CONTROL OF SOLVENT EXPOSURE IN CHEMICAL LABORATORIES

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INTRODUCTION

In laboratories, a wide variety of chemicals is used in small amounts, with a notable exception for organic solvents which are used in bulk. Each year, a large laboratory consumes a few thousand litres of common solvents (such as acetone, ethanol and chloroform). Several other solvents are used for crystallization purposes and for cleaning equipment and glassware.

This involves a number of risks. Many solvents are flammable and, to a greater or lesser extent, toxic. Exposure of laboratory workers (through the skin or by inhalation of solvent vapour) may produce a variety of toxic effects. Hexane, for example, is neurotoxic and chloroform is harmful to the liver. In addition to benzene, which is carcinogenic, several other widely used solvents (such as chloroform, dichloromethane, 1,4-dioxane and carbon tetrachloride) are under suspicion of causing cancer in humans.

A risk assessment starts with the collection of data on solvents and their use. A registration of the quantities of solvents used already provides some information.

The use of carbon tetrachloride and benzene is restricted by statutory measures in the Netherlands, and they are hardly used nowadays in laboratories. Chloroform is increasingly being replaces by dichloromethane in many laboratories. The pattern of use of solvents over the years therefore shows distinct trends.

A survey among laboratory workers on the use of chemicals showed that acetone is not only the most popular solvent but also the one most often used outside the protective fume hoods. Chloroform and in particular dichloromethane tend to be used more often in laboratory hoods.

To get a better idea of the exposure to vapours of organic solvents in our laboratories, we performed some measurements using different detection techniques. It became clear that elevated concentrations in the breathing zone of workers and students are not observed under "normal" circumstances when the solvents are handled in laboratory hoods (ventilation constant of 5-10 h^{-1}; hoods with by pass and a face velocity of 0.25 m/s). The concentrations measured never exceed 1 - 10 ppm and are "low" when compared with most exposure limits (i.e. Dutch MAC values) of solvents.

Significant concentrations are sometimes observed when solvents are handled outside laboratory hoods. The concentrations measured are influenced by several factors, such as air turbulence by moving co-workers, the ventilation pattern of the laboratory room, the type of work performed and the volatility of the solvent. Close observation reveals that exposure mainly takes place during operations in which a volatile

solvent is poured from one piece of glassware into another (e.g. during filtration, column chromatography, recrystallization and cleaning of glassware).

Model experiments

Therefore we performed several model experiments with eight solvents (acetone, chloroform, dichloromethane, diethylether, ethanol, ethyl acetate, methanol and toluene) in which all external influences were kept constant and solvents were poured from one (standard) piece of glassware into another.

Although the concentrations measured varied widely in these experiments, a certain pattern became clear. The results do not differ significantly from expectations, based on a small amount of literature data and on unpublished results of colleagues. Not surprisingly higher ventilation rates result in lower concentrations and the concentrations measured in the breathing zone are also slightly dependent on the height of the experimenter. Under normal circumstances, the concentrations in the breathing zone show a simple dependency on the volatility of the solvent, the influence of the vapour density being essentially negligible.

The results show that evaporation rates of solvents increase as a function of the size of the glassware and the mass of the solvent used; considerable differences may occur, up to a factor of 3.

Evaporation also increases with vapour pressure. The average rate of evaporation during (continuous) pouring varies from approximately 1 g/min for less volatile solvents (toluene, ethanol) to 10 g/min for volatile solvents (ether, dichloromethane).

A more or less linear relationship was observed between the vapour pressure of the solvent and the (geometrical mean) concentration measured in the breathing zone. This makes it possible to estimate the concentration to which laboratory workers are exposed when working with solvents outside the hoods.

The proportionality constant between concentration and vapour pressure is between 0.1 and 0.5 ppm/mbar. Under normal circumstances (working at a laboratory bench with a ventilation rate of approximately 5 h^{-1}), a proportionality constant of 0.25 ppm/mbar seems a fair estimate in our laboratories. This makes it possible to estimate exposure concentrations during pouring of any solvent outside the laboratory hoods on the basis of the vapour pressure.

Studies in other laboratories reveal that the relationship between the mean concentration in the breathing zone and the vapour pressure is mainly determined by the ventilation flow rate (in m^3/h) and the dimensions of the laboratory. The rate of air renewal (in h^{-1}) is less relevant. It also became clear that the proportionality constant between concentration and vapour pressure (0.25 ppm/mbar) can be exceeded. It is advised to use 1 ppm/mbar as a preliminary rule of thumb. Only under very unfavourable conditions is this value possibly too low.
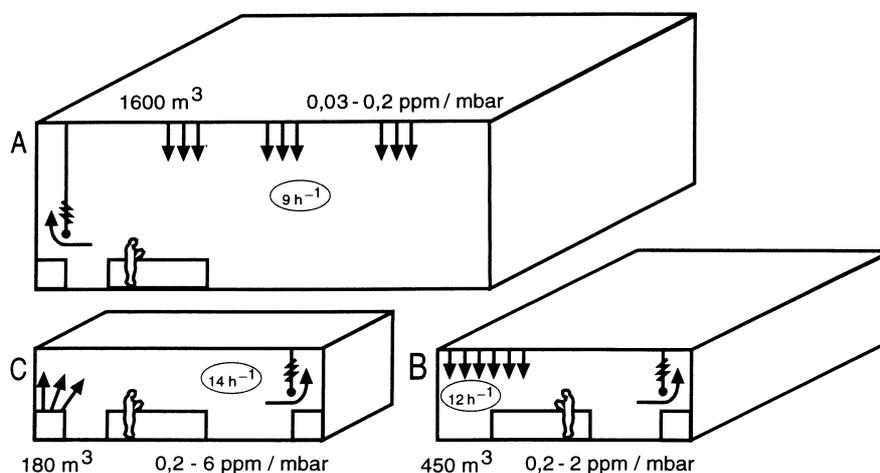

Figure: Proportionality constants between concentration and vapour pressure in three different laboratories.

Exposure assessment

In the situations examined, it is unlikely that the maximum acceptable concentration will be exceeded, even for a short period, when working with solvents at laboratory benches, with the exception of substances for which p/MAC exceeds approximately 5 mbar/ppm. Examples are chloroform, carbon tetrachloride, benzene, carbon disulphide and n-hexane.

The survey among laboratory workers mentioned above reveals the time of working outside laboratory hoods with any solvent for each worker. I.e. the time is known during which exposure to solvent vapours may occur. This makes it possible to estimate the time-weighted average exposure during the working day on the basis of a worst case assumption. For each solvent a frequency distribution results from which the probability that the mean concentration exceeds the exposure limit can be estimated, assuming lognormality. This leads to the conclusion that the probability of non-compliance is less than 1% for all solvents except chloroform and n-hexane.

Whole-day exposure to organic solvents, determined by personal gas diffusion badges, suggests that the worst case approach overestimates the actual exposure probably by one or two orders of magnitude.

On the other hand, the approach underestimates the exposure in special cases such as exposure during flash chromatography. In this case the worst case approach is not applicable. Higher concentrations were measured and exposure limits are easily exceeded, especially for chloroform.

A risk index

For the risk of inhalation of solvent vapours in a laboratory, a risk index A is based upon use, volatility and maximum allowable concentration of all solvents used. Priorities in laboratory safety policy and practice can be based on this index.

A gives the total "weighted use" of solvents in the laboratory: $A = \Sigma_i \, a_i$, in which the summation is over all solvents. The quotient p_i/MAC_i is used to "weigh" the use q_i of solvent i in the laboratory: $a_i = (p_i / MAC_i) \, q_i$.

It is thus assumed that p_i/MAC_i (with p_i the vapour pressure and MAC_i its exposure limit) is a useful index for the relative (inhalation) exposure hazard when working with solvent i.

If q_i is known, a_i can be calculated yearly for each solvent using the vapour pressure at the experimental temperature. For many situations this temperature can as a first approximation be taken 20 °C e.g. when exposure mainly takes place during a relatively small number of procedures (weighing, pouring, filtration, extraction) all taking place at room temperature.

Owing to a combination of extensive use, high vapour pressure and low exposure limit, the chlorinated solvents chloroform and dichloromethane are at present the main concern with regard to the risk of inhalation. The fact that the Dutch MAC for chloroform has recently been set at a particularly low level (1 ppm) is important.

Realizing that our first aim is eliminating hazards at the source (i.e. the solvents), the "weighted use" A may be used as a crude indicator in a safety and health policy. The simple index A of course has several limitations. From the definitions of A and a_i it is obvious that the use of volatile solvents with a low exposure limit dominates the value of A, masking the use of solvents with low volatility or high MAC values. Exposure limits are moreover not relative indices of toxicity but merely guides for good industrial practice, based on widely different grounds and data.

Risk control

To reduce exposure of students and laboratory workers in a chemical research laboratory to organic solvents several strategies may be followed. It is important to stimulate the correct use of laboratory hoods, to apply sufficient ventilation, and to supply information on the use of protective gloves when skin absorption is relevant.

A number of technical measures was taken to control exposure to solvent vapours. Increasing the number of available laboratory hoods was one of the most important measures. A very fundamental way to reduce health hazards is to stimulate the use of less toxic alternatives for hazardous chemicals. Instead of benzene, toluene can often be used. Similarly pentane may be a suitable alternative for the neurotoxic n-hexane, and dichloromethane for carbon tetrachloride or chloroform.

Several attempts have been made to influence the use of solvents in our laboratory. For benzene and carbon tetrachloride a very strict approach has been followed since 1978. Since that year, according to national legislation, the use of these solvents is only permitted under special conditions. In the laboratory benzene or carbon tetrachloride may only be used with the permission of the safety coordinator. In daily practice this means that these solvents are only used after the possibilities of alternative solvents have been investigated. Since the use of alternatives (e.g. toluene for benzene; dichloromethane for carbon tetrachloride) proved feasible in many cases, the usage of benzene and carbon tetrachloride decreased strongly.

The use of chloroform has a dominant influence on the value of the risk index A. Providing extensive information of the toxic properties of chloroform (e.g. its carcinogenic properties in different laboratory animals) and changing the way the solvent is distributed within the laboratory has caused an overall shift to the use of dichloromethane.

Together, these activities led to a shift to safer substitutes for hazardous solvents, resulting in a gradual but significant lowering of the risk index A over the past twenty years.

The concentrations of airborne solvent vapours we determined are low. One should however be careful to conclude that significant exposures never take place in laboratories. In the first place several chemicals with low MAC other than solvents are used in laboratories. Secondly ventilation systems and their efficiency have been shown to differ widely from one laboratory to another. Furthermore solvents, or even chemicals, represent only one of the stressors students and laboratory workers are exposed to. Combined exposure (to chemicals, radiation, micro-organisms, etc.) may be considered typical of a laboratory environment.