Chlorinated Solvents - The Key to Surface Cleaning Performance

June 2008

Typical Properties of Chlorinated Solvents

	Methylene Chloride	Perchloro-ethylene	Trichloro-ethylene	1,1,1-Trichloro-ethane
Chemical Formula	CH_2Cl_2	C_2Cl_4	C_2HCl_3	$C_2H_3Cl_3$
Molecular Weight	84.9	165.8	131.4	133.4
Boiling Point ^oF (^oC) @ 760 mm Hg	104 (40)	250 (121)	189 (87)	165 (74)
Freezing Point ^oF (^oC)	-139 (-95)	-9 (-23)	-124 (-87)	-34 (-37)
Specific Gravity @ 68^oF (g/cm^3)	1.33	1.62	1.46	1.34
Pounds per gallon @ 77^oF	10.99	13.47	12.11	11.10
Vapor Density (air = 1.00)	2.93	5.76	4.53	4.55
Vapor Pressure @ 77^oF (mm Hg)	436	18.2	74.3	123
Evaporation Rate @ 77^oF				
- ether=100	71	12	30	37
- n-butyl acetate=1	14.5	2.1	4.5	6.0
Specific Heat @68^oF (cal/g per ^oC or BTU/lb per ^oF)	0.28	0.205	0.225	0.25
Heat of Vaporization (cal/g) @ boiling point	78.9	50.1	56.4	56.7
Viscosity (cps) @ 77^oF	0.41	0.75	0.54	0.79
Solubility (g/100 g)				
- water in solvent	0.17	1.01	0.04	0.05
- solvent in water	1.70	0.015	0.10	0.07
Surface Tension @68^oF (dynes/cm)	28.2	32.3	29.5	25.6
Kauri-Butanol (KB) Value	136	90	129	124
Flash Point				
- tag open cup	none	none	none	none
- tag closed cup	none	none	none	none
Flammable Limits (% solvent in air)				
- lower limit	13	none	8	8
- upper limit	23	none	11	13

The Key to Surface Cleaning Performance

Today's manufacturing engineers and plant managers can face a difficult challenge when choosing among the many available surface cleaning options. Aqueous, semi-aqueous, flammable, combustible, fluorinated and brominated solvents are just a few of the possibilities. Among these many choices, however, one process stands out for its ability to produce a clean, dry part at a reasonable price -- vapor degreasing with the chlorinated solvents.

Trichloroethylene (TRI), perchloroethylene (PERC) and methylene chloride (METH), have been the standard for cleaning performance in precision parts cleaning for more than 50 years. Today, the development of new equipment and processes that minimize emissions and maximize solvent recovery makes TRI, PERC, and METH more effective than ever.

Despite their superior performance attributes, however, some companies have replaced TRI, PERC, or METH with other solvents or processes. Their decision was based on misperceptions about the chlorinated solvents' regulatory status, continued availability, and safety in use. The facts are:

- **TRI, PERC, and METH have not been banned.** Among the commonly used chlorinated solvents, only 1,1,1-trichloroethane (methyl chloroform) was phased out of production, due to its ozone depletion potential. Meanwhile, the U.S. Environmental Protection Agency (EPA) has issued a 1994 decision under its Significant New Alternatives Policy (SNAP) program that the other three chlorinated solvents are viewed as acceptable substitutes for ozone depleting solvents.

- **Chlorinated solvents will continue to be available.** TRI and PERC demand has remained steady or increased in recent years as a result of their use as raw materials in the production of refrigerant alternatives to CFCs. METH continues to be used in a wide variety of applications. The producers of these solvents remain committed to serving their markets for many years to come.

- **TRI, PERC, and METH can be used safely.** From the point of view of health and the environment, the chlorinated solvents are among the most thoroughly studied industrial chemicals. Animal tests and epidemiological studies indicate that when the solvents are handled, used, and disposed of in accordance with recommended and mandated practices, they do not cause adverse health or environmental effects.

- **The potential impacts of the solvents can be minimized.** Environmental, health, and safety regulations governing the chlorinated solvents are strict, but manageable. In complying with these regulations companies can get help from several sources – EPA, the Occupational Safety and Health Administration (OSHA), and state and local agencies, producers and distributors of solvents and degreasing equipment, and organizations like the Halogenated Solvents Industry Alliance.

Far from replacing chlorinated solvents with alternative cleaning technologies, manufacturers may wish to seriously consider surface cleaning with chlorinated solvents as the most efficient, effective and economical cleaning process for precision products.

engineers and managers face a difficult challenge choosing a cleaning option

Principles of Vapor Degreasing

The vapor degreasing process is the ideal technology for high quality cleaning of parts. It is able to remove the most stubborn soils. It reaches into small crevices in parts with convoluted shapes. Parts degreased in chlorinated solvent vapors come out of the process dry, with no need for an additional drying stage.

Vapor degreasing is particularly effective with parts that contain recesses, blind holes, perforations, crevices, and welded seams. Chlorinated solvent vapors readily penetrate complicated assemblies as well. Solid particles such as buffing compounds, metal dust, chips, or inorganic salts contained in the soils are effectively removed by the washing action of the solvent vapor.

Vapor degreasing can be carried out in either a batch or an in-line degreaser. The traditional batch degreaser is a covered tank, with cooling coils at the top, into which the dirty parts are lowered. Solvent in the bottom of the tank is heated to produce vapor. On contacting the cooler work, the vapor condenses into pure liquid solvent. The condensation of solvent dissolves the grease and carries off the soil as it drains from the parts into the solvent reservoir below. This process continues until the parts reach the temperature of the vapor, at which point condensation ceases and the parts are lifted out of the vapor, clean and dry.

Many degreasers contain one or several immersion tanks below the vapor zone, so that parts can be lowered into liquid solvent – often in a tumbling basket – before being raised into the vapor for final rinsing. Ultrasonic cleaning can be added to remove heavy oil deposits and solid soils by installing transducers in the degreaser. When ultrasonic energy is transmitted to a solution, it imparts a scrubbing action to the surface of soiled parts through cavitation – the rapid buildup and collapse of thousands of tiny bubbles.

Several types of conveyorized equipment provide in-line vapor degreasing. These large, automatic units, which can handle a volume of work and are enclosed to provide minimal solvent loss, include the monorail and the cross-rod degreasers. They are particularly valuable when production rates are high.

Although conveyorized degreasers are enclosed, there is still some solvent loss through the openings where work enters and leaves the equipment. Consequently, some companies have found it cost effective to install one of the advanced types of degreasers that have no air/vapor interface. These sealed units were first introduced in Europe, but have become available in the United States in recent years.

Typically these degreasers perform the cleaning operation in a sealed chamber into which solvent is introduced after the chamber is closed. Solvent vapor then performs the final drying stage, and all vapors are exhausted after each cycle and passed into a solvent recovery system. With the sealed chamber, control of solvent loss exceeds 90 percent. Operation is programmed and automated, permitting a variety of cleaning programs, including hot solvent spray.

Although these sealed units can be costly and may not be effective for some cleaning jobs, a few U.S. plants have installed them to ensure compliance with safety and environmental regulations.

Solvent Properties

TRI, PERC, and METH are clear, heavy liquids with excellent solvency. All are virtually nonflammable, since they have no flash point as determined by standard test methods. Each has its own advantages for specific applications, based on its physical profile (see inside front cover). These solvents work well on the oils, greases, waxes, tars, lubricants, and coolants generally found in the metal processing industries. They are widely used in the vapor degreasing process.

TRI has been long recognized for its cleaning power. TRI is a heavy substance (12.11 pounds per gallon) with a high vapor density (4.53 times that of air) that allows for relatively easy recovery from vapor degreasing systems. The solvent's ability to provide constant pH and to protect against sludge formation has helped make it the standard by which other degreasing solvents are compared. Its high solvency dissolves soils faster, providing high output.

TRI is used extensively for degreasing zinc, brass, bronze and steel parts during fabrication and assembly. It is especially suited for degreasing aluminum without staining or pitting the work, because its stabilizer system protects the solvent against decomposition. For cleaning sheet and strip steel prior to galvanizing, TRI degreases more thoroughly and several times faster than alkaline cleaning, and it requires smaller equipment that consumes less energy.

PERC has the highest boiling point, weight (13.47 pounds per gallon), and vapor density (5.76 times that of air) of the chlorinated solvents. PERC's high boiling point gives it a clear advantage in removing waxes and resins that must be melted in order to be solubilized. The higher temperature also means that more vapors will be condensed on the work than with other solvents, thus washing the work with a larger volume of solvent.

PERC is effective in cleaning lightweight and light-gauge parts that would reach the operating temperature of lower-boiling solvents before cleaning is complete. When cleaning parts with fine orifices or spot-welded seams – especially if there is entrapped moisture – PERC's high boiling point is essential for obtaining good penetration.

Inherently more stable than other chlorinated (and brominated) solvents, PERC also incorporates a multi-component stabilizer system that provides the greatest resistance to solvent decomposition available in the industry. While it can be used to degrease all common metals, PERC is especially applicable to cleaning those which stain or corrode easily, including aluminum, magnesium, zinc, brass, and their alloys.

METH has the lowest boiling point of the chlorinated solvents, as well as the lightest vapor density (2.93 times that of air) and weight (10.98 pounds per gal). METH is uniquely suited for use as a vapor degreasing solvent in applications where low vapor temperatures and superior solvency are desirable. The low boiling point of METH makes it a popular choice for cleaning temperature-sensitive parts such as thermal switches or thermometers.

Vapor degreasing with METH allows more rapid processing and handling, particularly when cleaning large, heavy parts. The more aggressive nature of METH is especially useful when degreasing parts soiled with resins, paints, or other contaminants that are difficult to remove.

Environmental Considerations

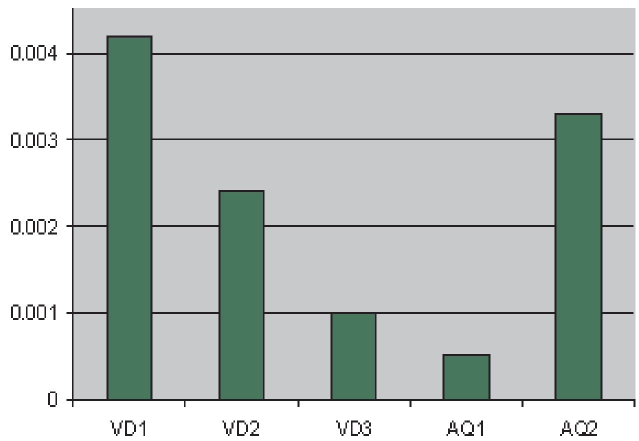
In reviewing the acceptability of TRI, PERC, and METH in its SNAP review, EPA noted that these compounds are regulated under several other environmental laws and regulations, including the occupational limits and national emission standards described elsewhere in this brochure. The Agency concluded that compliance with these regulations will significantly reduce the potential for environmental releases and worker exposure from degreasing operations. As a result, the SNAP program does not impose further use restrictions on the three solvents in degreasing.

Three cleaning substitutes were found to be "unacceptable" under the SNAP program because of their significant ozone depletion potential – hydrochlorofluorocarbon (HCFC) 141b, dibromomethane, and chlorobromomethane. Another brominated solvent, n-propyl bromide or nPB, is listed as acceptable under SNAP based on the ability of existing equipment to control worker exposure.

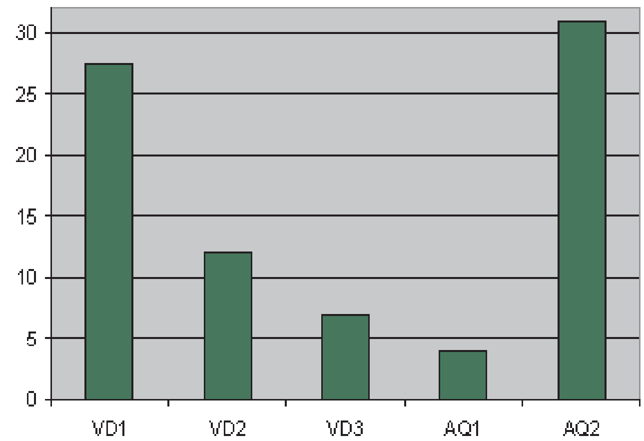
Two other solvents or solvent classes – HCFC 225 and the perfluorocarbons (PFCs) – are listed by EPA as "acceptable subject to use conditions" under SNAP. According to the Agency, they may only be used in electronics and precision cleaning for high performance, precision-engineered parts when companies have made reasonable efforts to ascertain that alternatives are not feasible due to performance or safety requirements. EPA also specifies that companies using HCFC-225 meet the manufacturer-recommended occupational limit of 50 parts per million (ppm) for an eight-hour time-weighted average (TWA).

TRI, PERC, and METH are excellent solvents with no flash point

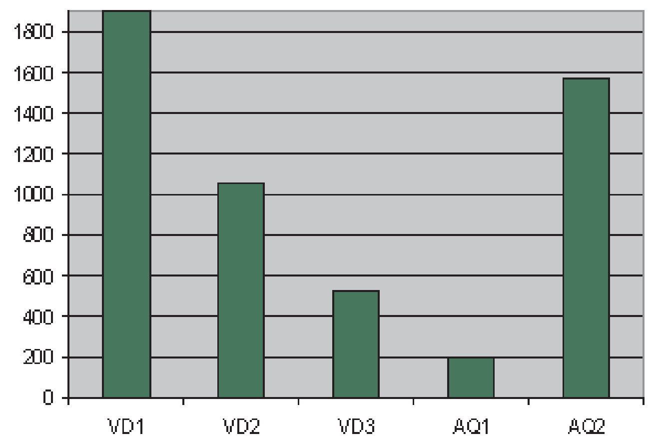
Results of Life Cycle Assessment
(per square meter of metal part cleaned)



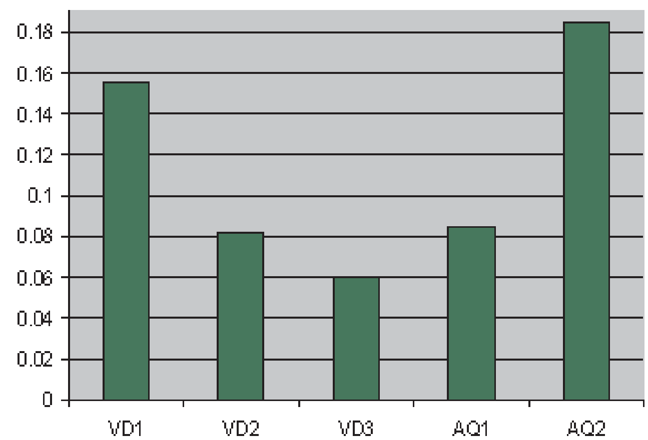
Nonrenewable Resource Depletion (kg/year)



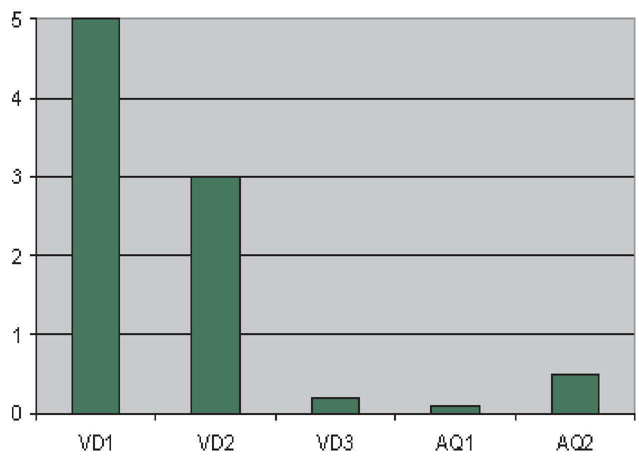
Total Energy Use (MJ)



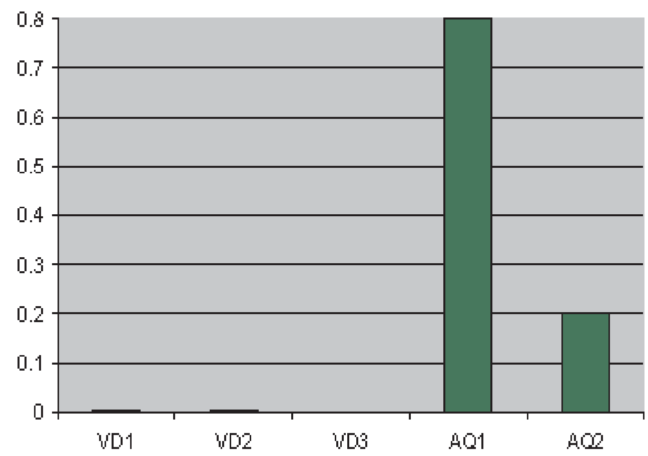
Greenhouse Effect (g equiv. CO_2)



Solid Waste (Kg)



Air Pollution (g equiv. H^+)



Water Pollution (g equiv. $PO_4^{\ 3-}$)

Scenarios: VD1 - open-top degreaser without NESHAP-compliant controls; VD2 - NESHAP-compliant degreaser with on-site distillation; VD3 - NESHAP-compliant degreaser with on-site distillation and carbon adsorption; AQ1 - aqueous cleaning with primary wastewater treatment; AQ2 - aqueous cleaning with primary and secondary wastewater treatment and drying.

Source: LCA Comparison of Metallic Parts Degreasing with Trichloroethylene and Aqueous Solutions, Ecobilan, December 1996.

Life Cycle Assessment

Competitors and others frequently propose replacing one of the chlorinated solvents with an alternative for cleaning metal parts. Indeed, alternatives such as water and detergents are often perceived as having less environmental impact than vapor degreasing with TRI. In 1997, the European Chlorinated Solvents Association (ECSA) sponsored a "life cycle assessment" to provide robust data comparing the environmental impact of metal parts cleaning in TRI with aqueous processes.

Each cleaning technology was found to have potentially significant environmental impact. The primary disadvantage of TRI, air pollution (i.e., air acidification), can be minimized with emission controls. The water pollution disadvantages of aqueous cleaning, however, can remain significant even after treatment of the cleaning residues is applied. With aqueous cleaning, impact on water was between 200 and 2,000 times higher than with TRI degreasing, depending on the site under consideration.

While both TRI degreasing and aqueous cleaning technologies have environmental strengths and disadvantages, it can be generally concluded that:

- Aqueous cleaning is best for producing clean and wet metal parts. In this case, even the best TRI scenario studied (i.e., with carbon adsorption) had a greater environmental impact than the aqueous technologies studied.

- Enclosed solvent degreasing is best to produce clean and dry metal parts, even without carbon recovery. Thus, solvent cleaning is preferable when the subsequent treatment requires dry parts.

For cleaning and drying metal parts, TRI degreasing was found to have a lower overall environmental impact than aqueous technology. This is true provided that equipment complies with EPA emission standards (see below). While air pollution with TRI degreasing can be relatively high, use of technologies to reduce solvent release can minimize this impact.

Regulatory Controls

U.S. federal regulations affecting the use, handling, transportation, and disposal of chlorinated solvents can be found under the Clean Air Act, the Clean Water Act, the Occupational Safety and Health Act, the Resource Conservation and Recovery Act (RCRA), and the Comprehensive Environmental Response Compensation and Liability Act (CERCLA, or Superfund). State and local regulations also exist for the purpose of controlling emissions. Though numerous, these regulations are manageable and companies can obtain compliance assistance from numerous sources. Federal regulations pertaining to the chlorinated solvents are summarized below.[1]

Volatile Organic Compound (VOC) regulations under the Clean Air Act apply to TRI and limit its emissions in order to reduce smog formation, particularly in ozone non-attainment areas. Exact requirements vary by state, but generally include obtaining a permit allowing a specific amount of VOC emissions from all sources within a facility. PERC and MC, however, are exempt from VOC regulations in most states.

The Clean Air Act also calls for the three chlorinated solvents to be regulated as hazardous air pollutants. EPA has issued a National Emission Standard for Hazardous Air Pollutants (NESHAP) for solvent cleaning with halogenated solvents, which is discussed in

96% of companies feel that cleaning performance is the most important attribute of a solvent or process

[1] This is not intended as a complete listing of regulations that may apply to degreasing with chlorinated solvents. It is important that each individual company determine just how these regulations apply to your business, as well as whether additional state and local regulations may apply.

detail on the next page. Other NESHAPs govern dry-cleaning with PERC and the use of MC in aerospace manufacture and rework, wood furniture manufacture, and polyurethane foam manufacture.

The Clean Water Act defines chlorinated solvents as toxic pollutants and regulates their discharge into waterways. Under RCRA, wastes containing chlorinated solvents from solvent cleaning operations are considered hazardous. Generators, transporters, and disposers of such hazardous waste must obtain an EPA ID number.

The Superfund law requires that if a reportable quantity of a chlorinated solvent or other hazardous chemical is released into the environment in any 24 hour period, the federal, state, and local authorities must be notified immediately. Reportable quantities are 1000 pounds (lbs.) for METH and 100 lbs. for PERC and TRI.

OSHA has set permissible exposure limits (PELs) for chlorinated solvents. The PEL for PERC and TRI is 100 ppm for an 8-hour TWA. The limits for METH are 25 ppm for an 8-hour TWA and 125 ppm for a 15-minute short term exposure limit, or STEL. In addition to the TWA and STEL, the OSHA standard for METH imposes several additional requirements. The American Conference of Governmental Industrial Hygienists (ACGIH), moreover, recommends Threshold Limit Values®, or TLVs, for the chlorinated solvents. The solvent producers recommend maintaining workplace exposure levels within the OSHA limits or the ACGIH levels, whichever is lower (see inside back cover).

OSHA's Hazard Communication (HAZCOM) standard specifies a minimum element of training for people working with hazardous materials, including the chlorinated solvents. This includes how to detect the presence or release of a solvent, the hazards of the solvent, and what protective measures should be used when handling it.

OSHA's HAZCOM standard also regulates the labeling of all hazardous chemicals. Labels must contain a hazard warning, the identity of the chemical, and the name and address of the responsible party. Guidelines are provided by an OSHA compliance document (OSHA Instruction No. CPL-2-2.38 D (1998)) and by the American National Standards Institute (ANSI) publication on precautionary labeling (ANSI Z129.1-1994).

In an open-top degreaser, although the vapor generally stays below the primary condensing coils, there can still be considerable solvent loss. Drafts in the work area cause solvent vapor to be pulled out. Parts loading disturbs the solvent/air interface and causes losses. In addition, cleaned parts may carry solvent with them when removed from the degreaser. These factors can cause an uncontrolled open-top degreaser to lose up to 70 percent of the solvent over a year. Consequently, procedures are necessary to minimize this loss to ensure compliance with environmental and occupational requirements.

EPA's Degreasing NESHAP

EPA's NESHAP for new and existing halogenated solvent cleaning operations governs emission standards for chlorinated solvent degreasing operations. These standards cover both vapor degreasing and cold cleaning with TRI, PERC and MC.

In developing the standards, EPA focused on equipment and work practice requirements which permit a level of control between 50 and 70 percent. Companies operating batch or in-line degreasers are given three options for compliance:

- Installing one of several combinations of emission control equipment and implementing automated parts handling and specified work practices;
- Meeting an idling-mode emission limit, in conjunction with parts handling and work practice requirements; or
- Meeting a limit on total emissions.

The multiple compliance options in the NESHAP recognize the vast number of different industries and operating schedules associated with the use of halogenated solvent cleaners. EPA's standard allows companies considerable flexibility in complying with the control requirements. The alternative idling and total emissions limits allow the use of new and innovative technologies to achieve a level of control equivalent to the available equipment combinations.

Recent amendments to the NESHAP also imposed facility-wide emission limits on companies that vapor degrease with the chlorinated solvents. The annual limits, including emissions from all the degreasing units at a facility vary depending on the solvent - 60,000 kilograms, or kg, (132,000 lbs) for METH, 14,100 kg (31,000 lbs) for TRI, and 4,800 kg (10,500 lbs) for

PERC. Higher limits - 100,000 kg for METH, 23,500 kg for TRI, and 8,000 kg for PERC - apply to federal facilities involved in the maintenance of military vehicles. An exemption from the facility-wide limits for narrow tube manufacturing, aerospace manufacture and, and facilies operating continuous web cleaning equipment is the subject of litigation and currently is being reconsidered by EPA.

Equipment and Work Practices

When a company chooses the equipment option to comply with the NESHAP, it may choose from a series of combinations of two or three procedures, which include:

- Freeboard ratio of 1.0: The height of the freeboard above vapor level must be equal to the width (shorter dimension) of the degreaser.
- Freeboard refrigeration device: A refrigerated system which supplements the traditional water cooling system and creates a cold air blanket above the vapor zone.
- Reduced room draft: Air movements above the freeboard must be kept at or below 50 feet per minute (15.2 meters per minute).
- Working-mode cover: A cover or machine design that shields the machine from outside air disturbances during the parts cleaning cycle.
- Dwell: The time in which cleaned parts remain in the freeboard area above the vapor zone after cleaning. EPA defines proper dwell time as 35 percent of the time required for the parts to cease dripping in the vapor zone.
- Superheated vapor: Use of vapor maintained 10^{o} F above the boiling temperature of the solvent. This promotes more thorough drying of the work before it is removed from the degreaser.

In addition to these options, solvent cleaning processes must include an automated hoist or conveyor that carries parts at a controlled speed of 11 feet per minute or less through the complete cleaning cycle.

Compliance with one of the control options for batch or in-line vapor equipment is demonstrated by periodic monitoring of each of the control systems chosen. Work practices are also required as part of the new EPA standards. Rather than require direct monitoring of work practice compliance, however, EPA has developed a qualification test, included as an appendix to the standard. The test is to be completed by the operator during inspection, if requested.

Emission Limits

A company choosing to comply with the second NESHAP option, the idling-emission limit (0.045 lbs/ft^2-hour for batch vapor equipment, 0.021 lbs/ft^2-hour for in-line equipment), is required to demonstrate initial compliance by using EPA's idling reference test method 307. Data from the equipment manufacturer may be used, provided the unit tested is the same as the one for which the report has been submitted. Compliance with the idling-emission limit also requires installation of an automated parts handling system and compliance with the work-practice requirements under the . In addition, the company must show that the frequency and types of parameters monitored on the solvent cleaning machine are sufficient to demonstrate continued compliance with the idling standard.

Complying with the third option, the limit on total emissions, requires the company to maintain monthly records of solvent addition and removal. Using mass-balance calculations, the company calculates the total emissions from the cleaning machine, based on a three-month rolling average, to ensure they are equal to or less than the established limit for the cleaner (30.7 lbs/ft^2-month for small batch vapor machines, 31.4 lbs/ft^2-month for large batch vapor machines, 20.3 7 lbs/ft^2-month for in-line machines). For new machine designs without a solvent/air interface, EPA has established an emission limit based on cleaning capacity (= 330 x $(vol)^{0.6}$).

EPA provides considerable flexibility in complying with the degreaser NESHAP requirements

Companies meeting the total emission limit requirements do not need to conduct monitoring of equipment parameters, but must maintain records of their solvent usage and removal of waste solvent. According to EPA, this compliance option provides an incentive for innovative emission control strategies to limit solvent use. For some cleaning machines, EPA calculates that the alternative total emission limit could be more stringent than the equipment specifications. In particular, EPA expects that this alternative standard will be more difficult to meet for larger machines, for machines operating more than one shift, and for machines cleaning parts with difficult configurations.

For Further Information

Users of chlorinated solvents can obtain help in meeting regulated standards, and in applying emission control procedures, from a number of sources.

The 1990 Amendments to the federal Clean Air Act mandate EPA to provide funding to each state to set up a small business assistance program (SBAP). State SBAPs provide a state Small Business Ombudsman and a Technical Assistance Director to facilitate communications between the EPA and small businesses and to provide information on new and existing environmental regulations and policies. To qualify as a small business, a company must have fewer than 100 employees and must not be "dominant in its field."

The federal Small Business Ombudsman provides literature and a toll-free hot-line to answer questions, although primary assistance for a business comes from the state SBAP office. You can find out whom to contact on a state level by calling the federal Small Business Ombudsman's hot line, 1-800-368-5888, or visiting the website, www.epa.gov/smallbusiness.

Producers and distributors of chlorinated solvents also provide support for solvent users. Federal law requires these companies to provide a Material Safety Data Sheet (MSDS), containing complete information on safety and handling, to all customers. In addition, the Responsible Care™ initiative of the Chemical Manufacturers Association and the Responsible Distribution Process™ of the National Association of Chemical Distributors require members to share product stewardship information on use, disposal, and regulatory compliance with customers.

HSIA provides legislative and regulatory news to the industry, sponsors research on chlorinated solvents, and presents information to EPA, OSHA, and other regulatory agencies in support of solvent users. Companies can obtain information and literature from HSIA on use of the solvents and applicable regulations by calling the Alliance at 703-741-5780, or visiting our website at www.hsia.org.

Operating Parameters for the Chlorinated Solvents

	Methylene Chloride	Perchloro-ethylene	Trichloro-ethylene	1,1,1-Trichloro-ethane
Vapor Thermostat Setting °F (°C)	95 (35)	180 (82)	160 (71)	130 (54)
Boil Sump Thermostat Setting[1] °F (°C)	110 (43)	260 (127)	195 (91)	175 (79)
Steam Pressure (psi)	1 -3	40 - 60	5 - 15	1 - 6
Solvent Condensate Temperature[2] °F (°C)	100 (38)	190 (88)	155 (68)	130(54)
Cooling Coil Outlet Temperature Range (°F)	75 - 85	100 - 120	100 - 120	100 - 120
Occupational Exposure Limits				
OSHA PELs[3]				
- 8-hour TWA	25	100	100	350
- 15-minute STEL	125	-	-	-
- Ceiling	-	200	200	-
- Peak	-	300	300	-
ACGIH TLVs[4]				
- 8-hour TWA	50	25	10	350
- 15-minute STEL	-	100	25	450

1 Maximum boiling temperature, based on 25-percent contamination with oil.

2 To facilitate effective separation of the solvent from the water.

3 8-hour time weighted average (TWA) is an employee's permissible average exposure in any 8-hour work shift of a 40-hour week. The short-term exposure limit (STEL) is a 15-minute TWA exposure that should not be exceeded at any time during a work day. The Acceptable Ceiling Concentration is the maximum concentration to which a worker may be exposed during the shift, except that brief excursions to the Acceptable Maximum Peak are permissible.

4 Threshold Limit Values (TLVs) are established by the American Conference of Governmental Industrial Hygienists (ACGIH).

Sources: ASTM Standard D3698 Standard Practice for Solvent Vapor Degreasing Operations; ACGIH Guide to Occupational Exposure Values (2008); 29 CFR 1910.1052; and 29 CFR 1910.1000, Table Z-1 - Limits for Air Contaminants.

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