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Formaldehyde exposure in work and the general environment

Occurrence and possibilities for prevention

by Raimo Niemelä, MSc, Harri Vainio, MD [1]

NIEMELÄ R, VAINIO H. Formaldehyde exposure in work and the general environment: Occurrence and possibilities for prevention. *Scand j work environ health* 7 (1981) 95—100. Formaldehyde is extensively used for many different purposes. For this reason, serious concern has been expressed about the health hazards related to its potent irritating and sensitizing properties. Recently published information about the potential carcinogenicity of formaldehyde has generated further discussion of the potential health hazards of this compound. This article briefly reviews the health hazards of formaldehyde, the occurrence of formaldehyde in the environment, and general aspects of the prevention of existing hazards.

Key terms: asthmatic reactions, carcinogenicity, environmental exposure, occupational exposure.

Formaldehyde and its possible health hazards

Irritating and sensitizing properties

Formaldehyde, the simplest of the aldehydes, is chemically more reactive than its higher homologues. It is used extensively in a wide spectrum of commercial processes.

Exposure to low atmospheric concentrations of formaldehyde causes irritation, especially of the eyes and respiratory tract at concentrations above 0.3 cm^3/m^3 (0.38 mg/m^3). A clear dose-response relationship has been observed (17). A concentration as low as 0.5—1 cm^3/m^3 (0.63—1.25 mg/m^3) causes irritation of the mucous membranes in some individuals. About 17 % of the workers exposed to a concentration of 2 cm^3/m^3 (2.5 mg/m^3) experiences moderate to strong irritation. A formaldehyde concentration of 10 cm^3/m^3 (12.5 mg/m^3) is tolerated only with difficulty; exposure to concentrations above this level causes severe difficulty in breathing, burning of the eyes, nose and trachea, intense lacrimation, and severe coughing (14).

Direct contact with solutions, solids, or resins containing free formaldehyde has been shown to cause both inflammatory and allergic dermatitis (14). In Finland more than 100 cases of occupational eczema due to formaldehyde have been reported from 1975 to 1979.

Most of the cases of eczema have been allergic reactions. In addition a few cases of occupational asthma have annually been reported in Finland. Asthmatic symptoms may be due to allergic sensitivity to formaldehyde, even at low concentrations (2). The obstructive symptoms may be of either the acute or the delayed type.

Carcinogenicity of formaldehyde

Formaldehyde is mutagenic in some bacteria, fungi, yeast, and *Drosophila* (8). Formaldehyde has been shown to induce

[1] Department of Industrial Hygiene and Toxicology, Institute of Occupational Health, Helsinki, Finland.

Reprint requests to: Mr Raimo Niemelä, Institute of Occupational Health, Laajaniityntie 1, SF-01620 Vantaa 62, Finland.

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single-strand breaks in DNA (deoxyribonucleic acid) of both prokaryotic and eucaryotic cells (11, 16). Despite its wide use and known genetic effects, only little information is available on its potential carcinogenicity. Nasal carcinomas have been found in 25 % of Sprague-Dawley rats exposed to formaldehyde (14.6 cm^3/m^3; 18.25 mg/m^3), and hydrochloric acid (10.7 cm^3/m^3; 13.38 mg/m^3) (18). Tumors were suggested to be due to the formation of bis(chloromethyl)ether, a known agent causing nasal cancer (9). Others have suggested, however, that the carcinogenicity of bis(chloromethyl)ether may be due to hydrolysis to formaldehyde (19).

Just recently, the carcinogenic potential of formaldehyde vapor was evaluated in Fischer-344 rats and B6C3F1 mice exposed in inhalation chambers to formaldehyde concentrations of 0, 2, 6 or 15 cm^3/m^3 (0, 2.5, 7.5, or 18.75 mg/m^3) 6 h/d, 5 d/week (20, 21). For each species, exposure groups consisted of 120 animals per sex per exposure level. At six-month intervals (at 6, 12, 18 & 24 months) predetermined numbers of animals of both species were killed and dissected. Dose-related histological changes were observed, including rhinitis, epithelial hyperplasia, and squamous metaplasia. A total of 37 and 95 squamous cell carcinomas were detected in rats exposed to a formaldehyde concentration of 15 cm^3/m^3 (18.75 mg/m^3) by 18 and 24 months, respectively. Three rats exposed to 6 cm^3/m^3 (7.5 mg/m^3) had developed a squamous cell carcinoma of the nose by 24 months.

Two neoplasms of the nasal turbinates were identified in the mice at 15 cm^3/m^3 (18.75 mg/m^3) exposure levels after 24 months of exposure (WD Kerns, personal communication). No nasal cancers were observed among the control animals.

While the exposure levels used in the experimental carcinogenicity studies have been higher than those which occur at workplaces (table 1) and while rodents, in contrast to humans, breathe through the nose, the degree and site of carcinogenicity may be modified in humans. As an example, bis(chloromethyl)ether causes nasal tumors in rats (9), whereas cancers of the lungs are found in humans (24). Quantitative human risk assessment can be achieved only after careful and extensive epidemiologic studies.

Formaldehyde in the work environment

Formaldehyde and its derivatives are used in numerous industrial operations involving the manufacture, formulation, commercial distribution, and production of a variety of products. Formaldehyde is used mainly in phenolic, urea, melamine and acetal resins. These resins are utilized in the production of particle board, plywood, insulation materials, adhesives, paints, textiles, the coatings of papers, etc.

The Institute of Occupational Health in Finland has measured the level of airborne formaldehyde in occupational and nonoccupational environments during the last few years. The measurements have been made either as a service based on the orders of employers or in conjunction with research projects. Air samples were collected in midget impingers and analyzed by the chromotropic acid method (7). The results of the measurements of formaldehyde concentrations are summarized in table 1. In Finland the threshold limit value (TLV) ceiling for the work environment is 2 cm^3/m^3 (2.5 mg/m^3) (12).

The textile industry uses synthetic resins in permanent press fabrics, in fireproofing, and in dying. The concentrations of formaldehyde used are lower than 1 cm^3/m^3 (1.25 mg/m^3).

In the tanning and shoe manufacturing industry, Formalin® (an aqueous solution of formaldehyde) is used in finishing operations to glue substances together. It is sprayed onto the surface to be treated. The evaporation of formaldehyde during this operation is so great that the TLV for formaldehyde is often exceeded.

Synthetic resins with formaldehyde as a component are used in the manufacturing of particle board and plywood. The most commonly used are urea-formaldehyde, melamine-formaldehyde and phenol-formaldehyde resins. These resins are soluble in water and always contain a small amount of free formaldehyde. Phenolic resin is nearly the only plywood adhesive used in Finland. Particle boards are mainly glued with urea resin, even when melamine-urea-formaldehyde resin is used in the manufacturing of moisture resistant particle board. Formaldehyde does not evaporate from phenolic resins as readily as from urea and melamine resins.

For this reason the formaldehyde problem is more serious in the particle board industry than in the plywood industry.

In the process of manufacturing particle board, formaldehyde is released during the following stages: the mixing of glue, the forming stages, the hot pressing stage, the cooling stage. The evaporation of formaldehyde is especially great during the hot pressing and cooling stages. The concentrations of formaldehyde measured range from 0.1 to 4.9 cm/m^3 (1.25 to 6.13 mg/m^3 (13). A great amount of formaldehyde is chemically bound by the curing process. Nevertheless, a small residue remains in the free or loosely bound state; during the course of time, this residue is released in warehouses and even in dwellings.

The release of residues of free formaldehyde results in high concentrations during the first year or more. Due to the continuous depolymerization of formaldehyde-urea resin, the release of residues decreases exponentially to a steady concentration which is higher than the concentration of the natural background. Greater amounts of free formaldehyde in boards result if resins with a higher content of free formaldehyde are incorrectly applied or if the resins are insufficiently cured during the pressing stage.

The manufacturing of wooden furniture requires a wide range of adhesives, lacquers, paints, and hardeners containing formaldehyde as a component. Formaldehyde is released during the mixing, spreading, hot pressing and drying operations of glue application. During painting, the highest formaldehyde exposure occurs during the application and drying process. The formaldehyde concentrations measured have been quite high; 18 % of the measurements obtained exceeded the Finnish TLV of 2 cm^3/m^3 (2.5 mg/m^3). This value was exceeded in an adhesive plant during the manufacture of urea resins.

At present, many welding metals are painted or treated with corrosion preventives containing synthetic resins. The products of thermal decomposition may contain formaldehyde. Painting is also a typical work operation in machine shops. Formaldehyde exposure may occur if the paints used contain formaldehyde. The formaldehyde concentrations measured have usually been below 2 cm^3/m^3 (2.5 mg/m^3).

In the manufacturing of electrical machinery and apparatus, soldering and lac-

Table 1. Airborne formaldehyde concentration in occupational and nonoccupational environments. Air samples were taken during 10 min — 2 h and analyzed with the chromotropic acid method.

Items	Number of items[a]	Formaldehyde concentration (cm^3/m^3)[b]			Source
		Arithmetic mean	Range	Number of measurements	
Textile plants	2 (1977—1979)	0.2	0.1—0.5	16	Finishing and dyeing substances
Shoe factories	1 (1977)	1.9	0.9—2.7	4	Formalin spraying
Particle board plants	3 (1977—1979)	1.15	0.1—4.9	220	Urea and melamine resins
Plywood plants	6 (1977—1979)	0.35	0.1—1.2	91	Phenolic and urea resins
Wooden furniture manufacturing plants	19 (1977—1979)	1.35	0.1—5.4	134	Adhesives, lacquers, paints
Adhesive plants	1 (1977)	1.75	0.8—3.5	17	Urea-formaldehyde resin
Foundries	10 (1972—1975)	2.7 (38 % > TLV)		43	Furan resin
	3 (1977—1979)	0.6	0.05—2.0	8	
Welding and machine shops	3 (1977—1980)	0.5	0.05—1.2	9	Plastic tape, paints, corrosion preventive
Workshops manufacturing electrical machinery	10 (1977—1979)				
Soldering		below 0.1		47	Solder
Lacquerng, treatment of plastic		0.35	0.2—0.5	8	Lacquer, melamine-formaldehyde plastic
Construction sites	7 (1974—1975)	2.8	0.5—7.0	10	Lacquer
Hospitals, policlinics	7 (1977—1979)	0.7	0.05—3.5	25	Formaldehyde disinfectant
Offices, schools	4 (1977—1980)	0.24	0.05—0.77	12	Insulation foam, adhesive, lacquer
Dwellings	65 (1976—1980)	0.29	0.01—0.93	186	Particle board, insulation foam, glue of wall panel

[a] Year(s) of measurement in parentheses.

[b] 1 cm^3/m^3 = 1.25 mg/m^3.

quering are common work operations. This industry uses a great variety of plastic products. Many solders contain colophony resins whose pyrolysis during the soldering operation produces formaldehyde (3). The formaldehyde concentrations measured have been very low, below 0.1 cm^3/m^3 (0.13 mg/m^3). The formaldehyde concentrations measured were below 0.5 cm^3/m^3 (0.63 mg/m^3) during the pressing of melamine-formaldehyde plastics and the lacquering of transformers.

The cold-setting furan resins are used in foundries as binding agents for sand, mainly in the making of cores. Furan binders contain either urea-formaldehyde or phenol-formaldehyde resins. As a volatile component in furan resin, formaldehyde is released into the air of the workroom when the sand is mixed and when the core boxes are filled. According to a study of Finnish foundries in 1972—1975, 38 % of the measurements obtained exceeded the TLV (23). Later measurements, in 1977—1979, based on orders from foundries showed somewhat lower concentrations of formaldehyde.

In the construction industry, the highest formaldehyde exposure was found during the lacquering of parquet floors (1). In most cases, carbamide lacquer of two components was used for this purpose. Carbamide lacquer always contains some free formaldehyde, which evaporates during the application and drying of the lacquer. The average concentration of formaldehyde was at the level of 2 cm^3/m^3 (2.5 mg/m^3); 40 % of the measurements exceeded the present Finnish TLV. Momentary concentrations were found to be many times greater than the average figure.

In hospitals, formaldehyde is used to preserve tissue specimens and as an agent of chemical sterilization. Momentary formaldehyde concentrations stemming from autoclaves and disinfection have exceeded the valid TLV, but the time-weighted average has remained below 1 cm^3/m^3 (1.25 mg/m^3).

Even though particle board is a common construction material in offices and schools, the formaldehyde problems which we have encountered have occurred only in the presence of other sources of formaldehyde. Urea-formaldehyde foam, which is used for thermal insulation, has caused problems along with carpet adhesive or parquet lacquer. The fact that particle board has caused less complaints in offices and schools than in dwellings is obviously due to better ventilation. Urea-formaldehyde insulation foam may cause long-term releases of formaldehyde. Formaldehyde evolves from carpet adhesives and lacquers only during short periods of application and drying. Evaporation for a few weeks, however, is possible if the composition of lacquer and hardener is incorrect. The measured concentrations have ranged from 0.05 to 0.77 cm^3/m^3 (0.06 to 0.96 mg/m^3).

Formaldehyde in nonoccupational environments

Formaldehyde commonly occurs in nonoccupational environments. It is formed during the thermal decomposition of many organic substances. The concentration of aldehyde in the exhaust fumes of combustion motors is usually 10—30 cm^3/m^3 (12.5—37.5 mg/m^3). Cigarette smoke contains even more formaldehyde than the prevailing TLV (22). Some drugs used in the treatment of urinary infections (methenamine mandelate and methenamine hippurate) are metabolized in a way that formaldehyde is released in the urinary tract (10).

In dwellings, formaldehyde evaporates from construction materials and furniture. The Institute of Occupational Health in Finland has measured the formaldehyde concentration in 65 dwellings during the last 4 a. Particle board was the main source of formaldehyde in 61 dwellings, urea-formaldehyde foam in 3, and the adhesive of a wall panel in 1. The highest measured concentration was 0.93 cm^3/m^3 (1.16 mg/m^3). In Finland, no indoor air standards for nonoccupational environments have been set. An upper limit for formaldehyde concentration — 0.12 cm^3/m^3 (0.15 mg/m^3) — has been suggested for the indoor home environment in Denmark (6). According to Danish investigations (4, 5), the concentration of formaldehyde in dwellings depends on the sources of formaldehyde, the age of the building, ventilation, air temperature, and air humidity conditions.

The standard proposal for minimum ventilation in dwellings put forward by the Nordic Committee for Building Codes is

0.5 air change/h (15). In some modern dwellings today, however, it is as low as 0.1 change/h. These low ventilation rates cause an increase in indoor humidity; in periods when the sun shines through the windows of well-insulated dwellings, the hot-humid indoor environment and the low rate of ventilation may cause high indoor concentrations of formaldehyde. Therefore, the change in building technology caused by increases in the cost of energy may aggravate the hazards of formaldehyde.

Control and elimination of formaldehyde hazards

Substituting a less toxic compound for toxic material is the classic proposal for reducing risks to workers' health. Formaldehyde is an important and inexpensive chemical that is used in many ways, and it is therefore not an easy task to find a substitute. However, it has been possible to reduce the airborne formaldehyde concentrations, eg, in the plywood and particle board industries, by rearranging ventilation, by using new types of glues, and by other similar methods (13).

Any process including the handling of formaldehyde should be isolated as completely as possible. If total isolation is impossible, then at least the strongest sources of emission should be enclosed. Spray booths or rooms, as well as drying areas, should be equipped with exhaust systems. In cases of lesser sources of formaldehyde, it is possible to remove vapors with local exhaust ventilation. If formaldehyde evaporates from large surfaces, general ventilation should be effective enough. In some cases formaldehyde exposure is of short duration; it is then possible to reduce exposure by the use of proper respirators.

The most serious problems in dwellings arise when residents move into a newly constructed house with unfinished or poor quality particle boards. For the reduction of formaldehyde hazards in dwellings, the amount of free formaldehyde in boards must be kept as low as possible. Effective quality control of boards is therefore necessary. The rate of air change should be sufficient. Treatment with a formaldehyde-absorbing paint can also reduce evaporation (6).

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