Kirk-Othmer Encyclopedia of Chemical Technology.

CHLOROHYDRINS

A chlorohydrin has been defined (1) as a compound containing both chloro and hydroxyl radicals, and chlorohydrins have been described as compounds having the chloro and the hydroxyl groups on adjacent carbon atoms (2). Common usage of the term applies to aliphatic compounds and does not include aromatic compounds. Chlorohydrins are most easily prepared by the reaction of an alkene with chlorine and water, though other methods of preparation are possible. The principal use of chlorohydrins has been as intermediates in the production of various oxirane compounds through dehydrochlorination.

1. Properties

Ethylene chlorohydrin [107-07-3], $HOCH_2CH_2Cl$, is the simplest chlorohydrin. It may also be called 2-chloroethanol, 2-chloroethyl alcohol, or glycol chlorohydrin. Ethylene chlorohydrin is a liquid at 15°C and 101.3 kPa (1 atm) (Table 1). This polar compound is miscible with water [7732-18-5] and ethanol [64-17-5] and is slightly soluble in ethyl ether [60-29-7] (5).

Table 2 gives physical property data for propylene chlorohydrins. 2-Chloro-1-propanol [78-89-7], $HOCH_2CHClCH_3$, is also named 2-propylene chlorohydrin, 2-chloropropyl alcohol, or 2-chloro-1-hydroxypropane. 1-Chloro-2-propanol [127-00-4], $ClCH_2CHOHCH_3$, also known as *sec*-propylene chlorohydrin, 1-chloroisopropyl alcohol, and 1-chloro-2-hydroxypropane, is a colorless liquid, miscible in water, ethanol, and ethyl ether.

3-Chloro-1,2-propanediol [96-24-2], $HOCH_2CHOHCH_2Cl$, a liquid with $n_D^{20} = 1.4831$ (6), boils at 213°C and 101.3 kPa (1 atm) with decomposition. It can be distilled at 114–120°C at 1.87 kPa (14 mm Hg). Synonyms for this compound include 3-chloro-1,2-dihydroxypropane, glycerol monochlorohydrin, α-chlorohydrin, and 3-chloropropylene glycol. It is miscible in water, ethanol, ethyl ether, and acetone [67-64-1] (8) and is soluble in hot benzene [71-43-2].

3-Chloro-1,2-propanediol has a mol wt of 110.48 and a specific gravity at 20°C of 1.3218. Its flash point is 135°C (9). Its heat of formation at 298 K is −525.8 kJ/mol (− 125.7 kcal/mol) and the heat of combustion at constant volume is 15.2 kJ/g (3.63 kcal/g) (8).

Physical property data for dichloropropanols, $C_3H_6Cl_2O$, appear in Table 3. 1,2-Dichloro-3-propanol [616-23-9] $ClCH_2CHClCH_2OH$, is also known as 1,2 dichlorohydrin, β-dichlorohydrin, or 1,2-dichloro-3-hydroxypropane. It is miscible in ethanol, ether, acetone, and benzene and is slightly soluble in H_2O (5).

1,3-Dichloro-2-propanol [96-23-1], $ClCH_2CHOHCH_2Cl$, has a vapor pressure at 28°C of 0.13 kPa (0.98 mm Hg) (10). Other names for it include 1,3-dichlorohydrin, glycerol dichlorohydrin, and 1,3-dichloro-2-hydroxypropane. It is very soluble in water and ethanol, miscible in ethyl ether; and soluble in acetone (5).

Composition and bp data for selected binary azeotropes of chlorohydrins are given in Table 4 (11).

Table 1. Physical Properties of Ethylene Chlorohydrin[a]

Property	Value
molecular formula	C_2H_5ClO
molecular weight	80.51
boiling point at 101.3 kPa[b], °C	128.7
melting point, °C	−67.5
density at 20°C, g/cm^3	1.2015–1.2025
vapor pressure at 20°C, kPa[b]	0.65
specific thermal capacity at 20°C, kJ/(kg·K)[c]	1.965
viscosity at 20°C, mPa·s(= cP)	3.43
refractive index, n_D^{20}	1.4418–1.442
flash point, °C	55
autoignition temperature, °C	425
explosive limits in air, vol %	5–16
specific heat of vaporization, kJ/kg[c]	552
heat of formation[d] at 298 K, kJ/mol[c]	−294.3
heat of combustion[d], kJ/kg[c]	15,080

[a] Ref. 3 unless otherwise noted.
[b] To convert kPa to mm Hg, multiply by 7.5.
[c] To convert kJ to kcal, divide by 4.184.
[d] Ref. 4.

Table 2. Physical Properties of Propylene Chlorohydrins, C_3H_7ClO

Property	2-Chloro-1-propanol	1-Chloro-2-propanol	Reference
mol wt	94.54	94.54	
boiling point, °C	133–134	126–127	
specific gravity at 20°C	1.103	1.115	6
refractive index at 20°C	1.4362	1.4362	6
vapor density (air = 1)	3.3	3.3	
flash point, °C	44[a]	52	7

[a] ASTM D3278.

Table 3. Physical Properties of Dichloropropanols

Property	1,2,-Dichloro-3-propanol	1,3-Dichloro-2-propanol
mol wt	128.99	128.99
boiling point, °C	183–185	174.3[a]
mp, °C		−4
specific gravity	1.3607[b]	1.3506[c]
heat of combustion at constant volume, kJ/g	13.3[d]	
refractive index	1.4819[b]	1.4802[c]
flash point, °C		85
vapor density (air = 1)		4.4[e]

[a] Ref. 6.
[b] At 20°C (5).
[c] At 17°C.
[d] To convert kJ to kcal, divide by 4.184 (8).
[e] Ref. 7.

Table 4. Binary Azeotropes of Chlorohydrins

A component	B component	Bp, °C[a]	Wt % A
2-Chloroethanol		128.6	100
	water	98[b]	42
	2-methoxyethanol [109-86-4]	130	69
	2-ethoxyethanol [110-80-5]	136	15
	3-methyl-1-butanol [123-51-3]	128	75
	chlorobenzene [108-90-7]	120	42
	cyclohexene [110-83-8]	81	11
	4-methyl-3-penten-2-one [141-79-7]	130	33
	cyclohexane [110-82-7]	78.5	10
	2-hexanone [591-78-6]	129	75
	butyl acetate [123-86-4]	125.6	31
	o-chlorotoluene [95-49-8]	128	75
	toluene [108-88-3]	107	24.4
1-Chloro-2-propanol		127	100
	water	95.4	54
	chlorobenzene	122	55
	butyl acetate	125.5	25
	toluene	109	15
	heptane [142-82-5]	96.5	17
	o-xylene [95-47-6]	125.5	85
	perchloroethylene [127-18-4]	113	28
2-Chloro-1-propanol		133.7	100
	water	96	49
	chlorobenzene	126	36
	o-xylene	130.5	70
	isobutyl ether [628-55-7]	120	25
	perchloroethylene	115	13
	butyl ether [142-96-1]	130.5	70
1,3-Dichloro-2-propanol		175.8	100
	water	99	23.2
	o-dichlorobenzene [95-50-1]	170.5	60
	p-dichlorobenzene [106-46-7]	168	45
	o-chlorotoluene	158	15
	ethoxybenzene [103-72-1]	169	37
	1,3,5-trimethylbenzene [108-67-8]	161.5	32
	d-limonene [5989-27-5]	166	67
2,3-Dichloro-1-propanol		182.5	100
	o-dichlorobenzene	174	40
	p-dichlorobenzene	171	30
	p-methylanisole [104-93-5]	175.5	32
	mesitylene [108-67-8]	163	18
	d-limonene	169	40
	ethyl butyl ether [628-81-9]	180	53
1,3-Dichloro-2-methyl-2-propanol [597-32-0]		174	100
	water	98.3	35.2
1-Chloro-2-methyl-2-propanol [558-42-9]		126.7	100
	water	93–94	66

[a] At 101.3 kPa (1 atm) unless otherwise noted.
[b] At 99.7 kPa (0.98 atm).

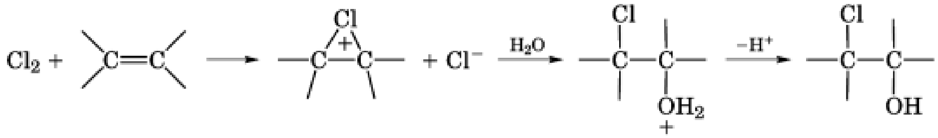
2. Chemistry

2.1. Synthesis of Chlorohydrins

2.1.1. Hypochlorination

Both ethylene chlorohydrin and propylene chlorohydrin were prepared by Wurtz (12) as a result of the reactions of HCl [7647-01-0] with the corresponding glycol under pressure. Shortly afterward, Carius (13) synthesized ethylene chlorohydrin by reaction of hypochlorous acid with ethylene [74-85-1]. The first detailed investigation of the formation of ethylene chlorohydrin by the reaction of ethylene with hypochlorous acid [7790-92-3] was performed by Gomberg (14).

Hypochlorous acid is most readily made by the reaction of chlorine [7782-50-5] with water: $Cl_2 + H_2O \rightleftarrows HCl + HOCl$. However, since the equilibrium constant for this reaction is only 4.2×10^{-4} (15), the amount of hypochlorous acid, as compared to that of chlorine, is quite small. Thus it was expected that the addition of chlorine to the double bond to produce 1,2-dichloroethane [107-06-2] would be the principal reaction. However, when the reaction is done under well-stirred conditions so that the ethylene can only react with the chlorine in solution and not with gaseous chlorine, the main product is the ethylene chlorohydrin. Very little 1,2-dichloroethane is observed until a concentration of chlorohydrin in the reaction solution reaches 6–8%. These results suggested that the reaction of the ethylene with the hypochlorous acid is significantly faster than the reaction of ethylene with dissolved chlorine. Subsequent studies have shown that in an aqueous system chlorohydrins are not formed by the addition of hypochlorous acid but rather by the **reaction of the olefinic compound with chlorine and water**, successively (2).



2.1.2. Chlorohydrins from Epoxides

Traditionally epoxides have been manufactured by the dehydrochlorination of chlorohydrins. However, the reverse reaction may be used as a source of chlorohydrins, especially in the case of ethylene chlorohydrin from ethylene oxide [75-21-8], which is now produced by the direct oxidation of the olefin. A study of the reaction of hydrogen chloride with propylene oxide [75-56-9] showed that an anhydrous system at low temperatures ($<0°C$) gives the highest yield of chlorohydrin with best isomeric selectivity (16).

Various techniques are mentioned in the literature for the reaction of ethylene oxide and HCl. These include gas-phase reaction (17); reaction of gaseous HCl with ethylene oxide (18); and in solution, especially with ethylene chlorohydrin as solvent (19–21).

Glycerol dichlorohydrin (1,3-dichloro-2-propanol) may be synthesized by the reaction of HCl with epichlorohydrin (chloromethyloxirane [106-89-8]). A patent describes a continuous process using the dichlorohydrin as the reaction solvent to suppress by-product formation (22).

2.1.3. Chlorohydrins via Enzyme Technology

During the 1980s a series of patents assigned to Cetus Corp. (23–25) appeared and describe the synthesis of chlorohydrins by the use of a halogenating enzyme, an oxidizing agent, and a halide ion source. A preferred embodiment involves chloroperoxidase derived from the microorganism *Caldariomyces fumago*, hydrogen peroxide [7722-84-1] as the oxidizing agent, and sodium chloride [7647-14-5] as the halide ion source. The hydrogen peroxide and sodium chloride are mixed in a buffered aqueous solution, the enzyme is added, and the olefin is added to the system either as a gas or a liquid.

2.1.4. Chlorohydrins from Chromyl Chloride

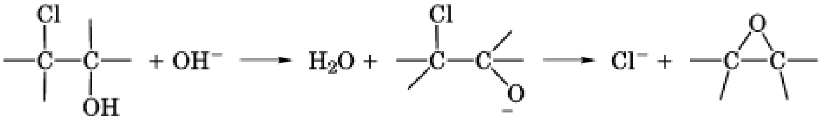
Several olefins have been treated with chromyl chloride [14977-61-8], CrO_2Cl_2, in carbon tetrachloride [56-23-5]. Chlorohydrins were formed in 35–50% yields from propylene [115-07-1], 1 butene [106-98-9], 1-pentene [109-67-1], and 1-hexene [592-41-6]. In each case the hydroxyl group of the chlorohydrin was located almost exclusively in the primary position, which is in contrast to the main product from the reaction of olefins with aqueous chlorine (26).

2.2. Reactions of Chlorohydrins

2.2.1. Dehydrochlorination to Epoxides

The most useful chemical reaction of chlorohydrins is dehydrochlorination to form epoxides (oxiranes). This reaction was first described by Wurtz in 1859 (12) in which ethylene chlorohydrin and propylene chlorohydrin were treated with aqueous potassium hydroxide [1310-58-3] to form ethylene oxide and propylene oxide, respectively. For many years both of these epoxides were produced industrially by the dehydrochlorination reaction. In the past 40 years, the ethylene oxide process based on chlorohydrin has been replaced by the direct oxidation of ethylene over silver catalysts. However, such epoxides as propylene oxide (qv) and epichlorohydrin are still manufactured by processes that involve chlorohydrin intermediates.

The conversion of chlorohydrins into epoxides by the action of base is an adaptation of the Williamson synthesis of ethers. In the presence of hydroxide ion, a small proportion of the alcohol exists as alkoxide, which **displaces the chloride ion from the adjacent carbon atom to produce a cyclic ether** (2).



The dehydrochlorination of chlorohydrins to epoxides exhibits second-order kinetics in that the rate is dependent on both the concentration of the chlorohydrin and the hydroxide ion (27). This suggests a rapid formation of the alkoxide ion in the presence of base followed by the slower, rate-determining elimination of the chloride ion with accompanying ring closure (28). Intramolecular displacements leading to epoxides are generally thousands of times faster than the intermolecular attack of alkoxides on alkyl chlorides under comparable conditions (29). Although ring strain causes the epoxide formation to be less favored energetically than is the case with a noncyclic ether, far less restriction of motion is necessary in closing a small ring than in bringing together two free molecules into a single activated complex. Thus the ease of formation of epoxides from chlorohydrins is an entropy effect.

Epoxide formation from chlorohydrins is marked by an increase in rate with alkyl substitution (28) as shown in Figure 1. This phenomenon has been explained on the basis that steric crowding in the chlorohydrin is somewhat relieved as the epoxide is formed, so that the greatest relief of strain results from ring closure of the most crowded chlorohydrin (28).

2.2.2. Formation of Mustard Gas from Ethylene Chlorohydrin

Ethylene chlorohydrin is readily converted to bis(2-chloroethyl)sulfide [505-60-2], the so-called mustard gas, $C_4H_8Cl_2S$, used widely in World War I (14). The preparation involves the addition of a 70–80% aqueous solution of ethylene chlorohydrin to solid sodium sulfide hydrate [1313-84-4]. There is little temperature change because although the reaction of the chlorohydrin with the sulfide is exothermic, the process of dissolving the sodium sulfide is endothermic. When the reaction is over, the excess sodium sulfide is neutralized with 90% sulfuric acid [7664-93-9]. Concentrated hydrochloric acid is added to the neutralized solution, and the precipitated sodium salts are filtered and washed with acid. When the clear, yellow hydrochloric acid solution of the thiodiglycol is

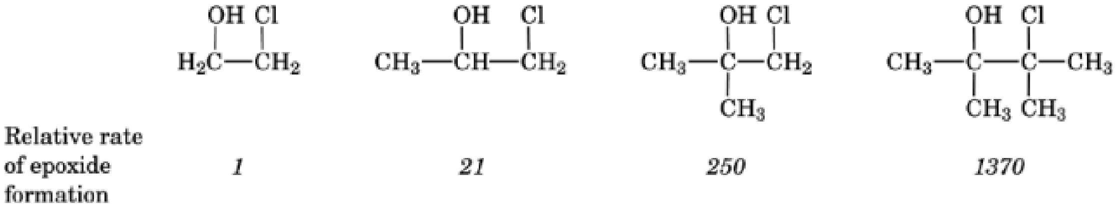


Fig. 1. Effect of alkyl substitution on chlorohydrin epoxidation.

heated to 60–75°C, dichloroethyl sulfide, $ClCH_2CH_2SCH_2CH_2Cl$, separates as a heavy, yellow oil. Yields of up to 98% based on starting chlorohydrin are reported (14). In view of the ease of manufacture of this dangerous war gas from ethylene chlorohydrin, the U.S. State Department imposed export controls on ethylene chlorohydrin to Iran, Iraq, and Syria in 1986 (30).

2.2.3. Hydrolysis to Glycols

Ethylene chlorohydrin and propylene chlorohydrin may be hydrolyzed in the presence of such bases as alkali metal bicarbonates sodium hydroxide, and sodium carbonate (31–33). In water at 97°C, 1-chloro-2-propanol forms acid, acetone, and propylene glycol [57-55-6] simultaneously; the kinetics of production are first order in each case, and the specific rate constants are nearly equal. The relative rates of solvolysis of 2-chloroethanol, 1-chloro-2-propanol, and 1-chloro-2-methyl-2-propanol in water at 97°C are 1.0:0.81:5.5 (34). Glycerol monochlorohydrin (3-chloro-1,2-propanediol) is readily hydrolyzed to glycerol when treated with 3% excess sodium bicarbonate for 30 minutes at 150°C. In a continuous system, monochlorohydrin was fed simultaneously with a 10% NaOH, 1% Na_2CO_3 solution to a stirred autoclave to produce glycerol in about 90% yield (35).

2.2.4. Formation of Cyclic Carbonates

In the absence of water, chlorohydrins such as 2-chloroethanol and 1-chloro-2-propanol react with an alkali carbonate or bicarbonate to produce cyclic carbonates such as ethylene carbonate [96-49-1] and propylene carbonate [108-32-7] in yields of up to 80% (36). An improved method involves the reaction of a chlorohydrin and CO_2 in the presence of an amine, which gives cyclic carbonate selectivities of 90–95% (37). Cyclic carbonates are produced in high yield under very mild conditions by treating chlorohydrins with tetramethylammonium hydrogen carbonate in acetonitrile [75-05-8] under a CO_2 atmosphere (38).

2.2.5. Esterification

Chlorohydrins can react with salts of carboxylic acids to form esters. For example, 2-hydroxyethyl benzoate [134-11-2] was prepared in 92% yield by heating sodium benzoate [532-32-1] with an excess of ethylene chlorohydrin in the presence of a small amount of diethylamine [109-89-7] at 140°C for four hours (38).

2.2.6. Etherification

A mixture of ethylene chlorohydrin in 30% aqueous NaOH may be added to phenol at 100–110°C to give 2-phenoxyethanol [122-99-6] in 98% yield (39). A cationic starch ether is made by reaction of a chlorohydrin–quaternary ammonium compound such as 3-chloro-2-hydroxypropyl trimethyl-ammonium chloride [101396-91-2] with a starch slurry at pH 11–12 (40).

2.2.7. Oxidation

Monochloroacetic acid [79-11-8] may be synthesized by the reaction of ethylene chlorohydrin with nitric acid [7697-37-2]. Yields of greater than 90% are reported (41). >Beta-chlorolactic acid (3-chloro-2-hydroxypropanoic acid) [1713-85-5] is produced by the reaction of nitric acid with glycerol monochlorohydrin (42). Periodic acid [10450-60-9] and glycerol monochlorohydrin gives chloroacetaldehyde [107-20-0] in 50% yield (43).

2.2.8. Quaternization

Choline chloride [67-48-1] was prepared in nearly quantitative yield by the reaction of trimethylamine [121-44-8] with ethylene chlorohydrin at 90–105°C and 981–1471 kPa (10–15 kg/cm^2) pressure (44). Precursors to quaternary ammonium amphoteric surfactants have been made by reaction of ethylene chlorohydrin with tertiary amines containing a long chain fatty acid group (45).

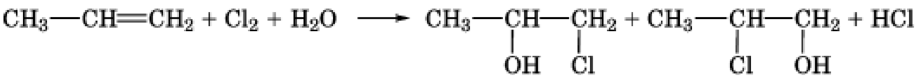
3. Manufacture and Processing

For many years ethylene chlorohydrin was manufactured on a large industrial scale as a precursor to ethylene oxide, but this process has been almost completely displaced by the direct oxidation of ethylene to ethylene oxide over silver catalysts. However, since other commercially important epoxides such as propylene oxide and epichlorohydrin cannot be made by direct oxidation of the parent olefin, chlorohydrin intermediates are still important in the manufacture of these products.

3.1. Propylene Chlorohydrin

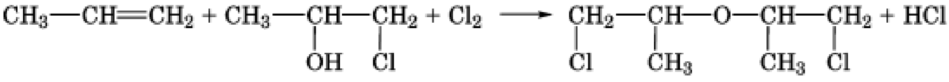
3.1.1. Chlorohydrination in Chlorine and Water

The **hypochlorination** of propylene gives two isomers: 90% 1-chloro-2-propanol and 10% 2-chloro-1-propanol.



$$CH_3{-}CH{=}CH_2 + Cl_2 + H_2O \longrightarrow CH_3{-}\underset{OH}{\underset{|}{CH}}{-}\underset{Cl}{\underset{|}{CH_2}} + CH_3{-}\underset{Cl}{\underset{|}{CH}}{-}\underset{OH}{\underset{|}{CH_2}} + HCl$$

The principal by-products are the result of **direct chlorine addition** to give 1,2-dichloropropane [78-87-5] and ether formation. The ether product is dichloropropyl ether [108-60-1] or 2,2′-oxybis(1-chloropropane).



$$CH_3{-}CH{=}CH_2 + CH_3{-}\underset{OH}{\underset{|}{CH}}{-}\underset{Cl}{\underset{|}{CH_2}} + Cl_2 \longrightarrow \underset{Cl}{\underset{|}{CH_2}}{-}\underset{CH_3}{\underset{|}{CH}}{-}O{-}\underset{CH_3}{\underset{|}{CH}}{-}\underset{Cl}{\underset{|}{CH_2}} + HCl$$

Commercial chlorohydrin reactors are usually towers provided with a chlorine distributor plate at the bottom, an olefin distributor plate about half way up, a recirculation pipe to allow the chlorohydrin solution to be recycled from the top to the bottom of the tower, a water feed into the recirculation pipe, an overflow pipe for the product solution, and an effluent gas takeoff (46). The propylene and chlorine feeds are controlled so that no free gaseous chlorine remains at the point where the propylene enters the tower. The gas lift effect of the feeds provides the energy for the recirculation of the reaction solution from the top of the tower.

Chlorohydrination occurs as the propylene and dissolved chlorine pass up through the tower. It is important that no significant amount of free chlorine remain in the effluent gas as this could cause explosive reactions. After scrubbing through a solution of NaOH and a sufficient amount is bled off to prevent accumulation of inert gases, the effluent gas is mixed with fresh propylene and fed back to the reactor. Fresh water is fed into the recirculation leg of the tower at a rate sufficient to maintain the chlorohydrin concentration in the circulating liquid at 4–4.5% by weight. An equivalent amount of chlorohydrin solution overflows for further processing. The reactions are exothermic, which maintains a temperature in the reaction column of 30–40°C without external heating or cooling. A diagram of a typical chlorohydrin reactor for the manufacture of propylene oxide is shown in Figure 2 (47).

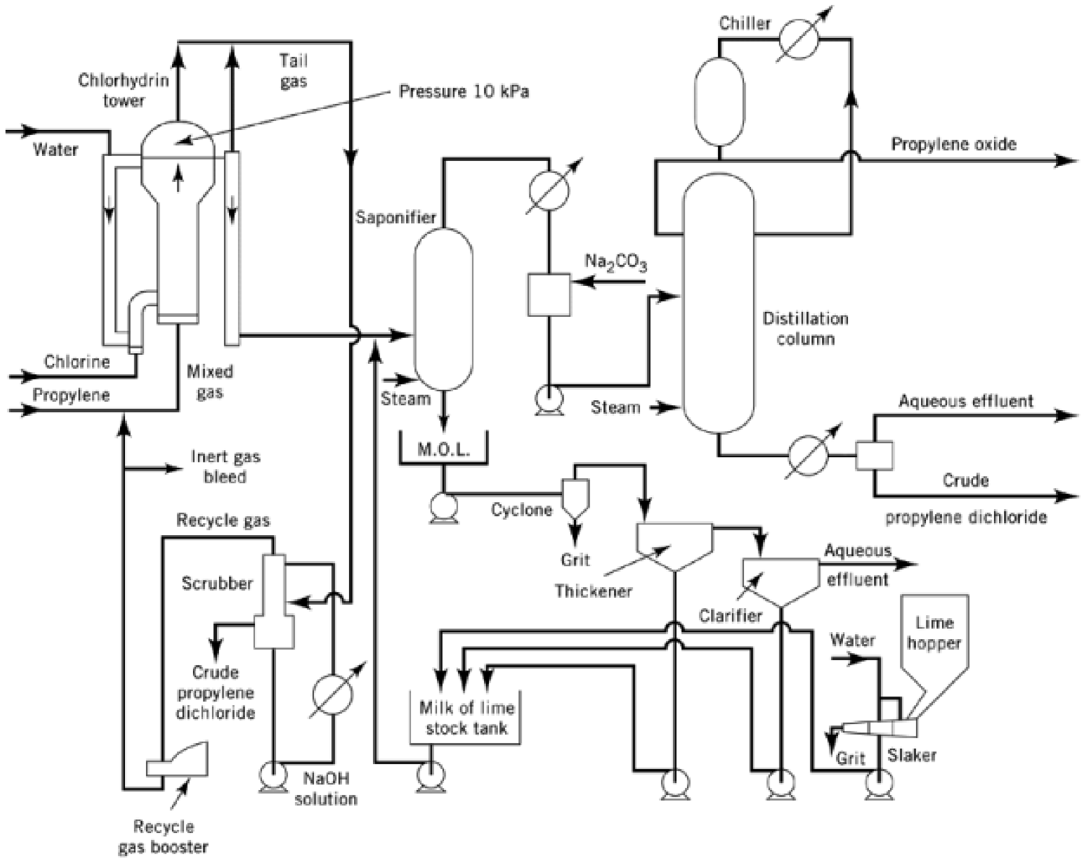


Fig. 2. Diagram of a typical chlorohydrin reactor for manufacture of propylene oxide. M.O.L.=milk of lime. To convert kPa to mm Hg, multiply by 7.5.

In addition to maintaining the circulation of the reaction liquid, the inert gas is important in temperature control, and it prevents the formation of a separate nonaqueous phase by carrying off substantial quantities of dichloropropane in the effluent.

Since the formation of the chlorohydrin is accompanied by the production of an equimolar quantity of hydrogen chloride [7647-01-0], the reaction solution is strongly acidic and corrosive. The first chlorohydrin reaction towers were built of stoneware or of mild steel and lined with rubber and ceramic tiles. More recently corrosion-resistant reinforced plastics have been used with good results, but operating pressures must be maintained at or near atmospheric.

Yields of propylene chlorohydrin range from 87–90% with dichloropropane yields of 6–9%. The dichloropropane is not only a yield loss but also represents a disposal problem as few uses are known for this material. Since almost all the propylene chlorohydrin is dehydrochlorinated to propylene oxide with lime or sodium hydroxide, none of the chlorine appears in the final product. Instead, it ends up as dilute calcium or sodium chloride solutions, which usually contain small amounts of propylene glycol and other organic compounds that can present significant disposal problems.

3.1.2. Chlorohydrination with Nonaqueous Hypochlorous Acid

Because the presence of chloride ions has been shown to promote the formation of the dichloro by-product, it is desirable to perform the chlorohydrination in the absence of chloride ion. For this reason, methods have been reported to produce hypochlorous acid solutions free of chloride ions. A patented method (48) involves the extraction of hypochlorous acid with solvents such as methyl ethyl ketone [78-93-3], acetonitrile, and ethyl acetate [141-78-6]. In one example hypochlorous acid was extracted from an aqueous brine with methyl ethyl ketone in a 98.9% yield based on the chlorine used. However, when propylene reacted with a 1 *M* solution of hypochlorous acid in either methyl ethyl ketone or ethyl acetate, chlorohydrin yields of only 60–70% were obtained (10).

3.1.3. Chlorohydrination with tert-Alkyl Hypohalites

Olefins react with ethyl hypochlorite [624-85-1] to form the corresponding chlorohydrin (49). In 1938 both Shell Development Co. (50) and Arthur D. Little, Inc. (51) patented the preparation of chlorohydrins by the reactions of olefins with tertiary alkyl hypochlorites. Examples with ethylene and propylene in the Shell patent reported chlorohydrin yields of greater than 95% with *tert*-butyl hypochlorite [507-40-4].

Almost 40 years later the Lummus Co. patented an integrated process involving the addition of chlorine along with the sodium chloride and sodium hydroxide from the cathode side of an electrolytic cell to a tertiary alcohol such as tertiary butanol to produce the tertiary alkyl hypochlorite. The hypochlorite phase separates, and the aqueous brine solution is returned to the electrolytic cells. The *tert*-alkyl hypochlorite reacts with an olefin in the presence of water to produce a chlorohydrin and the tertiary alcohol, which is returned to the chlorinator. With propylene, a selectivity to the chlorohydrin of better than 96% is reported (52). A series of other patents covering this technology appeared during the 1980s (53–56).

3.2. Manufacture of Glycerol Monochlorohydrins

3.2.1. From Allyl Alcohol

The reaction of allyl alcohol [107-18-6] with chlorine and water gives a mixture of glycerol monochlorohydrins consisting of 73% 3-chloropropane-1,2-diol and 27% of 2-chloropropane-1,3-diol (57). In a recycle reaction system in which allyl alcohol is fed as a 4.5–5.5 wt % solution, chlorine is added at a rate of 7–9 moles per hour. The reaction time is about five seconds, the reaction temperature 50–60°C and the recycle ratio is 10–20:1. Under these conditions monochlorohydrins have been obtained in 88% yield with 9% dichlorohydrins (58) (see Allyl alcohol and derivatives).

3.2.2. From Glycerol

A procedure for synthesizing alpha-monochlorohydrin (3-chloro-1,2-propanediol) in 85–88% yields by the reaction of glycerol [56-81-5] with aqueous hydrochloric acid in the presence of a catalytic amount of acetic acid has been developed (59). An anhydrous procedure that involves the reaction of glycerol and HCl gas in the presence of acetic acid has also been described (60).

3.3. Manufacture of Glycerol Dichlorohydrins

3.3.1. From Allyl Chloride

The hypochlorination of allyl chloride [107-05-1] gives a mixture of the glycerol dichlorohydrins, 2,3-dichloropropanol and 1,3-dichloropropanol about 7:3 ratio. Because of the poor solubility of allyl chloride in water, it is essential to minimize the formation of an organic phase in which direct chlorination of the allyl chloride results in the unwanted by-product 1,2,3-trichloropropane.

Many techniques have been developed to accomplish this, for example, the use of a cooled recirculating system in which the chlorine is dissolved in one part and the allyl chloride is dissolved and suspended in another (61). The streams are brought together in the main reaction zone and thence to a separator to remove water-insoluble products. Another method involves maintaining any organic phase present in the reaction zone in a highly dispersed condition (62). A continuous reactor consists of a recycle system in which make-up water and allyl chloride in a volume ratio of 10–50:1 are added upstream from a centrifugal pump so that the allyl chloride is completely dispersed in the aqueous phase as particles less than 100 mμ in diameter by the time of chlorine addition is reached. Dichlorohydrin yields of greater than 92% based on the allyl chloride feed are reported.

Emulsifiers may also be used to disperse the allyl chloride (63). Finely emulsified water and allyl chloride are fed into a tubular reactor along with gaseous chlorine. This is a single-pass reactor with a residence time of at least 15 seconds and a linear velocity of the reaction mixture of at least 0.5 m/s. The emulsion is prepared by feeding water and allyl chloride in a weight ratio of at least 25:1 along with nonionic or anionic surfactants (0.2–0.5 wt % with respect to allyl chloride) through a static mixer. Maximum dichlorohydrin yields of greater than 94% are reported, compared to an 84.5% yield in the same reactor without the inclusion of an emulsifier.

The reaction of allyl chloride and chlorine in water produces trichloropropane as a by-product even in the aqueous phase, along with tetrachloropropyl ether. For maximum dichlorohydrin yield it is necessary to run the reaction at low concentrations of chloride ion and of chlorohydrin, that is, with high water dilution. However, high dilution results in an aqueous effluent that contains minor amounts of these by-products that require significant treatment to reduce them to levels acceptable in outfalls to rivers, lakes, and other public waterways.

One patent (64) describes an extraction method to remove both trichloropropane and tetrachloropropyl ether from the dichlorohydrin solution by the use of carbon tetrachloride as a solvent. In this way the by-products are removed from the aqueous phase into an organic phase from which they can be separated by distillation and disposed of in a safe and proper manner.

3.3.2. From Allyl Alcohol

An alternative route to dichlorohydrins from allyl chloride begins with the hydrolysis to allyl alcohol. Significant yields of 2,3-dichloropropanol can be obtained from the reaction of chlorine with allyl alcohol if the reaction is performed in the presence of concentrated hydrochloric acid (65). Several patents for the manufacture of 2,3-dichloropropanol by the chlorination of allyl alcohol at low temperature, -30° to $+20^\circ\mathrm{C}$, in 25–40% HCl solution have appeared (66–68). Product yields as high as 98% are claimed.

4. Economic Aspects

The most important chemical reaction of chlorohydrins is dehydrochlorination to produce epoxides. In the case of propylene oxide, The Dow Chemical Company is the only manufacturer in the United States that still uses the chlorohydrin technology. In 1990 the U.S. propylene oxide production capacity was listed as 1.43×10^6 t/yr, shared almost equally by Dow and Arco Chemical Co., which uses a process based on hydroperoxide intermediates (69, 70). More recently, Dow Europe SA, announced a decision to expand its propylene oxide capacity by 160,000 metric tons per year at the Stade, Germany site. This represents about a 40% increase over the current capacity (71).

Epichlorohydrin (chloromethyloxirane), which has a production capacity in the United States of 291,000 t/yr, is manufactured by the chlorohydrination of allyl chloride and subsequent dehydrochlorination of the glycerol dichlorohydrin isomers (69). Dow and Shell Chemical are the two producers of epichlorohydrin in the United States.

The merchant market for chlorohydrins is small, primarily for specialty applications. Ethylene chlorohydrin is sold in the United States by BASF Corp., Parsippany, N.J., available in 230 kg net lined steel drums.

Glycerol monochlorohydrin (3-chloro-1,2-propanediol) is available from Dixie Chemical Co., Houston, Tex., in lined steel drums (227.3 kg net); from Raschig Corp., Richmond, Va.; and from Henley Chemicals, Inc., Montvale, N.J., in steel drums (240 kg net). Glycerol dichlorohydrin (1,3-dichloro-2-propanol) is not currently being produced for the U.S. merchant market but has been available in the past at a selling price of $5–6/kg.

5. Health and Safety Factors

In general, chlorohydrins are relatively toxic irritants. They are harmful if swallowed, inhaled, or absorbed through the skin. They cause irritation to the eyes, skin, mucous membrane, and upper respiratory tract.

For handling chlorohydrins, chemical safety goggles, chemical-resistant gloves, OSHA/MSHA approved respirators, and other protective clothing are required. In case of contact, one should immediately flush eyes or skin with copious amounts of water for at least 15 minutes and remove contaminated clothing and shoes. If inhaled, the person should be moved to fresh air (72).

Chlorohydrins are combustible and should be stored away from heat and open flame in a cool, dry place. These materials are generally incompatible with strong oxidizing agents and strong bases. Under fire conditions toxic fumes of hydrogen chloride, phosgene, and carbon monoxide may be generated.

5.1. Toxicity of 2-Chloroethanol

Ethylene chlorohydrin is an irritant and is toxic to the liver, kidneys, and central nervous system. In addition, it is rapidly absorbed through the skin (73). The vapor is not sufficiently irritating to the eyes and respiratory mucous membranes to prevent serious systemic poisoning. Contact of the liquid in the eyes of rabbits causes moderately severe injury, but in humans corneal burns have been known to heal within 48 hours. Several human fatalities have resulted from inhalation, dermal contact, or ingestion. One fatality was caused by exposure to an estimated 300 ppm in air for 2.25 hours. In another fatal case, autopsy revealed pulmonary edema and damage to the liver, kidneys, and brain (73).

Toxic amounts can be absorbed through the skin without causing dermal irritation. The dermal LD_{50} for rabbits is 68 mg/kg. Two-year dermal studies showed no evidence of carcinogenicity in rats given 50 to 100 mg/kg/d or mice given 15 mg per animal per day (73) (Table 5). A ceiling limit for exposure to ethylene chlorohydrin of 1 ppm is recommended by the American Conference of Governmental Industrial Hygienists. Protection against skin absorption is strongly recommended.

Ethylene chlorohydrin is classified as a Class B poison in the Code of Federal Regulations. The NFPA Hazard Classification gives the material a health hazard rating of 3, a flammability rating of 2, and a reactivity rating of 0. Fire-extinguishing agents include water, alcohol or polymer foam, dry chemical powder or carbon dioxide (4).

5.2. Uses of Chlorohydrins

From a volume standpoint almost all of the chlorohydrins produced are immediately converted into epoxides such as propylene oxide and epichlorohydrin. The small quantity of various chlorohydrins sold in the merchant market are used in specialty applications.

Ethylene chlorohydrin may be used in the manufacture of dye intermediates, pharmaceuticals, plant-protection agents, pesticides, and plasticizers (3).

Glycerol monochlorohydrin has been found to be an effective toxicant-chemosterilant specifically for the Norway rat (78). This compound was approved for commercial use in the United States by the Environmental Protection Agency in 1982 and is sold under the trade name Epibloc by Pestcon Systems Inc. (79). Glycerol monochlorohydrin is also used to make guaiacol glycerol ether, an expectorant used in cough remedies, by

Table 5. Toxicity Data for Selected Chlorohydrins[a, b]

Compound andanimal test	LD_{50}, mg/kg	LC_{50}	LCL_0, ppm/4 h[c]	LDL_0
2-Chloroethanol				
oral (rat)	71			
inhalation (rat)		290 mg/m^3		
skin (human)			305[d]	
skin (rabbit)	67			
2-Chloro-1-propanol				
oral (rat)	218			
inhalation (rat)			500	
oral (dog)				200 mg/kg
skin (rabbit)	529			
1,3-Dichloro-2-propanol				
oral (rat)	110			
inhalation (rat)				125 ppm/4 h
skin[e] (rabbit)	800			
2,3-Dichloropropanol				
oral (rat)	90			
inhalation (rat)			500	
skin[f] (rabbit)	200			
3-Chloro-1,2-propanediol				
oral (rat)	26[g]			
skin (rat)	1057–1849[h]			
inhalation (rat)		125 ppm/4 h[i]		

[a] Ref. 74.

[b] Toxicity parameters are defined as follows: LD_{50} = lethal dose 50% kill; LCL_0 = lowest published lethal concentration; LC_{50} = lethal concentration 50% kill; LDL_0 = lowest published lethal dose.

[c] Unless otherwise stated.

[d] 305 ppm/2 h.

[e] Also causes moderately severe injury to rabbit's eyes (75).

[f] Similar to acetone in rabbit eyes, reversible.

[g] Ref. 72.

[h] Ref. 76.

[i] Ref. 77.

its reaction with sodium guaiacolate (6). Another application is as an intermediate in the production of x-ray contrast media.

BIBLIOGRAPHY

"Epichlorohydrin" in *ECT* 1st ed., Vol. 3, pp. 865–869, P. H. Williams, Shell Development Co.; "Glycerol Chlorohydrins" in *ECT* 1st ed., Vol. 3, pp. 857–865, P. H. Williams, Shell Development Co.; "Propylene, Trimethylene, and Tetramethylene Chlorohydrins" in *ECT* 1st ed., Vol. 3, pp. 856–857, M. G. Gergel and M. Revelise, Columbia Organic Chemicals Co.; "Chlorohydrins" in *ECT* 2nd ed., Vol. 5, pp. 304–324, G. D. Lichtenwalter and G. H. Riesser, Shell Chemical Co.; in *ECT* 3rd ed., Vol. 5, pp. 848–864, by G. H. Riesser, Shell Development Co.

Cited Publications

1. R. Grant and C. Grant, *Grant & Hackh's Chemical Dictionary*, 5th ed., McGraw-Hill Book Co., New York, 1987, p. 132.
2. R. T. Morrison and R. N. Boyd, *Organic Chemistry*, 5th ed., Allyn and Bacon, Inc., Boston, Mass. 1987, p. 323.
3. *Ethylene Chlorohydrin*, Technical Bulletin, BASF Corp., Parsippany, N.J., 1989.
4. *Chemical Hazard Response Information System (CHRIS)*, Vol. **II**, U.S. Coast Guard, Washington, D.C., 1984.
5. J. G. Grasselli, ed., *Atlas of Spectral Data and Physical Constants for Organic Compounds*, CRC Press, Cleveland, Ohio, 1973.
6. M. Windholz, ed., *The Merck Index*, Merck & Co., Inc., Rahway, N.J., 1976.
7. *Catalog Handbook of Fine Chemicals*, Aldrich Chemical Co., Inc., Milwaukee, Wis., 1990–1991.
8. F. Richter, ed., *Beilsteins Handbuch der Organischen Chemie*, Vol. **III**, Springer-Verlag, Berlin, Germany, 1958, p. 2151.
9. *3-Chloropropane-1,2-diol*, Technical Data Sheet, Raschig Corp., 1988.
10. I. Kh. Bikbulatov and co-workers, *Zh. Prik. Khim.* **58**, 2499 (1985).
11. L. H. Horsley, *Azeotropic Data*, Advances in Chemistry Series, No. 6, American Chemical Society, Washington, D.C., 1952.
12. A. Wurtz, *Ann.* **110**, 125 (1859).
13. L. Carius, *Ann.* **124**, 265 (1862).
14. M. Gomberg, *J. Am. Chem. Soc.* **41**, 1414 (1919).
15. F. A. Cotton and G. Wilkinson, *Advanced Inorganic Chemistry*, Interscience Publishers, New York, 1962.
16. C. A. Stewart and C. A. VanderWerf, *J. Am. Chem. Soc.* **76**, 1259 (1954).
17. Eur. Pat. Appl. 10,013 (Apr. 16, 1980), W. Jequier and co-workers, (to Produits Chimiques Ugine Kuhlmann).
18. V. Parausanu and co-workers, *Rev. Chim. (Bucharest)* **21**, 743 (1970).
19. Jpn. Pat. 69 18,841 (Aug. 16, 1969), K. Miyauchi, S. Senoya, and M. Yoshino (to Japan Oils and Fats Co., Ltd).
20. Jpn. Pat. 83 146,521 (Sept. 1, 1983), (to Nisso Petrochemical Industries Co., Ltd.).
21. Rom. Pat. 60,731 (Apr. 15, 1976), C. Roncea and co-workers (to Institutul de Cercetari pentru Chimizarea Petrolului).
22. Ger. Offen. 2,719,463 (Nov. 2, 1978), (to Hoechst A-G).
23. U.S. Pat. 4,247,641 (Jan. 27, 1981), S. L. Neidleman, W. F. Amon, Jr., and J. Geigart (to Cetus Corp.).
24. U.S. Pat. 4,426,449 (Jan. 17, 1984), J. Geigart and S. L. Neidleman (to Cetus Corp.).
25. U.S. Pat. 4,587,217 (May 6, 1986), J. Geigart and S. L. Neidleman (to Cetus Corp.).
26. S. J. Cristol and K. R. Eilar, *J. Am. Chem. Soc.* **72**, 4353 (1950).
27. S. Winstein and H. J. Lucas, *J. Am. Chem. Soc.* **61**, 1576 (1939).
28. E. S. Gould, *Mechanism and Structure in Organic Chemistry*, Holt, Rinehart, and Winston, New York, 1959, p. 567.
29. J. E. Stevens, C. L. McCabe, and J. C. Warner, *J. Am. Chem. Soc.* **70**, 2449 (1948).
30. *Fed. Reg.* **51**(108), 20467 (1986).
31. U.S. Pat. 1,442,386 (Jan. 11, 1923), (to Carbide and Carbon Chemicals Corp.).
32. U.S. Pat. 1,695,250 (Dec. 11, 1928), (to Carbide and Carbon Chemicals Corp.).
33. P. Sherwood, *Petroleum Refiner* **28**, 120 (1949).
34. I. K. Gregor, N. V. Riggs, and V. R. Stimson, *J. Chem. Soc.*, 76 (1956).
35. E. C. Williams, *AIChE Trans.* **37**, 157 (1941).
36. U.S. Pat. 1,907,891 (May 9, 1933), G. Steimmig and M. Wittwer (to I. G. Farben).
37. U.S. Pat. 3,923,842 (Dec. 2, 1975), Y. Wu (to Phillips Petroleum Co.).
38. C. Venturello and R. D'Aliosio, *Synthesis*, 33 (1985).
39. N. K. Bliznyvk and co-workers, *Zh. Obsch. Khim.* **36**, 480 (1966).
40. U.S. Pat. 2,876,217 (Mar. 3, 1959), E. F. Paschall (to Corn Products Co.).
41. U.S. Pat. 2,455,405 (Dec. 7, 1948), L. A. Burrows and M. F. Fuller (to E. I. du Pont de Nemours & Co., Inc.).
42. C. F. Koelsch, *J. Am. Chem. Soc.* **52**, 1105 (1930).
43. L. F. Hatch and H. E. Alexander, *J. Am. Chem. Soc.* **67**, 688 (1945).
44. Ger. Pat. 105,207 (Apr. 12, 1974), E. Fibitz and B. Nussbuecker.
45. N. Parris, J. K. Weil, and W. M. Linfield, *J. Am. Oil Chem. Soc.* **53**, 97 (1976).
46. A. J. Gait, in E. G. Hancock, ed., *Propylene and Its Industrial Derivatives*, John Wiley & Sons, Inc., New York, 1973, 274–279.
47. A. C. Fyvie, *Chem. Ind.*, 384–388 (Mar. 7, 1964).

48. U.S. Pat. 3,578,400 (May 11, 1971), J. A. Wojtowicz, M. Lapkin, and M. S. Puar (to Olin Corp.).
49. S. Goldschmidt, R. Endres, and R. Dirsch, *Ber.* **58**, 572 (1925).
50. U.S. Pat. 2,106,353 (Jan. 25, 1938), S. L. Langedijk (to Shell Development Co.).
51. U.S. Pat. 2,107,789 (Feb. 8, 1938), C. G. Harford (to Arthur D. Little, Inc.).
52. U.S. Pat. 4,008,133 (Feb. 15, 1977), A. P. Gelbein and J. T. Kwon (to The Lummus Co.).
53. U.S. Pat. 4,126,526 (Nov. 21, 1978), J. T. Kwon and A. P. Gelbein (to The Lummus Co.).
54. U.S. Pat. 4,342,703 (Aug. 3, 1982), J. T. Kwon (to The Lummus Co.).
55. U.S. Pat. 4,443,620 (Apr. 17, 1984), A. P. Gelbein and A. S. Nislick (to The Lummus Co.).
56. U.S. Pat. 4,496,777 (Jan. 29, 1985), G. D. Suciu, J. T. Kwon, and A. M. Shaban (to The Lummus Co.).
57. P. B. D. DeLaMare and J. G. Pritchard, *J. Chem. Soc.*, 3990 (1954).
58. J. Myszkowski and A. Z. Zidinski, *Przemysl Chem.* **44**, 249 (1965).
59. T. H. Rider and A. J. Hill, *J. Am. Chem. Soc.* **52**, 1521 (1930).
60. H. Gilman, ed., *Organic Syntheses*, Collective Vol. **I**, John Wiley & Sons, Inc., New York, 1941, p. 294.
61. C. S. Miner and N. N. Dalton, eds., *Glycerol*, Reinhold Publishing Corp., New York, 1953, p. 83.
62. U.S. Pat. 2,714,121 (May 25, 1951), J. Anderson, G. F. Johnson, and W. C. Smith (to Shell Development Co.).
63. Brit. Pat. 2,029,821 (Mar. 26, 1980), C. Civo, M. Petri, M. Lazzari, and A. Bigozzi (to Euteco SPA).
64. U.S. Pat. 4,900,849 (Sept. 9, 1988), D. I. Saletan (to Shell Oil Co.).
65. H. R. Ing, *J. Chem. Soc.* 1393 (1948).
66. Fr. Demande 2,565,229 (Dec. 6, 1985), N. Nagato, H. Mori, K. Maki, and R. Ishioka (to Showa Denko K.K.).
67. Jpn. Pat. 87 19,544 (Jan. 28, 1987), S. Takakuwa, T. Nakada, and K. Nagao (to Osaka Soda Co.).
68. Jpn. Pat. 88 290,835 (Nov. 28, 1988), N. Nagato, H. Mori, and R. Ishioka (to Showa Denko K.K.).
69. H. H. Szmant, *Organic Building Blocks of the Chemical Industry*, John Wiley & Sons, Inc., New York, 1989, p. 281.
70. *Chem. Mark. Rep.*, (Jan 8, 1990).
71. *Chem. Week*, (Sept. 4, 1989).
72. R. E. Lenga, ed., *The Sigma-Aldrich Library of Chemical Safety Data*, Sigma-Aldrich Corp., 1985.
73. N. H. Proctor, J. P. Hughes, and M. L. Fischman, *Chemical Hazards of the Workplace*, J. B. Lippincott Co., Philadelphia, Pa. 1988, p. 240.
74. N. I. Sax and R. J. Lewis, Sr., *Dangerous Properties of Industrial Materials*, Van Nostrand Reinhold, New York, 1989.
75. W. M. Grant, *Toxicology of the Eye*, Charles C Thomas, Springfield, Ill., 1974, p. 266.
76. *3-Chloropropane-1,2-diol*, Material Safety Data Sheet, Raschig Corp., 1989.
77. *3-Chloro-1,2-propanediol*, Material Safety Data Sheet, Dixie Chemical Co., 1986.
78. R. V. Andrews and R. W. Belknap, *J. Hyg.* **91**, 359 (1983).
79. *J. Commerce.*, 22B (Aug. 6, 1982).

W. FRANK RICHEY
The Dow Chemical Company

Related Articles

Allyl alcohol and derivatives; Chemicals in war