Method no.:	PV2083
Matrix:	Air
Target concentration:	10 ppm (57 mg/m³) (ACGIH TWA TLV)
Procedure:	Samples are collected by drawing a known volume of air through an XAD-2 tube. Samples are desorbed with 1 mL of carbon disulfide (CS_2) for one hour and analyzed by gas chromatography using a flame ionization detector (GC-FID).
Recommended air volume and sampling rate:	10 L at 0.2 L/min
Reliable quantitation limit:	0.54 ppm (3.095 mg/m^3)
Status of method:	Partially Evaluated Method. This method has been subjected to established evaluation procedures, and is presented for information and trial use.

Date: January, 1996

Chemist: Wayne Potter

Organic Service Branch I
OSHA Salt Lake Technical Center
Salt Lake City, UT 84165-0200

1. General Discussion

1.1 Background

1.1.1 History

The OSHA Technical Center has received several requests for sampling and analytical information for vinyl cyclohexene dioxide (VCD). The threshold limit value (TLV) for VCD is 10 ppm. The purpose of this study was to obtain data on retention, storage and desorption of VCD at the TLV level.

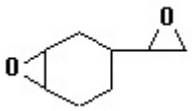
1.1.2 Toxic effects (This section is for information only and should not be taken as the basis of OSHA policy.) (Ref. 5.1)

Vinyl cyclohexene dioxide is irritating to the eyes and skin, and exposure can induce acute respiratory tract irritation and pulmonary congestion. VCD is a direct-acting mutagen and it induces tumors both local and distant from the site of application after topical treatment or after parenteral injection. The rat LC_{50} was 800 ppm. This atmosphere could not exist except in a state of supersaturation. Given the reported vapor pressure of 0.1 torr at 20°C the corresponding saturated vapor concentration was 132 ppm in air. Even at a temperature of 30°C a concentration of 800 ppm could not be reached. Hence, the risk of acute intoxication by inhalation of VCD is considered slight.

1.1.3 Workplace exposure (Ref. 5.1)

Vinyl cyclohexene dioxide has been used by the plastics industry since the 1950s in polymer formation and in other types of organic syntheses. The National Institute of Occupational Safety and Health (NIOSH) estimated that 6227 U.S. workers were exposed to VCD during 1981-1983.

1.1.4 Physical properties and other descriptive information (Ref. 5.1, 5.2)

Synonyms:	7-Oxabicyclo(4.1.0) heptane,3-(epoxyethyl)-; 1,2-Epoxy-4-(epoxyethyl) cyclohexane; 1-Epoxyethyl-3,4-epoxycyclohexane; Vinyl cyclohexene diepoxide; 1-Vinyl-3-cyclohexane dioxide; 4-Vinyl-1-cyclohexane diepoxide
CAS number:	106-87-6
IMIS:	2581
RTECS:	RN8640000
Molecular weight:	140.18
Flash point:	110°C (230 °F)(oc)
Boiling point:	227°C
Freezing point:	-55°C
Color:	clear, colorless liquid or pale yellow liquid
Specific gravity:	1.0986 at 20°C
Molecular formula:	$C_8H_{12}O_2$
Structural formula:	

The analyte air concentrations throughout this method are based on the recommended sampling and analytical parameters. Air concentrations listed in ppm are referenced to 25°C and 101.3 kPa (760 mmHg).

1.2 Limit defining parameters

1.2.1 Detection limit of the overall procedure (DLOP)

The detection limit of the overall procedure is 9.28 µg per sample (0.162 ppm or 0.928 mg/m³). This is the amount of analyte spiked on the sampler that will give a response that is significantly different from the background response of a sampler blank.

The DLOP is defined as the concentration of analyte that gives a response (Y_{DLOP}) that is significantly different (three standard deviations (SD_{BR})) from the background response (Y_{BR}).

$$Y_{DLOP} - Y_{BR} = 3(SD_{BR})$$

The direct measurement of Y_{BR} and SD_{BR} in chromatographic methods is typically inconvenient, and difficult because Y_{BR} is usually extremely low. Estimates of these parameters can be made with data obtained from the analysis of a series of samples whose responses are in the vicinity of the background response. The regression curve obtained for a plot of instrument response versus concentration of analyte will usually be linear. Assuming SD_{BR} and the precision of data about the curve are similar, the standard error of estimate (SEE) for the regression curve can be substituted for SD_{BR} in the above equation. The following calculations derive a formula for the DLOP:

$$SEE = \sqrt{\frac{\sum (Y_{obs} - Y_{est})^2}{n - k}}$$

Y_{obs} = observed response
Y_{est} = estimated response from regression curve
n = total no. of data points
k = 2 for a linear regression curve

At point Y_{DLOP} on the regression curve

$$Y_{DLOP} = A(DLOP) + Y_{BR}$$

A = analytical sensitivity (slope)

therefore

$$DLOP = \frac{(Y_{DLOP} - Y_{BR})}{A}$$

Substituting 3(SEE) + Y_{BR} for Y_{DLOP} gives

$$DLOP = \frac{3(SEE)}{A}$$

The DLOP is measured as mass per sample and expressed as equivalent air concentrations, based on the recommended sampling parameters. Ten samplers were spiked with equal descending increments of analyte, such that the lowest sampler loading was 22.80 µg/sample. This is the amount, when spiked on a sampler, that would produce a peak approximately 10 times the background response for the sample blank. These spiked samplers, and the sample blank were analyzed with the recommended analytical parameters, and the data obtained used to calculate the required parameters (A and SEE) for the calculation of the DLOP. Values of 9.44 and 29.214 were obtained for A and SEE respectively. DLOP was calculated to be 9.28 µg/sample (0.162 ppm or 0.928 mg/m^3).

Table 1.2.1
Detection Limit of the Overall Procedure

mass per sample (µg)	area counts (µV-s)
0	0
22.8	211
28.5	241
34.2	264
39.9	383
45.6	446
51.3	459
57.0	504
62.7	622
68.4	625
74.1	658

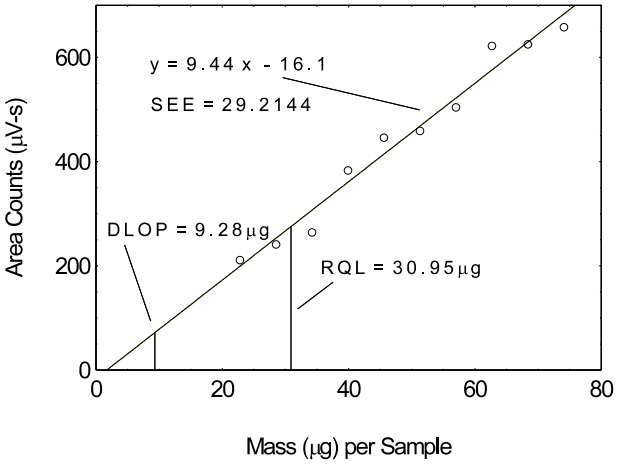


Figure 1.2.1. Plot of data to determine the DLOP/RQL

1.2.2 Reliable quantitation limit (RQL)

The reliable quantitation limit is 30.95 µg per sample (0.54 ppm or 3.095 mg/m^3). This is the amount of analyte spiked on a sampler that will give a signal that is considered the lower limit for precise quantitative measurements.

The RQL is considered the lower limit for precise quantitative measurements. It is determined from the regression line data obtained for the calculation of the DLOP (Section 1.2.1), providing at least 75% of the analyte is recovered. The RQL is defined as the concentration of analyte that gives a response (Y_{RQL}) such that

$$Y_{RQL} - Y_{BR} = 10(SD_{BR})$$

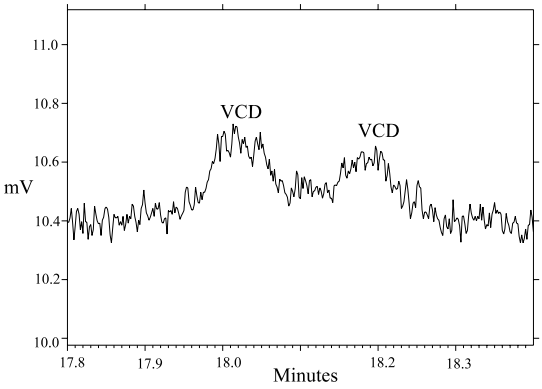


Figure 1.2.3. Chromatogram of the RQL.

therefore

$$RQL = \frac{10(SEE)}{A}$$

RQL= 30.95µg per sample (0.54 ppm or 3.095 mg/m^3)

2. Sampling Procedure

2.1 Apparatus

2.1.1 Samples are collected using a personal sampling pump calibrated, with the sampling device attached, to within ±5% of the recommended flow rate.

2.1.2 Samples are collected with tubes 7 cm × 4 mm i.d. × 6 mm o.d. glass sampling tubes packed with two sections of XAD-2. The front section contains 80 mg and the back section contains 40 mg of XAD-2. The sections are held in place with glass wool plugs and are separated by a glass wool plug. For this evaluation, commercially prepared sampling tubes were purchased from SKC Inc., (Eighty Four, PA) catalog No. 226-30, Lot 879.

2.2 Technique

2.2.1 Immediately before sampling, break off the ends of the sampling tube. All tubes should be from the same lot.

2.2.2 Attach the sampling tube to the pump with flexible tubing. It is desirable to utilize sampling tube holders which have a protective cover to shield the employee from the sharp, jagged end of the sampling tube. Position the tube so that sampled air passes through the front section of the tube first.

2.2.3 Air being sampled should not pass through any hose or tubing before entering the sampling tube.

2.2.4 Attach the sampling tube vertically with the front section pointing downward, in the worker's breathing zone, and positioned so it does not impede work performance or safety.

2.2.5 After sampling for the appropriate time, remove the sample and seal the tube with plastic end caps. Wrap each sample end-to-end with a Form OSHA-21 seal.

2.2.6 Submit at least one blank sample with each set of samples. Handle the blank sample in the same manner as the other samples except draw no air through it.

2.2.7 Record sample volumes (in liters of air) for each sample, along with any potential interferences.

2.2.8 Ship any bulk samples separate from the air samples.

2.2.9 Submit the samples to the laboratory for analysis as soon as possible after sampling. If delay is unavoidable, store the samples in a refrigerator.

2.3 Desorption efficiency

The desorption efficiencies of VCD were determined by liquid-spiking the XAD-2 tubes with the analyte at 0.1 to 2 times the target concentration. The loadings on the tubes were 57, 285 ,570 and 1140 µg of VCD. These samples were stored overnight at ambient temperature and then desorbed with 1 mL of CS_2 with 0.25 µL/mL *p*-cymene internal standard, and analyzed by GC-FID. The average desorption efficiency over the studied range was 97.0%.

Table 2.3
Desorption Efficiency of VCD

	% Recovered			
Tube #	0.1 × 57µg	0.5 × 285µg	1.0 × 570µg	2.0 × 1140µg
1	91.5	98.2	97.8	96.9
2	90.9	99.7	96.5	96.4
3	93.1	99.4	98.4	97.3
4	93.5	100.2	99.5	97.5
5	96.6	99.3	100.5	96.0
6	90.7	100.1	101.0	96.9
average	92.7	99.5	99.0	96.8
overall average	97.0			
standard deviation	±2.98			

2.4 Retention efficiency

The glass wool in front of the front section of the XAD-2 tube was pulled towards the end, so that none of it was in contact with the XAD-2. The glass wool was spiked with 1140 µg VCD, and the XAD-2 tube had 10 L humid air (80% RH at 25°C) pulled through it at 0.2 L/min. The glass wool was spiked to determine if VCD would volatize off the glass wool and collect onto the XAD-2. They were opened, desorbed, and analyzed by GC-FID. The retention efficiency averaged 97.7%. The values in Table 2.4 were not corrected for desorption efficiency. There was no VCD found on the glass wool indicating that all of it vaporized off. There was no VCD on the back sections of the tubes, indicating that no breakthrough occurred.

Table 2.4
Retention Efficiency of VCD

Tube #	% Recovered			
	Glass wool	Front section	Back section	Total
1	0.0	96.9	0	96.9
2	0.0	97.1	0	97.1
3	0.0	95.8	0	95.8
4	0.0	98.6	0	98.6
5	0.0	99.9	0	99.9
6	0.0	98.1	0	98.1
			average	97.7

2.5 Sample storage

The front sections of twelve sampling tubes were each spiked with 1140 µg (19.9 ppm) of VCD, and had 10 liters of dry air drawn through them. Six of the tubes were stored in the refrigerator (-10°C), and six were stored at room temperature (25°C). Twelve more tubes were spiked with 1140 µg of VCD, and had 10 liters of humid air (80% RH at 25°C) drawn through them. Six tubes were stored in the refrigerator (-10°C), and six were stored at room temperature (25°C). Three of each type of samples were analyzed after 7 days and the remaining three samples of each type after 14 days. The amounts recovered indicate that humidity and temperature had no affect on the ability of XAD-2 to retain VCD over the 14 days studied. The results are not corrected for desorption efficiency.

Table 2.5
Storage Test for VCD

Time (days)	%Recovery Humid Ambient	%Recovery Humid Refrigerated	%Recovery Dry Ambient	%Recovery Dry Refrigerated
7	99.8	97.8	98.2	100.6
7	101.0	100.1	99.9	98.0
7	100.1	102.9	99.3	98.9
average	100.3	100.3	99.1	99.2
14	101.8	99.3	100.8	101.3
14	100.9	97.0	99.8	95.0
14	97.4	98.7	100.3	100.2
average	100.0	98.3	100.3	98.8

2.6 Recommended air volume and sampling rate.

Based on the data collected in this evaluation, 10 L air samples should be collected at a sampling rate of 0.2 L/min.

2.7 Interferences (sampling)

2.7.1 It is not known if any compounds will severely interfere with the collection of VCD on the sampling tubes. In general, the presence of other contaminant vapors in the air will reduce the capacity of the XAD-2 tube to collect VCD.

2.7.2 Suspected interferences should be reported to the laboratory with submitted samples.

2.8 Safety precautions (sampling)

2.8.1 Attach the sampling equipment to the worker in such a manner that it will not interfere with work performance or safety.

2.8.2 Follow all safety practices that apply to the work area being sampled.

2.8.3 Wear eye protection when breaking the ends of the glass sampling tubes.

3. Analytical Procedure

3.1 Apparatus

3.1.1 The instrument used in this study was a gas chromatograph equipped with a flame ionization detector, specifically a Hewlett Packard model 5890.

3.1.2 A GC column capable of separating the analyte from any interferences. The column used in this study was a 60 meter capillary column with a 1.5 µm coating of Rtx-Volatiles, with an I.D. of 0.32 mm.

3.1.3 An electronic integrator or some suitable method of measuring peak areas.

3.1.4 Two milliliter vials with Teflon™-lined caps.

3.1.5 A 10 µL syringe or other convenient size for sample injection.

3.1.6 Pipets for dispensing the desorbing solution. A Repipet® dispenser was used in this study.

3.1.7 Volumetric flasks - 5 or 10 mL and other convenient sizes for preparing standards.

3.2 Reagents

3.2.1 GC grade nitrogen, hydrogen, and air.

3.2.2 Vinyl cyclohexene dioxide (VCD), Reagent grade

3.2.3 Carbon disulfide (CS_2), Reagent grade

3.2.4 *p*-Cymene (internal standard), Reagent grade

3.2.5 Desorbing solution was carbon disulfide with 0.25 µL/mL *p*-cymene internal standard.

3.3 Standard preparation

3.3.1 At least two separate stock standards are prepared by diluting a known quantity of VCD with the desorbing solution of carbon disulfide with 0.25 µL/mL *p*-cymene internal standard. The concentration of these stock standards was 0.5 µL/mL or 549.3 µg/mL.

3.3.2 A third standard at a higher concentration was prepared to check the linearity of the calibration. For this study, two analytical standards were prepared at a concentration of 0.5 µL/mL (549.3 µg/mL), and one at 2.0 µL/mL (2197.2 µg/mL) VCD in the desorbing solution.

3.4 Sample preparation

3.4.1 Sample tubes are opened and the front and back section of each tube are placed in separate 2 mL vials.

3.4.2 Each section is desorbed with 1 mL of the desorbing solution of carbon disulfide with 0.25 µL/mL *p*- cymene internal standard.

3.4.3 The vials are sealed immediately and allowed to desorb for 60 minutes with occasional shaking.

3.5 Analysis

3.5.1 Gas chromatograph conditions.

Chromatogram:	
Injection size:	1 µL
<u>Flow rates (mL/min)</u>	
Nitrogen (make-up):	30
Hydrogen(carrier):	2
Hydrogen(detector):	40
Air:	420
<u>Temperatures (°C)</u>	
Injector:	200
Detector:	220
Column:	150°C for 5 min then 10°C/min to 200°C for 10 min

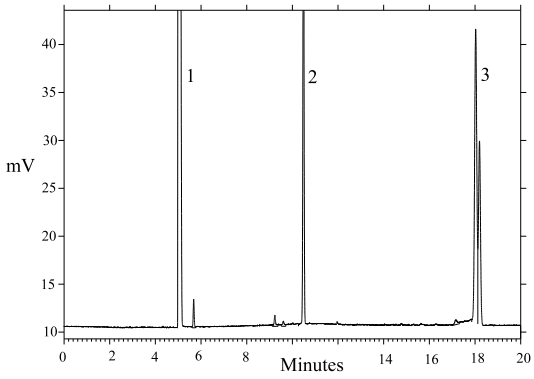


Figure 3.5.1 Chromatogram of an analytical standard at the target concentration. Peak identification: (1) carbon disulfide, (2) *p*-cymene, (3) VCD isomers.

3.5.2 Peak areas are measured by an integrator or other suitable means.

3.6 Interferences (analytical)

3.6.1 Any compound that produces a response and has a similar retention time as the analyte is a potential interference. If any potential interferences were reported, they should be considered before samples are desorbed. Generally, chromatographic conditions can be altered to separate an interference from the analyte.

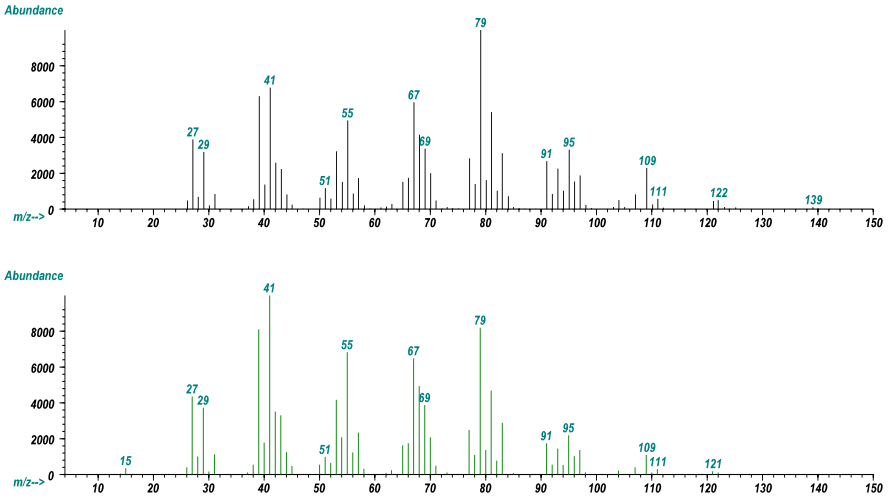


Figure 3.6.1. Mass spectra of the isomers of VCD.

3.6.2 When necessary, the identity or purity of an analyte peak may be confirmed by GC-mass spectrometer or by another analytical procedure.

3.7 Calculations

3.7.1 The instrument was calibrated with a standard of 570 µg/mL VCD in the desorbing solution. The linearity of the calibration was checked with a standard of 2160 µg/mL.

3.7.2 If the calibration is non-linear, two or more standard at different concentrations must be analyzed, bracketing the samples, so a calibration curve can be plotted and sample values obtained.

3.7.3 To calculate the concentration of analyte in the air sample the following formulas are used:

$$\text{mass of analyte in sample} = \frac{(\text{mg/mL})(\text{desorption volume})}{\text{desorption efficiency}}$$

$$\text{number of moles of analyte} = \frac{\text{mass of analyte in sample}}{\text{molecular weigth}}$$

Volume the analyte will occupy at 25 °C and 760 mmHg is number of moles of analyte times the molar volume at 25 °C and 760 mmHg.

$$\text{ppm} = \frac{(\text{volume analyte occupies})(10^6)}{\text{air volume}}$$

3.7.4 The above equations can be consolidated to the following formula.

$$\text{ppm} = \frac{(\text{mg/mL})(\text{DV})(24.46)(10^6)(\text{g})(\text{mg})}{(10\ \text{L})(\text{DE})(\text{MW})(1000\ \text{mg})(1000\ \text{mg})}$$

µg/mL = concentration of analyte in sample or standard

24.46 = molar volume (liters/mole) at 25 °C and 760 mmHg
MW = molecular weight (g/mole)
DV = desorption volume
10 L = 10 liter air sample
DE = desorption efficiency
* All units must cancel.

3.7.5 This calculation is done for each section of the sampling tube and the results added together.

3.8 Safety precautions (analytical)

3.8.1 Avoid skin contact and inhalation of all chemicals.

3.8.2 Wear safety glasses, gloves and a lab coat at all times while in the laboratory areas.

4. Recommendations for Further Study

Collection studies need to be performed from a dynamically generated test atmosphere.

5. References

5.1 “Documentation of the Threshold Limit Values and Biological Exposure Indices”, Fifth Edition, American Conference of Governmental Industrial Hygienists Inc., Cincinnati, OH, 1986, pp. 1708-1710.

5.2 Sweet, D.V., “Registry of Toxic Effects of Chemical Substances”, 1987, Vol. 3, U.S.D.H.E.W., Index Number RN8640000, p. 3058.