OWLSTONE NANOTECH INC

The Complete Guide to Testing Chemical Sensors

Owlstone Whitepaper

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Permeation tubes enable the generation of NIST traceable, precise and repeatable calibration gas standards, over long periods of time, with concentrations ranging from part per trillion to high part per million. Permeation tubes are inherently safe compared to gas cylinders as they operate at low pressures and contain a small quantity of chemical. With over 500 analytes available you can generate standards even for applications that are problematic with cylinders, for example, corrosive gases and explosive / chemical warfare simulants.

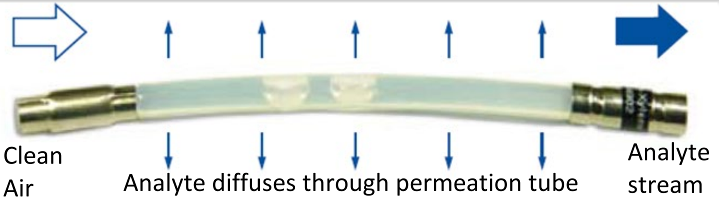
Contents

Permeation Tube Fundamentals

What is a Permeation Tube?

A permeation tube is a polymer tube, typically PTFE, that contains a solid, liquid or gas analyte, sealed and crimped at both ends. The calibration chemical permeates through the walls of the tube at a constant rate for a given temperature; it then mixes with, and is carried away by, a diluent, or make-up flow.

Individual permeation tubes are filled with the analyte to calibrate and test instruments, gas analysers and sensors e.g. FTIR, GC etc



The permeation tube is placed in the OVG-4, which generates a traceable gas standard for testing and calibration

That's it. You are now ready to test your sensors instruments against traceable, precise and repeatable gas standards

What Advantages do Permeation Tubes Provide over Gas Cylinders?

- ✓ All the Calibration Gases you need – with over 500 permeation tubes available you can create calibration gas standards for almost anything. Gas cylinders aren't suitable at all for some compounds e.g. explosive standards. They have problems with others; corrosive compounds tend to react with the internal sidewalls causing unknown changes in concentration over time.
- ✓ NIST Traceability – tubes are gravimetrically calibrated and are therefore traceable to primary standards. You'll have confidence that you are generating the concentration of calibration gas you need.
- ✓ Safety – permeation tubes contain a tiny quantity of chemical and operate at low pressure. Your Health and Safety manager will be happy that you won't need to buy high pressure gas cylinders with high concentrations of dangerous gases to blend down to lower, useable concentrations.
- ✓ Lifetime and Stability – a tube can last up to several years in continuous operation; giving precise, stable and repeatable concentrations the whole time.

Using the OVG-4 to Generate Calibration Gases with Permeation Tubes

To generate a calibration gas with a permeation tube you need to incubate the tube at a very stable and accurate temperature. A flow is then passed over the tube to generate the sample calibration gas. Owlstone has developed the OVG-4 Calibration Gas Generator to meet all your permeation tube calibration gas requirements.

BENEFITS

- High number of available analyte compounds, including solids and liquids as well as gases
- Easy generation of multi-component mixtures using combinations of tubes
- Cost savings by elimination of multiple expensive gas cylinders
- Reduced risk of exposure to dangerous chemicals due to small quantities used
- Fast and easy sample replacement
- Elimination of hazards associated with high pressure cylinders
- Quick and easy to set up and generate blended gas mixtures
- Adjustable concentration levels from ppm to ppb
- High accuracy and precision, even at the lowest concentrations
- Superior long term stability and repeatability*
- Portable, with compact footprint
- Easily integrated with the Owlstone Humidity Generator (OHG) for realistic environmental testing

**Owlstone offers an optional service for regular validation and instrument calibration*

The Owlstone OVG-4 is a system for generating trace concentration levels of chemicals and calibration gas standards. It is easy to use, cost-effective and compact and produces a very pure, accurate and repeatable output.

The very precise control of concentration levels is achieved using permeation tube technology, eliminating the need for multiple gas cylinders and thus reducing costs, saving space and removing a safety hazard. Complex gas mixtures can be accurately generated through the use of multiple tubes.

The OVG-4 is an ideal tool for numerous applications, ranging from calibration of explosive detectors in military and homeland defense to validation of personal monitors in industrial health and safety.

Current customers include – SELEX GALILEO, US Army, US Air Force, US Defense Threat Reduction Agency, Home Office Scientific Development Branch, DSTL, Commissariat à l'Énergie Atomique.

Adding Precision Humidity with the Owlstone OHG-4 Humidity Generator

The OVG-4 can be integrated with the OHG-4 Humidity Generator to create realistic test atmospheres to meet all your calibration and environmental testing requirements.

Calculating Concentration from Permeation Rate and Gas Flow Rate

The relationship between permeation rate of a tube and concentration is given by the following equation

$$q_d = \frac{CQ}{(\frac{22.4}{M})}$$ where

- q_d is the permeation rate (ng/min)
- C is concentration (ppm)
- Q is flow rate (mL/min)
- M is molecular weight (g/mol)

For example to generate a 1ppm concentration of DMMP (Sarin Gas Warfare Simulant) at a sample flow rate of 50mL/min would require a permeation rate of

$$q_d = \frac{(1)(50)}{(\frac{22.4}{124.08})} = 277ng/min$$

Fundamental Diffusion Equations and Calculation of Tube Permeation Rate

The permeation of gas through polymeric materials is a diffusion process due to concentration gradient between the inner and outer tube surfaces. Diffusion is defined by Fick's law; the diffusive flux goes from regions of high concentration to regions of low concentration, with a magnitude that is proportional to the concentration gradient.

$$(1)\ J = -D\nabla\emptyset = -D\frac{\delta\emptyset}{\delta x}$$

For a permeation tube Fick's law is expressed as

$$(2)\ q_d = \frac{DSA\,(P_1 - P_2)}{\mathrm{L}} = \frac{P_G A(P_1 - P_2)}{\mathrm{L}}$$ where

- q_d is the amount diffusing through polymer per unit area per unit time
- D is diffusion constant
- S is the solubility constant of the gas in the polymer
- A is the polymer area
- $P_{1,2}$ are the pressures on each side of the tube
- L is the tube thickness

- P_G is the gas permeability constant

Once equilibrated and assuming tubular geometry and negligible external pressure P_2 equation 2 reduces to

(3) $q_d = \frac{97 P_G M P_1}{\log\left(\frac{d_2}{d_1}\right)}$ where

- q_d is the permeation rate (mg/cm tube length)
- P_G is permeation constant (cm^2/sec)
- d_2 is outside diameter (mm)
- d_1 is inside diameter (mm)
- P_1 is the pressure (kPa)

The permeation constant is a function of the temperature, gas characteristics and tube properties

(4) $P_G = P_G^o e^{-E_p/RT}$ where

- P_G^o is a constant
- Ep is permeation tube activation energy
- R is molar gas constant
- T is absolute temperature

The only variable that changes in operation is the temperature. However it is usually the case that the various constants are not known a priori, which makes it difficult to calculate a desired permeation rate before building and calibrating a tube.

Permeation Rate as a Function of Temperature

The dependence of permeation rate as a function of temperature is derived from equation 4 and is given by

(5) $\ln\left(\frac{q_{d2}}{q_{d1}}\right) = \left(\frac{E_p}{R}\right)\left(\frac{1}{T_1} - \frac{1}{T_2}\right)$ where

- $q_{d1,2}$ are the permeation rates at the two temperatures (mg/cm)
- $T_{1,2}$ are the temperatures (^oK)
- E_P is the activation energy
- R is the molar gas constant (1.99 cal/g-mol-^oK)

If the permeation rate at one temperature is determined through calibration we can calculate the permeation rate at the new temperature with the empirical relationship derived from equation 5

(6) $\ln q_{d1} = \ln q_{d2} - 6794\left(\frac{1}{T_1} - \frac{1}{T_2}\right)$

This equation is typically accurate to +/- 5% for a 10^oC change in temperature.

For every 1°C change in temperature the permeation rate will change by 10%. The OVG-4 Calibration Gas Generator has precision control of the incubation oven to 0.1°C to give an accuracy of 1% on permeation rate.

Worked Example of Changing Permeation Rate with Temperature

Permeation rate 200ng/min at 25°C or 298°K. New Temperature 40°C or 313°K

$$\ln q_{d1} = \ln 200 - 6794\left(\frac{1}{313} - \frac{1}{298}\right)$$
$$\ln q_{d1} = 6.39$$
$$q_{d1} = 596\, ng/min$$

Calculating the Lifetime of a Permeation Tube

The permeation tube lifetime of a standard tube with wall thickness of 0.062 and 0.125in is given by

$$L_s = \frac{1465\rho}{q_d}$$ where

- L_s is service lifetime (months)
- p is density (g/mL)
- q_d is permeation rate (ng/min/cm)

When permeation tubes are not in use store them in a refrigerator to significantly increase the lifetime of the tubes.

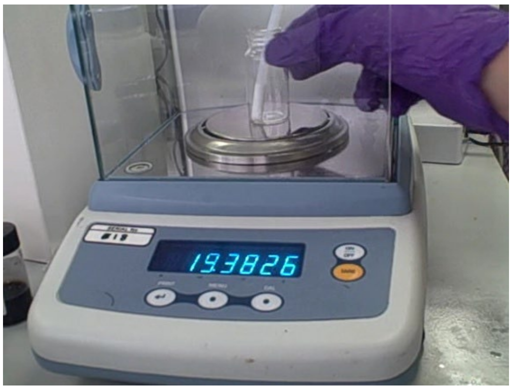
Worked Example Lifetime of Acetaldehyde Permeation Tube

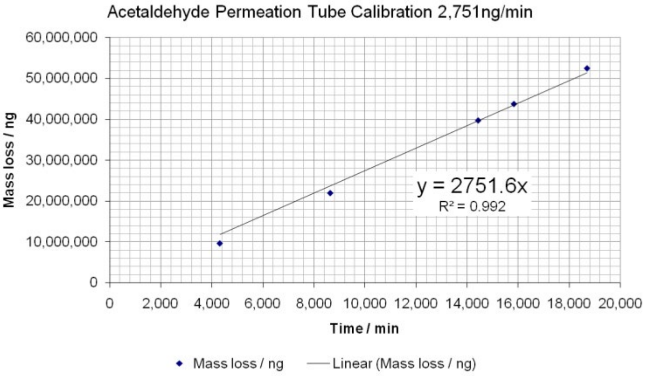
For example an acetaldehyde tube with a permeation rate of 45ng/min/cm and density 0.861g/mL has a service life of

$$L_s = \frac{1465(0.861)}{45} = 28\, months$$

Calibration of Permeation Tubes

Permeation tubes are typically calibrated gravimetrically i.e. the mass loss in ng/min is directly measured over time using a mass balance. The calibrated permeation rates are certified and NIST traceable. The time it takes to perform a calibration depends on the permeation rate; with high permeation rates e.g. 1,000’s ng/min there will be significant mass loss over a period of a few weeks to make an accurate calibration. For lower permeation rates e.g. 10’s ng/min it can take several months to see enough measurable mass loss to make an accurate determination of permeation rate. Alternate calibration methods such as GC/MS can be used to shorten this time period at the expense of additional complexity.





Alternatives to Permeation Tubes: Gas Cylinders

The most widely-used method of producing calibration gases for testing chemical sensors is to draw the component gases straight from gas cylinders. By attaching a flow meter to each cylinder, the amount of each gas entering the mixture can be measured, and the resulting concentration determined. Concentrations of 50% down to 0.01% can routinely be created.

Calculation of Concentration Using Gas Cylinders

It is a straightforward task to calculate the concentrations in a gas mixture produced using gas cylinders. If the flow meters attached to cylinders 1 and 2 measure flow rates of Q_1 and Q_2 respectively, then the concentration, C_1, of gas 1 in the mixture is

$$(7)\ C_1 = \frac{Q_1}{Q_1+Q_2}$$

and likewise, the concentration, C_2, of gas 2 in the mixture is

$$(8)\ C_2 = \frac{Q_2}{Q_1+Q_2}$$

Alternatives to Permeation Tubes: Injection Methods

Concentrations from a few percent down to parts per million may be created using injection methods, where a syringe or similar device slowly injects gas into a diluent flow. Motor-driven systems are available to control the speed of injection, but may be quite expensive. Also, if a liquid is being used as the source of the vapour, then it needs to be vaporized separately before being injected.

Calculation of Concentration Using Injection Methods

In order to calculate the concentration of a gas introduced into a mixture using injection methods, we need to know two things: the cross-sectional area, A, of the syringe and the velocity of advance, v_p, of the plunger. The flow rate, Q_I, from the syringe is then

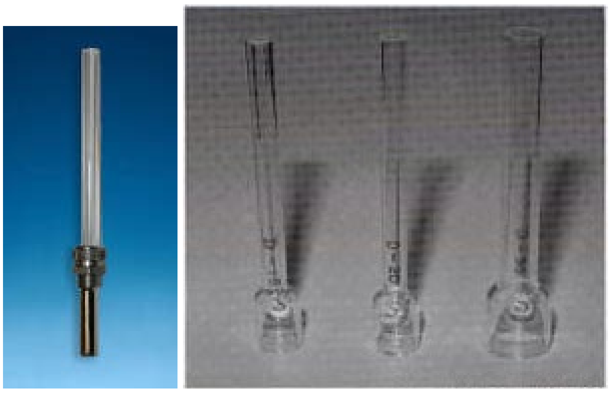
$$(9)\ Q_I = Av_p$$

and the concentration is

$$(10)\qquad C = \frac{Q_I}{Q_I + Q_F} = \frac{1}{1+\frac{Q_F}{Av_p}}$$

Alternatives to Permeation Tubes: Diffusion Methods

The familiar phenomenon of diffusion can be used to easily create concentrations in the low parts per million to parts per billion range. A reservoir of liquid is placed into a tube, and assuming the vapour pressure is sufficiently high, gas evaporating from the liquid will begin to diffuse along the tube. By maintaining a flow of diluent gas across the mouth of the tube, we can produce a gas mixture. The rate of diffusion will be governed by the tube geometry, temperature and concentration gradient, and so adjusting any of these parameters, or the flow rate of the diluent gas, will change the overall concentration. As is the case with permeation tubes, diffusion tubes are highly affected by fluctuations in temperature, with a change of 1°C capable of producing 5-10% changes in the diffusion rate.



Calculation of Concentration Using Diffusion Methods

As with injection methods, to calculate the flow rate introduced into a gas mixture using diffusion methods, we need to know the cross-sectional area, A, of the diffusion tube and the velocity, v_D, at which gas diffuses up the tube. The flow rate, Q_D, from the tube is

$$Q_D = Av_D \tag{11}$$

The velocity in turn depends on the concentration gradient, G, and the type of gas in the tube, represented by the diffusion coefficient, D. If the partial pressure of the diffusing gas is p_g, the pressure in the system is P and the length of the tube is L, then

$$G = \frac{ln\left(\frac{P}{P-p_g}\right)}{L} \tag{12}$$

The diffusion coefficient has units of area per unit time, and depends on temperature and pressure. Values for particular gases at standard temperature and pressure may be found in the literature, and values for other temperatures and pressures can be calculated using

$$D = D_{STP}\left(\frac{T}{T_{STP}}\right)^n\left(\frac{P_{STP}}{P}\right) \quad \text{where} \tag{13}$$

- n is the number of moles (usually taken to be 2).

The velocity of advance up the tube is given by the product of the concentration gradient and the diffusion coefficient

$$v_D = GD = \frac{D\,ln\left(\frac{P}{P-p_g}\right)}{L} \tag{14}$$

and the flow rate is

$$Q_D = Av_D = \frac{AD\,ln\left(\frac{P}{P-p_g}\right)}{L} \tag{15}$$

Assuming that $Q_D \ll Q_F$, then the concentration is

$$(16) \qquad C = \frac{Q_D}{Q_F} = \frac{AD\, ln\left(\frac{P}{P-p_g}\right)}{LQ_F}$$

Alternatives to Permeation Tubes: Evaporation Methods

Evaporation methods involve passing the diluent gas stream directly through the liquid form of the gas of interest. As the diluent gas bubbles through the liquid, some of the liquid evaporates and joins the gas flow, producing a gas mixture. This is a very useful way to add a single volatile liquid to a gas stream, but has the significant disadvantage that the concentration produced is highly variable, even if the setup remains constant. This means that the concentration needs to be determined by an independent analytical technique before the mixture can be used to test chemical sensors.

Estimation of Concentration Using Evaporation Methods

We can estimate the concentration of the mixture produced using evaporation methods by measuring the mass loss of the evaporation vessel, Δm, over a time t. If we know the molecular mass, M, of the evaporating gas, then we can calculate the number of moles per second being lost, as

$$(17) \qquad \Delta n = \frac{\Delta m}{Mt} \qquad \text{where}$$

- Δm is measured in grams and
- M is measured in atomic mass units.

We can then use the ideal gas law to determine the volume per second of the evaporating gas i.e. the flow rate Q_E.

$$(18) \qquad Q_E = \frac{\Delta nRT}{P} = \frac{\Delta mRT}{MtP} \qquad \text{where}$$

- R is the gas constant
- T is the system temperature and

- P is the pressure.

Comparative Accuracy

Li, Täffner, Bischoff and Niemeyer (International Journal of Chemical Engineering 2012) give the following comparison of the accuracies of four of these techniques.

Technique	Accuracy	Remarks
Injection	5–9%	i) The accuracy strongly depends on the accuracy of the injection devices. (ii) When multicomponents test gas is generated, the accuracy is not as precise as for pure components.
Permeation	2–5%	(i) The main source of the uncertainty comes from the permeation rate, which is influenced by thermodynamic and physical state variables, such as temperature, pressure and gas flow. (ii) Permeation methods can be used to generate very low concentrations (ppb level), the uncertainty of the calibration itself also has a strong influence on the overall accuracy.
Diffusion	3–5%	(i) The most important uncertainty is the diffusion rate. The variation of it is related to the compound itself, the design of the diffusion device, and thermodynamic state variables. (ii) In analogy to the permeation method, the calibration itself contributes to the overall uncertainty.
Evaporation	5–15%	(i) The marked deviation results from the dilution system and temperature variation. (ii) The vapour pressure of the compound is also one considerable factor. The error can be minimized for compounds with a low vapour pressure.

OVG-4 Calibration Gas Generator Frequently Asked Questions

What is the OVG-4 Calibration Gas Generator? The OVG-4 is an instrument that can generate accurate, precise and repeatable calibration gases for applications ranging from sensor / instrument test and calibration to generation of test atmospheres in corrosion chambers.

What is a permeation tube? A permeation tube is a small PTFE tube filled with the calibration analyte. When precisely heated the analyte diffuses through the tube at a controlled rate to generate an accurate calibration gas.

Does the OVG-4 generate traceable calibration gases? Yes. The permeation tubes are gravimetrically calibrated to NIST/UKAS traceable primary standards. Each tube comes with its own calibration certificate.

What and how many calibration gases can the OVG-4 generate? Generating new calibration gas standards is as easy as inserting a permeation tube into the OVG-4. You can view a full list of permeation sources and request pricing and availability. You can also watch a video of the OVG-4 in operation and see how easy it is to generate new calibration gas standards.

Can the OVG-4 provide mixtures of multiple calibration gases simultaneously? You can put multiple tubes into one oven to generate a gas mixture. If you want to control individual concentrations you can attach the outputs of multiple OVG units together to generate arbitrary calibration gas mixtures.

How do I calculate the calibration gas concentration generated by the OVG-4? Each permeation tube comes with a calibration certificate; these values are entered into the Owlstone OVG-4 concentration calculator software along with the instrument settings to obtain the concentration of gas. You can launch the Calibration Gas Calculator to see how you can easily change the calibration gas concentrations by adjusting temperature and flow on the OVG-4.

What are the lowest and highest calibration gas concentrations I can generate with the OVG-4? This depends on the permeation rate of the tube, the flow and the temperature. The OVG-4 can typically generate calibration gas concentrations from tens of part per trillion (ppt) levels up to tens of part per million (ppm). You can launch the Calibration Gas Calculator to see how to increase and decrease concentrations.

What sample flow rates are attainable with the OVG-4? The sample flow from the OVG-4 is controlled by a mass flow controller and can be adjusted from 50mL/min up to 3L/min. This can be further diluted with an arbitrary makeup flow to generate any total flow required for your application.

Can I further dilute the output of OVG-4 with a make-up flow? Yes, the output of the OVG can be blended with a make-up flow. The Owlstone OFC Flow Controller allows you to blend additional flows and the OHG Humidity Generator allows you to blend with humidified air for complete environmental testing.

Can I change the calibration concentration but keep the total flow the same? Yes. Owlstone has developed a unique split flow capability that allows you to change concentration while keeping total flow the same. This is very useful if you are testing / calibrating flow sensitive sensors or instruments.

How accurate and repeatable is the calibration gas generated by the OVG-4? You can achieve target calibration gas concentrations with a +/-5% error. The unit is extremely stable and repeatable over time; the sample flow is controlled with a mass flow controller and a large thermal mass incubation oven is adjusted to temperatures with an accuracy of +/- 0.1^{o}C.

Can I control the OVG-4 through software? Yes, the temperature and flow can be controlled through software provided with the OVG-4. In addition there is an RS-485 port that allows you to integrate the OVG-4 into your custom test set-up (e.g. Labview) for fully automated control and integration.

Is the OVG-4 system modular? Can I add more units later? The system is fully modular, the OVG-4, OHG Humidity Generator and OFC Flow controller can easily be added or removed from the 19" GENSYS rack. You can get a single OVG-4 and the other two slots are blanked off. If you want to extend your calibration gas capability down the line additional units can easily be added to the empty slot.

What else do I need before I can use the OVG-4 Calibration Gas Generator? You can download the the pre-installation guide to see what else you need to get started.

Do I need to heat the transfer line from the OVG-4 to the sensor / instrument under test? For low volatility compounds we would recommend using a simple wrap heater on the transfer line to avoid analyte condensation and memory effects.

How much training is required to use the OVG-4 Calibration Gas Generator? In short the OVG-4 is very straightforward to set-up and use. You can download a copy of the user guide to see for yourself.

What warranty is offered on the unit? One year limited warranty. We also offer extended warranty options. You can download our terms and conditions.

What servicing is required and when? We recommend that the mass flow controllers are recalibrated once a year.

Is the OVG-4 CE certified? Yes, the instrument is fully CE marked and certified to ISTA 3A.

Where can I view the full OVG-4 technical specification? You can view an html version and download a pdf version. You might also want to take a look at the user guide.

Appendix A: List of Permeation Sources

List of Permeation Tubes

1 - Propanol
1, 1, 3 -Trimethoxypropane
1, 2 - Propyleneimine
1, 2 , 4 -Trichlorobenzene
1, 2 ,3-Trimethylbenzene
1, 2, 4 -Trimethylbenzene
1,1,1 tetrafluoroethane
1,1,1-Chlorodifluoroethane
1,1,1-Dichlorofluoroethane
1,1,2,2-Tetrachloroethane
1,1,2-Trichloroethane
1,1,3,3-Tetramethyldisiloxane
1,1-Dichloroethane
1,1-Dimethylhydrazine
1,2 - Propanediol
1,2 Epoxybutane
1,2,3-Trichloropropane
1,2-Butadiene
1,2-Dichlorobenzene
1,2-Dichloroethane
1,2-Dichloropropane
1,2-Diethybenzene
1,2-Difluorobenzene
1,2-Dimethoxyethane
1,2-Dimethylnaphthalene
1,2-Ethanedithiol
1,3-Butadiene
1,3-Dichlorobenzene
1,4 Thioxane
1,4-Diaminocyclohexane
1,4-Dichloro-2-butene
1,4-Dichlorobenzene
1,4-Difluorobenzene
1,6-Dichlorohexane
1-Bromo-4-fluorobenzene
1-Bromobutane
1-Bromopropane
1-Butene
1-Chloro-2-methylpropane
1-Methoxy propanol acetate
1-Methoxy-2-propanol
1-Methoxy-2-propyl acetate
1-Methyl-2-propanol acetate
1-Methylbutadiene
1-Methylnaphthalene
1-Pentene
2-(2-Methoxyethoxy)ethanol
2-(Diethylamino)ethanethiol
2-(Disopropylaminc)ethanol
2-(Ethylamino)ethanol
2, 3, 5 -Trimethylnaphthalene
2, 3,5 -Trimethylphenol
2,2-Dimethylbutane
2,3-Dimethyl-2-butene
2,3-Dimethylphenol
2,4_Dinitrotoluene
2,4-Diaminotoluene
2,4-Lutidine
2,6-Diisopropylphenol
2,6-Disopropylphenyl isocyanate
2,6-Toluene diisocynanate
2'-Aminoacetophenone
2-Bromopropane
2-Butanone
2-Butyl mercaptan
2-Chlorethyl methyl sulfide
2-Chloroethanol
2-Chloroethyl ethylsulfide
2-Chloroethyl phenyl sulfide
2-Chlorophenol
2-Chloropropane
2-Ethylhexanol
2-Ethylhexyl acrylate
2-Ethylimidazole
2-Ethyltoluene
2-Heptanone
2-Hexanone
2-Methoxybutane
2-Methoxyethyl ether
2-Methyl pentane
2-Methyl pyrazine
2-Methyl-1-butanol
2-Methylbutanal
2-Methylnaphthalene
2-Nitrotoluene
2-Pentanone
3-(Methylthio)propionaldehyde
3,5-Difluoraniline
3-Buten-2-ol
3-Carene
3-Cyanopyridine
3-Ethyl pyridine
3-Methyl pyridine
3-Methyl valeric acid
3-Methyl-1-butanol
4 -Vinylpyridine
4-Aminobiphenyl
4-tert-Butyltoluene
4-Vinyl cyclohexane
a - Pinene
Acenaphthalene
Acetaldehyde
Acetamide
Acetic acid
Acetone
Acetonitrile
Acetophenone
Acetylene
Acrolein dimethyl acetal
Acrolein
Acrylamide
Acrylic acid
Acrylonitrile
Acrylonitrile-d3
Allene
Allyl chloride
Allyl isothiocyanate
Ammonia
Amyl acetate
Amyl alcohol
Aniline
Anthracene
Argon
Arsenic trichloride
Arsine
Benzaldehyde
Benzene
Benzene-d6
Benzofuran
Benzoic acid
Benzyl alcohol
Benzyl chloride
Benzyl mercaptan
Bibenzyl
Bicyclo (2.2.1) hepta-2.5-diene
Biphenyl
bis-2-Chloroethylether
Boron trichloride
Boron trifluoride
B-Pinene
Bromine
Bromochloromethane
Bromodichloromethane
Bromoform
Bromonitromethane
Butane
Butanol
Butyl acrylate
Butyl cellosolve
Butyl chloride
Butyl isocyanate
Butylamine
B-utylbenzene
Butyraldehyde
Butyric acid
Butyronitrile
Camphene
Carbon dioxide
Carbon disulfide
Carbon monoxide
Carbon tetrachloride
Carbonyl fluoride
Carbonyl sulfide
Catechol
Cellosolve acetate
Cellosolve
Chlorine
Chlorobenzene
Chlorobenzene-d5
Chlorodibromomethane
Chloroform
Chloroiodomethane
Chloromethyl methyl ether
Chloropicrin
cis-2-Butene
Crotonaldehyde
cs-1,2-Dichloroethylene
cs-1,3-Dichloropropene
Cumene
Cyclohexane
Cyclohexanol
Cyclohexanone
Cyclopentane
Cyclopropanecarboxaldehyde
Decane
Deuterium oxide
Diacetone alcohol
Dibutyl disulfide
Dibutyl sulfide
Dichlorosilane
Dichlorvos
Dicyclohexylmethylphosphonate
Dicyclopentadiene
Diethyl ether
Diethyl ethylphosphonate
Diethyl malonate
Diethyl methylphosphonate
Diethyl methylphosphonite
Diethyl phosphite
Diethyl sulfate
Diethylamine
Diethyldimethyphosphoramidate
Diethylenetriamine
Diethylethanolamine
Diethylmethylphosphonothioate
Diisopropyl methylphosphonate
Diisopropylamine
Dimethoxymethane
Dimethyl disulfide
Dimethyl ether
Dimethyl ethoxysilane
Dimethyl formamide
Dimethyl mercury
Dimethyl methylphosphonate
Dimethyl phosphite
Dimethyl phthalate
Dimethyl sulfate
Dimethyl sulfide
Dimethyl sulfone
Dimethyl sulfoxide
Dimethyl trisulfide
Dimethylacetamide
Dimethylamine
Dimethylethanolamine
Dimethylsilane
Dioxane
Dipropylene glycol methyl ether
Disilane
Disopropyl fluorophosphate
d-Limonene
Dodecafluorocyclohexane
Dodecane
Dowtherm
Epichlorohydrin
Ethane
Ethanol
Ethyl acetate
Ethyl acetylene
Ethyl acrylate
Ethyl benzene
Ethyl carbamate
Ethyl chloride
Ethyl disulfide
Ethyl lactate
Ethyl mercaptan
Ethyl methyl ether
Ethyl methyl sulfide

List of Permeation Tubes

Ethyl morpholine
Ethyl pyrazine
Ethyl sulfide
Ethylamine
Ethylbenzene-d10
Ethylbenzene-d10
Ethyldiethanolamine
Ethylene
Ethylene dibromide
Ethylene glycol
Ethylene oxide
Ethylenediamine
Ethyleneimine
Fluorobenzene
Formaldehyde *
Formamide
Formic acid
Freon 11
Freon 113
Freon 116
Freon 12
Freon 13
Freon 21
Freon 22
Freon 114
Furan
Furfural
g-Butyrolactone
Germane
Glycerol
Helium
Heptane
Heptanenitrile
Heptyl cyanide
Hexachloro-1,3-butadiene
Hexachlorobenzene
Hexadecane
Hexaldehyde
Hexamethylcyclotrisiloxane
Hexamethyldisilazane
Hexamethyldisiloxane
Hexamethylene-1,6-disocyanate
Hexane
Hexanenitrile
Hexanoic acid
Hexanol
Hydrogen bromide
Hydrogen chloride
Hydrogen cyanide
Hydrogen fluoride

Hydrogen sulfide
Hydrogen
Indan
Indene
Iodine
Iodoethane
Isoamyl acetate
Isobutane
Isobutanol
Isobutyl acetate
Isobutyl acrylate
Isobutyl chloroformate
Isobutyl mercaptan
Isobutylbenzene
Isobutylene
Isobutyraldehyde
Isooctane
Isopentane
Isoprene
Isopropanol
Isopropyl acetate
Isopropyl ether
Isopropyl mercaptan
Isovaleraldehyde
Krypton
m - Xylene
Malathion
Maleic anhydride
m-Cresol
Menthol
Mesitylene
Methacrolein
Methacrylic acid
Methane
Methanesulfonylfluoride
Methanol
Methyl acetate
Methyl acetylene
Methyl acrylate
Methyl amine
Methyl benzoate
Methyl bromide
Methyl cellosolve
Methyl cellosolve acetate
Methyl chloride
Methyl chloroform
Methyl Choloroformate
Methyl cyclopentane
Methyl hydrazine

Methyl iodide
Methyl isobutyl ketone
Methyl isocyanate
Methyl isopropyl ketone
Methyl isothiocyanate
Methyl mercaptan
Methyl methacrylate
Methyl phosphonic dichloride
Methyl phosphonic difluoride
Methyl salicylate
Methyl vinyl ketone
Methylamine
Methylaminoethanol
Methyldiethanolamine
Methylene bromide
Methylene chloride
Monoethanolamine
Morpholine
m-Tolualdehyde
n - Propyl acetate
n - Propyl mercaptan
N,N-Dimethylanline
n-Amyl acetate
Naphthalene
n-Butanol
n-Butyl acetate
n-Butyl mercaptan
Neon
n-Hexene
Nicotine
Nitric acid
Nitric acid-d
Nitric oxide
Nitric-15N-acid
Nitrobenzene
Nitrogen
Nitrogen dioxide
Nitrogen trifluoride
Nitrous oxide
n-Methyl pyrrolidinone
N-Nitrosodimethylamine
N-Nitrosomorpholine
n-Nonane
n-Octane
n-Propyl benzene
o -Toluidine
o-Anisidine
o-Cresol
Octamethylcyclotetrasiloxane
Octyl cyanide

tert-Butanol
tert-Butyl chloride
tert-Butyl ethyl ether
tert-Butyl mercaptan
tert-Butyl methyl ether
Tetrachloroethylene
Tetradecane
Tetraethyl orthosilicate
Tetrahydrobenzaldehyde
Tetrahydrofuran
Tetrahydrofurfuryl alcohol
Tetrahydrothiophene
Tetramethylsilane
Thiodiglycol
Thionyl chloride
Thiophene
Thiophosphoryl chloride
Toluene -2,4-diisocyanate
Toluene
Toluene-dp
tr-1,3-Dichloropropene
trans-Butene
Tributylamine
Trichloroethylene
Trichlorosilane
Tridecane
Triethyl phosphite
Triethylamine
Triethylenetetramine
Triethylphosphate
Trifluoroacetic acid
Trimethyl phosphite
Trimethylamine
Trimethylsiane
Undecane
Vanillin
Vinyl acetate
Vinyl acetylene
Vinyl bromide
Vinyl chloride
Vinyl fluoride
Vinylcyclohexene monoxide
Vinylidene chloride
Water
Xenon
α-Methylstyrene
α-Terpinene
ε-Caprolactam