Canadian Soil Quality Guidelines for the Protection of Environmental and Human Health

PROPYLENE GLYCOL

This fact sheet provides a summary of a review by the CCME Soil Quality Guidelines Task Group (SQGTG) of the implications of propylene glycol (PG) releases to Canadian soil environments. Following a review of the releases, fate and effects of PG in soils, the SQGTG opted not to develop Canadian soil quality guidelines at this time. Nonetheless, releases of PG to the environment can pose serious risks for groundwater supplies and aquatic life in surface water bodies, due to the high biochemical oxygen demand (BOD) associated with rapid microbial breakdown of PG. This high BOD in turn may result in depressed oxygen concentrations and low redox conditions in surface and groundwater, with a large number of secondary effects on geochemistry, microbial productivity, and the viability of aquatic life. PG releases may be managed in part through the use of propylene glycol Canadian Water Quality Guidelines for the protection of aquatic life (CCME 1999). Use of aircraft de-icing fluid represents one of the largest sources of PG release to the environment. In addition to issues associated with PG release, managers of de-icing activities should be aware of the environmental risks associated with other possible additives in commercial de-icing solutions; in particular triazoles added as corrosion inhibitors, and alkylphenol ethoxylates (including nonylphenol ethoxylates) that may be added as surfactants.

This fact sheet summarizes the chemical and physical properties of PG, its uses in Canada, environmental fate, toxicity, and the rationale for not developing soil quality guidelines at this time. This fact sheet accompanies the document titled *Canadian Soil Quality Guidelines for propylene glycol: Environmental and Human Health – Preliminary Discussion Document* (CCME 2004).

Background Information

Propylene glycol ($C_3H_8O_2$; CAS 57-55-6) belongs to a group of organic chemicals named dihydric or aliphatic alcohols, which are characterized by two hydroxyl (OH^-) functional groups attached to methyl subunits in an aliphatic chain. It is a clear, odourless, tasteless, viscous liquid with a melting point of -59^o C and a boiling point of 188.2^{o}C (USFDA 2003). PG has a low vapour pressure of 0.07 mm Hg at 20^o C and a low Henry's law constant of 1.7×10^{-7} atm·m^3·mol^{-1}; hence it is relatively non-volatile. PG is highly miscible in water and has an octanol/water partitioning coefficient of -0.92; therefore, bioaccumulation based on transfer into biological lipids is not expected to be significant.

PG is similar to ethylene glycol in many of its chemical properties; however, the two do not share a similar degree of toxicity in mammals. PG has a much lower mammalian toxicity than ethylene glycol. As such, PG is not on the National Pollutant Release Inventory in Canada, nor the Toxic Release Inventory in the US. Therefore, there is little data available on any releases of PG into the environment. There has been no manufacturer of PG in Canada since 1992.

There are two major markets in Canada which account for almost 80% of the total usage of PG: polyester resins and consumables (food, cosmetics and tobacco). The remainder is said to be 'miscellaneous', including use in paints, antifreeze and animal feeds. There has been a notable increase in the amount of PG used in the production of antifreeze and aircraft deicing/anti-icing fluids (ADFs), driven in part by environmental/ toxicological concerns associated with ethylene glycol. In most cases, glycols used in ADFs end up in the municipal sewer and/or storm water system.

Fate and Behaviour in Environmental Media

Soil

Soil factors that affect the fate and behaviour of PG in the terrestrial environment are pH, organic matter, clay content, cation exchange capacity, aeration and texture. The major processes that determine the mobility and distribution of PG in the terrestrial environment are partitioning into surface and ground water given the high aqueous solubility, as well as rapid biodegradation and photolysis. Volatilization and sorption to soils are fate processes with only minor importance.

No Canadian Soil Quality Guideline for propylene glycol is recommended at this time.

PG is estimated to have a half-life in soil due to biodegradation that is equal to or shorter than that in water (from 1 to 5 days). However, degradation rates will vary with soil properties, temperature and other environmental conditions. ATSDR (1997) estimated the half-life of PG in water to be l to 4 days under aerobic conditions and 3 to 5 days under anaerobic conditions, assuming first order kinetics. Soil temperature potentially has a large influence on PG biodegradation rates. No information was available on concentrations of PG in soil within a field setting.

Water

Propylene glycol is highly soluble in water, and readily metabolized by microbes and higher organisms once released into the environment. The biodegradation process requires oxygen; therefore, dissolved oxygen (DO) concentrations in receiving waters may be negatively impacted following a glycol release. Bielefeldt et al. (2002) examined secondary effects of PG introduction to soils on groundwater flow using 15 cm saturated sand columns. Rapid propylene glycol biodegradation was found to be accompanied by a decrease in the saturated hydraulic conductivity by one to three orders of magnitude, likely as a result of bacterial biomass build-up around soil particles.

Air

PG is not expected to readily volatilize into air from water, due to its high solubility and low vapour pressure. If released into the atmosphere during high temperatures, PG should exist almost entirely in the vapour phase and undergo rapid photochemical oxidation. The half-life for this reaction has been estimated to be 20-32 hours.

Behaviour and Effects in Biota

Mammals

There have been numerous studies regarding the toxicological effects of PG in mammals, and the interested reader is referred to WHO (1994), ATSDR (1997), and NTP (2004). The majority of research has been focused on the use of PG in food, cosmetic and pharmaceutical products. The U.S. FDA has ruled that PG is an additive that is “generally recognized as safe” (GRAS) for use in food substances. Dosage studies involving mammals indicate that PG had no effect on fertility and reproduction in multiple generations of Swiss mice at up to 10,000 $mg \cdot kg^{-1} \cdot day^{-1}$ (USDA 2002). The principle metabolites of PG include D-lactate, glucose, and CO_2. Like ethylene glycol, PG causes acidosis, through conversion to lactic and pyruvic acids. However, the acidosis from PG is not as severe as that caused by ethylene glycol.

Aquatic Life

Although the direct toxicity of propylene glycol is relatively low, indirect effects on aquatic life are common at release sites. Glycols may require oxygen to biodegrade (although anaerobic biodegradation is also potentially rapid), and aquatic toxicity may increase as a result of the creation of anaerobic conditions during periods of warm water temperatures. It should be noted that aircraft de-icer fluids (ADFs) are diluted with water, and therefore will exert a lower biological oxygen demand than pure glycol.

Toxicological data collected for PG in the environment has been based mainly on freshwater and marine environment studies involving aquatic species. Price *et al*. (1974) conducted laboratory studies where brine shrimp were exposed over 24 hours to PG in salt water. The observed LC_{50} was greater then 1.0×10^4 $mg \cdot L^{-1}$. Bridié et al. (1979) also conducted acute toxicity studies on goldfish and determined that the 24-h LC_{50} was greater than 5×10^3 $mg \cdot L^{-1}$.

While toxicity studies generally show ethylene glycol and PG to be fairly non-toxic in an aquatic environment, ADF toxicity is significantly higher. This increase has been attributed to the additives in ADFs, including surfactants, corrosion inhibitors and flame retardants. Exact concentrations and compositions of additives in ADFs is proprietary information. Surfactants (such as nonylphenol ethoxylates) are generally 0.5% by volume ADF, and corrosion inhibitors and flame retardants (such as tolytriazole) constitute up to 0.5% by volume ADF. Nonylphenol ethoxylates have been indirectly shown to produce a known endocrine disruptor during degradation (hydrophobic nonylphenol), which could cause interference with reproduction and growth of aquatic organisms and humans. Canadian environmental quality guidelines exist for nonylphenol ethoxylates (CCME 2002; Environment Canada 2002).

Soil Biota

There have been a limited number of studies involving the toxicity of PG to terrestrial plants, most notably *Lactuca sativa* (lettuce). Lettuce test results from Pillard and Dufresne (1999) compare favorably to the results from previous studies by Reynolds (1977). Reynolds reported a germination EC_{50} for lettuce of 50,540 $mg \cdot L^{-1}$, which was very similar to the emergence IC_{50} of 49,330 mg·L^{-1} in Pillard and Dufresne's study. Pillard and Dufresne (1999) also measured NOEC and LOEC endpoints for seedling emergence of both lettuce and perennial ryegrass (*Lolium perenne)*. They recorded soil concentrations of 4,500 and 15,000 mg·L^{-1}, respectively for lettuce, and 15,000 and 50,000 mg·L^{-1}, respectively, for ryegrass (Pillard and Dufresne 1999). A 1993 study (Hulzebos 1993) of the acute (7-14 days) effects of propylene glycol on *Lactuca sativa* population biomass, indicated an EC_{50} greater than 1,000 mg·kg^{-1} soil.

The majority of data on PG toxicity to plants is of limited value for establishing environmentally protective soil thresholds, since the studies were based on exposures from liquid media, rather than from spiked or field collected soils. The review of available literature did not indicate any published studies involving PG toxicity to soil invertebrates.

Guideline Derivation

Canadian soil quality guidelines are derived for different land uses following the process outlined in CCME (1996) using different receptors and exposure scenarios for each land use.

Soil Quality Guidelines for Environmental Health

Environmental soil quality guidelines (SQG_Es) are based on soil contact using data from toxicity studies on plants and invertebrates. In the case of agricultural land use, soil and food ingestion toxicity data for mammalian and avian species are included. To provide a broader scope of protection, a nutrient and energy cycling check is calculated. For industrial land use, an off-site migration check is also calculated.

Information on the toxicity of PG in soils was located for only one plant species (lettuce) and no soil invertebrate species. In light of the lack of data, it is not possible to calculate a preliminary soil quality guideline based on direct soil contact ($PSQG_{SC}$).

The environmental groundwater check was used to derive a PG soil concentration that is protective of freshwater aquatic life associated with groundwater recharge to surface water. Because of the known fate and behaviour of PG in the environment, this groundwater check value is applied in the determination of the environmental soil quality guideline. The preliminary SQG_{FWAL} calculated using the groundwater model along with the generic (CCME 2003) assumptions was 6,210 mg·kg^{-1}. It should be noted that the water quality guideline from which the SQG_{FWAL} is derived doesn't take into account potential problems coming from oxygen depletion caused by propylene glycol degradation.

Soil Quality Guidelines for Human Health

Health Canada has not defined a Tolerable Daily Intake limit for propylene glycol. The World Health Organization, however, has established an Allowable Daily Intake (ADI) of 25 mg·kg^{-1} bw·day^{-1}. Conservative exposure assumptions were used to determine a preliminary human health soil quality guideline ($PSQG_{HH}$). It was concluded that concentrations of propylene glycol exceeding 100% w:w soil concentration would not result in unacceptable human health risks. Therefore, there are no human health guidelines or check values nominated at this time.

Conclusions

There is sufficient scientific knowledge on the toxicological properties of PG as it pertains to human or mammalian exposures. Any soil guideline is likely to reflect the fact that PG has been designated as "Generally Recognized as Safe" for consumption purposes.

There is sufficient scientific knowledge on the toxicological properties of PG as it pertains to aquatic environments. It is this data that formed the basis for the development of the current Canadian Water Quality Guideline for PG for the protection of freshwater life. The estimation of soil-groundwater partitioning, K_D (and transfer to surface water bodies) based on the estimated K_{OC} may not be as accurate as other estimation methods, and this may limit the accuracy of groundwater model predictions. In addition, the predictions are highly sensitive to assumptions regarding persistence half-lives in the vadose zone and in the saturated zone under oxic or anoxic conditions.

There are insufficient scientific data available on the toxicological effects of PG on terrestrial plants or animals. Therefore, the derivation of an environmental soil quality guideline (SQG_E) is not currently feasible.

There is insufficient information on the effects of PG on soil microbial and fungal processes that in turn influence carbon, nitrogen, phosphorus and other macronutrient cycling in soil ecosystems. It is clear that PG releases tend to enhance the secondary productivity of heterotrophic bacteria in soil, and that PG can be used by microbes as a preferred and highly accessible sole carbon source.

Subsidiary effects on other soil microbial processes remain poorly investigated, however. In addition, the current understanding of factors that affect microbial activity at release sites for ADFs is insufficient for the development of strong predictive models.

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For further scientific information, contact:

Environment Canada
National Guidelines and Standards Office
351 St. Joseph Blvd.
Gatineau, QC K1A 0H3
Phone: (819) 953-1550
Facsimile: (819) 956-5602
E-mail: ceqg-rcqe@ec.gc.ca
Internet: http://www.ec.gc.ca/ceqg-rcqe

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