripropylene glycol to permit conclusions to be drawn regarding its chronic oral toxicity.

Propylene glycols produce a negligible degree of irritation upon eye or skin contact. From tests on New Zealand white rabbits (36) in 1982 it was concluded that propylene glycol is a slight eye irritant. Other tests conducted both *in vitro* and *in vivo* have shown propylene glycol to be a nonirritant to the eye. Both dipropylene glycol and tripropylene glycol have been tested for skin and eye irritation in rabbits and have been found to be nonirritating. The expert panel of the *Cosmetic Ingredient Review,* after conducting a comprehensive safety assessment, has concluded that propylene glycol may be used in cosmetic products in concentrations up to 50% (37).

**Table 8. Biodegradation of Propylene Glycols With Standard Municipal Inoculum**

| Glycol | Theoretical $O_2$ demand | 5-Day $O_2$ demand | 10-Day $O_2$ demand | 20-Day $O_2$ demand |
|---|---|---|---|---|
| PG | 1.68 | 1.16 | 1.18 | 1.45 |
| DPG | 1.91 | [a] | 0.14 | 0.71 |
| TPG | 1.38 | [a] | [a] | [a] |

[a] Data not available.

Inhalation of the vapors of any of the propylene glycols appears to present no significant hazard in ordinary applications and this is reflected in the fact that OSHA has not found it necessary to establish a permissible exposure level in the workplace. However, in 1985 the American Industrial Hygiene Association reviewed human experience and animal data and established a Workplace Environmental Exposure Level (WEEL) guideline for propylene glycol at 50 ppm total vapor and aerosol averaged over an eight-hour period. Although not legally binding, the WEEL guidelines have been adopted by industry as good industrial hygiene practice. Limited data indicate that breathing mists of di- and tripropylene glycol may be harmful. Prolonged inhalations of saturated vapors of propylene glycol have produced no ill effects in animals, but such concentrations would likely be irritating to the upper respiratory tract and possibly the eyes of humans. Only limited 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 unlikely that injury would occur as a result of limited vapor inhalation.

## 7. Environmental Considerations

The propylene glycols vary in biodegradability, as shown in Table 8. The tests involved were conducted with standard municipal inoculum, and other studies (31) have shown that biodegradability can be greatly enhanced when using an acclimated bacteria. For example, tripropylene glycol has shown 66% of theoretical oxygen demand at 20 days with an industrial seed. Thus it is expected that all of the propylene glycols will exhibit moderate to high biodegradability in a natural environment.

All of the propylene glycols are considered to be practically nontoxic to fish on an acute basis $(LC_{50} < 100\ mg/L)$ and practically nontoxic to aquatic invertebrates, also on an acute basis. Acute marine toxicology testing (38) on propylene glycol showed that the 96-h $LC_{50}$ for fathead minnows was 54,900 mg/L and the 48-h $LC_{50}$ for *Daphnia magna* was 34,400 mg/L. A 24-h NOEL of 50,000 mg/L was also observed for fingerling trout. Similar results were observed for guppies and rainbow trout (39).

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