

# Theoretical and Practical Control of Solvent Exposure During Electrical Cleaning

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**Abstract** – The variables in electrical cleaning solvent vapor exposure are explained. These variables are related to field use of cleaning solvents. A computer model is developed projecting solvent vapor levels for in-vault cleaning. A number of variations are run to demonstrate model capability. The primary controls available to engineer safer electrical cleaning are reviewed.

## INTRODUCTION

Solvent exposure during cable and other cleaning is a major concern in the electrical industry. Often, cleaning is done in vaults or other small, close working spaces so that solvent vapors can accumulate. The cleaners used on high voltage cables and connections can't leave residues to cause tracking or arcing, so they must be volatile and produce such vapors. What's important from a safety standpoint is how much solvent vapor a worker inhales. The amount inhaled can be directly equated to the solvent vapor concentration in the air. Such vapor concentrations are usually expressed as weight/volume (e.g. mg./liter) or parts per million of air (ppm).

The concentration of solvent vapor in a closed environment is dependent on several factors; namely, the emission rate, source amount, and dispersion character of the vapor, as well as rate of vapor removal by ventilation.

This paper models these factors, and applies them in the electrical construction environment, both theoretically and practically. The model is verified with experimental simulation. Finally, the practical controls and methods to minimize solvent vapor exposure in electrical cleaning are listed.

## BODY

### Toxicity

Toxicity is the ability of a chemical to cause injury once it reaches a susceptible site in or on the body. Different chemicals are rated as toxic or dangerous in different quantities. For some, very small amounts can be toxic (like cyanide), while others require very large quantities for toxic effect (like baking soda). These toxic quantities are specific to the characteristics of that particular chemical.

For electrical cleaning solvents, the exposure of greatest concern is usually entry in the body thru the lungs. The common empirical method used to measure such vapor toxicity is the median lethal concentration (LC<sub>50</sub>). The LC<sub>50</sub> is a measure of the quantity of solvent in air that will statistically result in the deaths of 50% of an animal population, usually rats, in a given period of time. While such animal testing cannot be directly applied to humans, LC<sub>50</sub> data does give a comparison of toxicity among solvents and their vapors.

Obviously, humans don't want to be exposed to anything close to an LC (lethal concentration). In the U.S., safe vapor concentration working levels called TLV-TWA's (Threshold Limit Value-Time Weighted Average) are established by OSHA and/or the American Conference of Governmental Industrial Hygienists. Such TLV's are many orders of magnitude less than experimentally established LC<sub>50</sub> levels. TLV's are general guidelines for safe levels of worker exposure to air concentrations of a given solvent for a 40-hour work week. Only the more common industrial solvents are used with the frequency to allow studies to establish TLV's. As Table I shows, TLV's are usually given in ppm. The threshold limit values are not absolute, and they can be revised as new information becomes available.

Table I. Common Solvent TLV Levels, in PPM

1,1,1 – Trichloroethane	350	Freon 113	1000
Ethanol	1000	Carbon Tetrachloride	2
Isopropanol	400	Toluene	100
MEK	200	Ammonia Gas	50
Acetone	750	Perchloroethylene	25
Decane	ND*	d-Limonene	ND*
Undecane	ND*	Butyl Cellosolve	25
Dodecane	ND*	* Not Determined	

Note from Table I that TLV's have not been developed for newer and less common solvents and solvent blends. This does not mean that the vapors from these solvents are non-toxic. The solvents have simply not been common enough in industry to give industrial hygiene researchers background or reason to study.

Remember that a TLV is a guideline for an "average" worker. Differences in the way a chemical affects an individual varies with age, sex, nutritional status, genetic background, body temperature, and anatomical differences. Certain individuals will develop allergies or become sensitized to solvent vapors. It is best to keep air contamination levels as far below a listed TLV as possible.

### Industrial Vapor Exposure Models

Remember that toxicity is fundamentally a concern with quantity. Air quality is a measure of the amount of air contaminants within a specified space. The amount is dependent on both the rate of solvent vapor emission and dispersion and the rate of dilution and removal by ventilation.

In the field of environmental engineering, much work has been done in creating mathematical models for indoor aerosol vapor dynamics and air ventilation patterns. These computer generated models predict air flow fields by breaking the enclosure into increments. Elemental mean velocity and flow patterns are handled iteratively using the equations known in the field.

Basically, the models sum all the "sources" of vapor and subtract all vapor "sinks" to establish air concentration (versus time). The sources in this model would include direct emission, advective transport from other chambers and outside, and coagulation of mass from smaller particles in the section. The sinks would include the vapor removed by ventilation and filtration, vapor deposition onto surfaces, and vapor loss as a result of larger droplet size due to coagulation. The balance between the emission and dispersion of a contaminant versus its dilution and removal quickly becomes complicated.<sup>[1][2]</sup>

However, electrical construction does not have the solvent dip tanks, paint spray booths, etc., typical of industrial solvent exposures. Usually, a small amount of solvent is put on a rag to wipe the contaminants off a surface. To create a practical model for telephone and electrical construction, we must simplify the factors that cause solvent vapor accumulation. These are :

- (1) source amount
- (2) evaporation rate
- (3) dispersion (within the confined space)
- (4) ventilation and distribution design factor
- (5) enclosure size

### Source Amount

This is an easy one to understand. If we have and use no more than one gram of solvent cleaner, then there can be no more than one gram in the air. On the other hand, if we use an open gallon of solvent, eventually close to 4,000 grams of solvent could be in the air. One can't be exposed to more than one uses.

### Evaporation

How quickly vapor is formed is described by the evaporation rate of a solvent. Evaporation is the process in which a substance changes from liquid or solid to gas or vapor. Electrical cleaning solvents are volatile (evaporate) at ambient temperatures. They form vapors under normal working conditions. Evaporation rates are specific to solvents and are found widely in product literature.

ASTM D3539 describes the most common method in which evaporation rates are measured (using a Shell Thin-Film Evaporometer). In this method, a filter paper disk is hooked to a spring scale and allowed to equilibrate within a climate controlled cabinet. Test conditions require strict temperature and humidity regulation. The filter paper disk is saturated with 0.7 ml. of solvent and weight loss measurements are taken.

Relative evaporation rate is calculated from the seconds for 90% weight loss and reported relative to n-butyl acetate. The higher this normalized number, the faster that solvent evaporates.

Some common evaporation rates from this test are:

1,1,1-Trichloroethane	= 6.0
Ethanol	= 1.7
Mineral Spirits	= 0.12

The Shell Thin-Film Evaporometer controls the effects that temperature, humidity, surface area, and surrounding air circulation have on evaporation rate. This is done because each of these variables significantly affects evaporation rate.

While the ASTM D3539 data is good for solvent comparisons, it's not so useful for determining how much solvent is released during electrical cleaning. Our laboratory studies show that a closed room with nominal air circulation can half the evaporation rate found in a larger room and good air circulation. The evaporation rate for a solvent wicked onto a towel is much faster than the same solvent in an open container. As mentioned previously, temperature and humidity can also affect evaporation rate.

In the actual field use of a solvent cleaner, these variables are even more complex. The cleaning actions of rubbing and wiping increase the surface area of the solvent film and create surface heat from both the friction and the body heat.

The evaporation rates we input into our model mimic field use as closely as possible. For instance, we may weigh a cleaner-saturated, non-linting towelette, use it to clean a cable (at a given temperature, etc.), then reweigh it. If the cleaning process took five minutes, and five grams of solvent have evaporated from the towelette, we would have an evaporation rate of one gram per minute. The important point is to have the rate reflect the process as much as possible. It won't be exact, but it will be a reasonable representation of how fast the solvent gets into the air.

### Dispersion—Vapor Density—Rate of Dilution

It is important to understand the movement of the solvent's vapor. If it is rising to the ceiling or sinking to the floor of the vault, concentrations can build to unpredictably dangerous levels. The property of concern is vapor density. Air, with a molecular weight of 29 grams/mole is lighter than most solvent vapors. So most solvent vapors should settle to the floor.

However, at the vapor concentrations we are concerned with here (less than 1,000 ppm), density differences do not have a dramatic effect. Turbulence caused by convection currents, wind, forced ventilation, and the motion of people results in the mixing and dispersion of these vapors.<sup>[3]</sup> Even in a closed room, intermolecular forces and convection currents cause molecular movement and dispersion.

### Dilution Ventilation

One method to control solvent vapors in the field is to use forced air ventilation (dilution ventilation). The amount of manhole ventilation commonly used today varies from several thousand cubic feet per minute to none (no forced ventilation). The most common type of ventilation is to blow fresh air into the vault through an entry hose.

### Dilution Ventilation—The Design Distribution Constant

Ventilation is not a simple exchange of air. In other words, outside air does not simply displace the solvent-contaminated air. Instead, the introduction of fresh air causes turbulent mixing. This means the vault will still contain a diluted mixture of the solvent vapor even after one complete air change. To compensate for these effects, ventilation is commonly measured as:

$$V = Q/K \quad (1)$$

Where:

- V = Calculational Ventilation Rate (ft.<sup>3</sup>/min)
- Q = Actual Ventilation Rate (ft.<sup>3</sup>/min.)
- K = Design Distribution Constant

"K" values are common in environmental engineering. The values range from 3 to 12 and are based on a number of factors.<sup>[4]</sup>

- (1) Contaminant toxicity.
- (2) Locations and number of points of generation of contaminant in the room at work area.
- (3) Location of air inlets and outlets.
- (4) Duration of the process operational cycle and normal location of workers relative to sources of contamination.
- (5) Geometry of enclosure or room.
- (6) Reduction in operating efficiency of mechanical air moving devices.
- (7) Seasonal changes in the amount of natural ventilation.
- (8) Other circumstances that may affect the concentration of the hazardous material in the breathing zone of the workers.

You can see that "K" values are basically a "downgrading" of ventilation rate that are situation specific. Table II is a simplified chart recommending "K" values.<sup>[5]</sup>

**Table II. Recommended "K" Values for Various Conditions**

TOXICITY	DISTRUBUTION CONDITIONS			
	Poor	Average	Good	Excellent
Slight (TLV > 500 ppm)	7	4	3	2
Moderate (TLV = 100-500 ppm)	8	5	4	3
High (TLV < 100 ppm)	11	8	7	6

### Enclosure Size

This is also an easy factor to understand. If we evaporate 10 grams of solvent in a 100-cubic-foot space, the concentration in the air will be 10 times that of 10 grams evaporated in 1,000 cubic feet of space.

It is interesting to note that ventilation rate is an effective compensator for small volume spaces. One hundred cubic feet/minute of air flow would turn the small room over 10 times as fast as the large room.

### Computer Model

While each of these factors is easy to understand by itself, the relationships between them get complicated. A computer program was developed to calculate vault vapor levels over time. Input is:

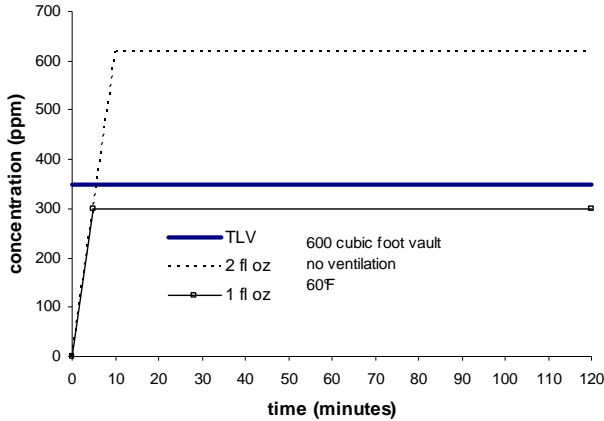
- (1) Source Amount (can be controlled by amount in package, measuring amount from bulk, etc.)
- (2) TLV (from the literature—a safety reference line only—does not affect actual vapor concentration.)
- (3) Evaporation Rate (determined in the laboratory based on solvent use method, temperature, etc.)
- (4) Vault Size (based on field input).
- (5) Ventilation Rate (based on field input and adjusted by an appropriate "K" factor).

The output from the program is a graph of projected vapor concentrations versus time, based on the specific inputs above.

The power of the computer model becomes obvious when we examine some of the variables (and possible controls) in cleaners themselves and use method.

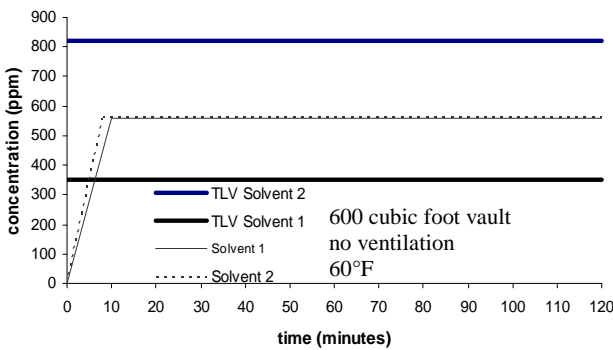
**Source Amount**

Figure 1 below shows the projected levels of trichloroethane when one fluid ounce versus two fluid ounces evaporates during cleaning. You can see that one level settles at double the other, and well over the 350 ppm TLV for trichlor. The model shows it is very possible to expose workers to excess solvent vapors if care is not taken.



**Figure 1. Two different amounts of cleaner (trichloroethane) evaporated**

Figure 2 shows two similar evaporation rate materials with different TLV's, trichloroethane with a 350 ppm versus proprietary blend #1 with a TLV of 850 ppm. Similar volumes are evaporated.

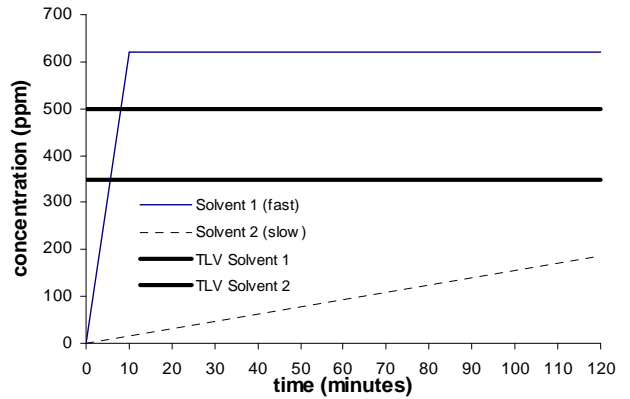


**Figure 2. Equal amounts evaporated of two different solvents with different TLV's**

While the final concentration of the two is the same, because of the TLV differences, one is below and the other above its TLV.

**Evaporation Rate Differences**

Figure 3 shows a similar amount (volume) of trichloroethane evaporated versus proprietary cleaner blend #2. The proprietary blend evaporates much slower than the trichlor, and has a higher TLV.

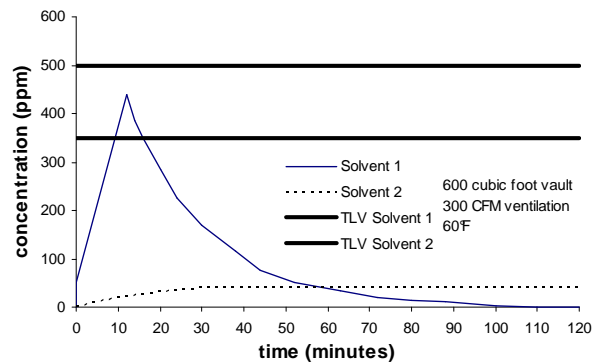


**Figure 3. Equal amounts evaporated of solvents with different evaporation rates**

The dramatic effect of evaporation rate can be seen.

**Ventilation Rate**

Figure 4 is basically the same situation shown in Figure 3 with a ventilation rate of 300 cfm and a "K" factor of 10.

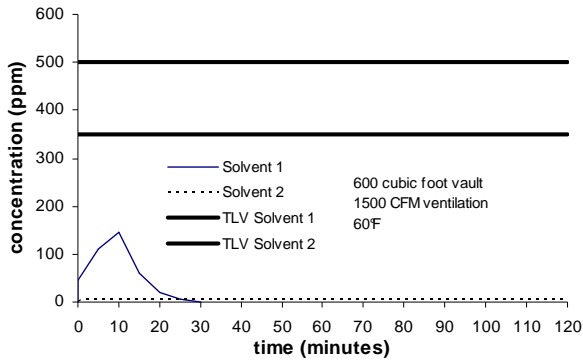


**Figure 4. Same situation as Figure 3 but with 300 CFM ventilation**

At this rate, the ventilation affects the concentration of the trichloroethane and eventually eliminates all vapors, but does not keep it below its TLV. The proprietary blend #2 is an order of magnitude under its TLV.

**Greater Ventilation**

Figure 5 is the same situation as Figure 4 but with five times the ventilation rate. At this rate, neither cleaner's vapors get close to their TLV levels.



**Figure 5. Same situation as Figure 4 but with 1500 CFM ventilation**

**Controlling Solvent Exposure**

The model shows that, from the standpoint of safety, the cleaning solvent package should contain a measured amount of solvent, hopefully enough to be effective but keep concentrations well under the TLV. An alternative is precision field metering from closed, bulk containers, although such equipment may not be field practical. It is also important that the solvent have a low level of toxicity (high TLV) and/or be a slow evaporation rate.

The work method can be very important. Is the solvent cloth set down in the vault to continue evaporation, or is it removed or enclosed to eliminate the source? Is ventilation necessary and at what levels?

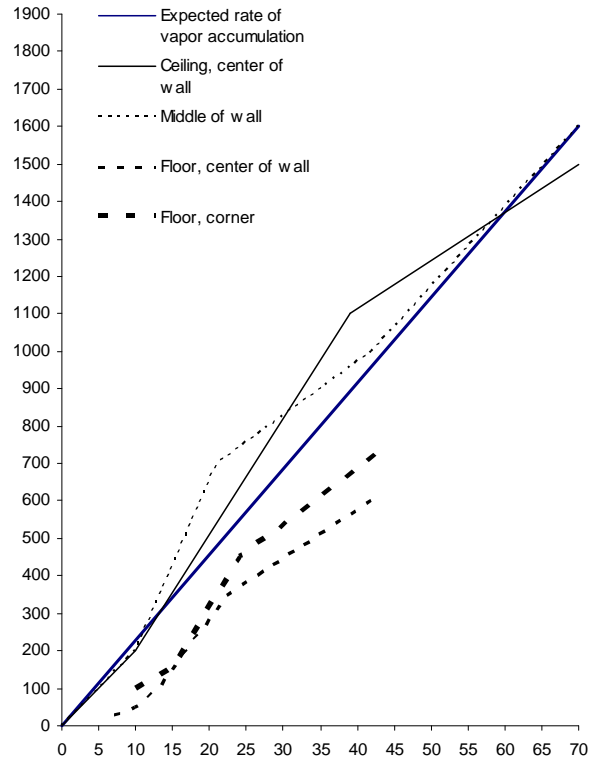
The power of the computer model is that it can answer these questions by projecting their effects. The examples given above are limited, and the flexibility of the model is obvious.

**Verifying the Model**

To verify the computer program, we designed an experiment to measure solvent vapor in a small closed room. For the vapor concentration measurement, we used Dräger tubes. For the solvent, we chose ethanol, as it is relatively innocuous, and has an evaporation rate fast enough to develop measurable solvent vapors in a reasonable span of time. Also, ethanol has a Dräger tube specific to measuring its vapors.

The Dräger detection tube indication is based on the oxidation of the alcohol with chromo-sulfuric acid. Tubes are calibrated to measure 100-3,000 ppm. Results are evaluated by a pale green discoloration. Dräger tubes are not intended for precision measurement, and the margin of error can be as high as 25%. Endpoints are difficult to judge exactly, but give helpful relative data.

A 12 by 12 inch towel was set in a large baking pan and saturated with 75 mls. of ethanol. The pan was placed 4 feet 4 inches above floor level in a room volume of 270.5 ft.<sup>3</sup> and temperature of 26°C. The ethanol was allowed to evaporate naturally. A concentration measurement was taken at 5, 10, 20, 40 and 70 minutes. Each measurement takes about one minute. Thus, readings from tube-to-tube are slightly delayed. We measured vapor concentration at the ceiling, floor, and source level, approximately 4 feet, 4½ feet and 2 feet from the source, respectively. A floor-level corner, roughly 7 feet from the source, was also measured for vapor concentration. See Figure 6 for results.



**Figure 6. Actual concentration measurements to verify model**

The results show a slightly higher ethanol vapor level at the ceiling. Likely, the heat convection currents drew the solvent up and around to the floor corners. The lowest concentration of vapor is at floor level underneath the stand of exposed ethanol. Even with these variations, the vapor concentrations follow the computer-projected concentrations quite well.

## **CONCLUSION**

Solvent vapor exposure is dependent on five variables: source amount, solvent evaporation rate, vapor dispersion pattern, ventilation and design distribution of enclosure, and enclosure size (volume). Each parameter changes with type of enclosure, type of solvent, temperature, and other field variables.

A computer model has been developed to calculate solvent vapor accumulation as a function of time. Variables that are specific to the field situation can be entered into the program. Experimental simulation confirms the computer results.

Using this computer model, solvent vapor levels in an enclosure can be compared to the established TLV level for that specific solvent vapor. Guidelines for solvent usage quantity during cable and other cleaning in the electrical industry can be established.

By using this technology, engineers can gain better control of the field environment and establish safer work procedures and standards.

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## **BIOGRAPHY**

Sheri L. Helmbrecht received a B.A. degree in chemistry and mathematics from Saint Olaf College in 1988.

She worked as an analytical chemist from 1988 to 1990 at the 3M Company, St. Paul, Minnesota. Since joining American Polywater in 1990, she has worked in the area of cleaner product development.

John M. Fee received a B.S degree in chemistry from Massachusetts Institute of Technology in 1968.

He worked from 1968 to 1991 at the 3M Company, St. Paul, Minnesota, on a variety of chemical product developments. Since 1981, he has been with American Polywater, and is currently President. He has worked extensively in the area of cable pulling lubricants and cleaners.

Mr. Fee is a member of the ICC of the PES, and chairs a working group developing compatibility test standards for lubricants and cables.